Recent lessons from Near Eastern archaeobotany: wild cereal use, pre-domestication cultivation and tracing multiple origins and dispersals.

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Abstract

Although the Near East has long been a textbook example of pristine agricultural origins, archaeobotanical research in the last decade has transformed our understanding of the processes involved and provides some important guidance and warning for agricultural origins research generally. While older theories tended to assume that the beginnings of cereal exploitation developed as part of a broad spectrum revolution shortly (and inevitably) before the transition to farming, it is now clear that there was a very long prehistory of wild cereal use by seed and nut gathering foragers. The evidence from Ohalo II puts wild wheat and barley use at least 10,000 years before cultivation. Also of particular importance are new archaeobotanical approaches to identifying the initial cultivation through analyses of associated weeds, which indicates that cultivation began significantly, perhaps a millennium or two, before recognizable morphologically domesticated cereals. What is also now becoming clear is that changes in cereal grain size may not be good indicators of domestication in terms of seed dispersal criteria (tough rachis) for all species. Seed size increase in pulses can also now be shown to not be closely linked to initial domestication. In general then, the quantitative increase in archaeobotanical data is showing the origins of crop cultivation to have been a dynamic and multi-stage evolutionary process and not a single simple 'revolution' or 'discovery.'

Introduction: The Role of Archaeobotany and its history

Much of the agenda for studying the origins of agriculture was set down by the British scholar Gordon Childe in the 1930s, and he was also the first to explore in detail the archaeology of agricultural origins in the Near East. He defined the Neolithic in terms of key changes in technology and society: the inter-relationships between the beginnings of pottery, sedentism, herding and cultivating together with changes in religious belief (Childe 1936). In his day, however, there was little archaeobotanical evidence through which to explore early cultivation. This only began to be gathered, and on a small scale, in the 1950s and 1960s, when scholars such as Maria Hopf and Hans Helbaek, became some of the first archaeobotanists of the Near East. Helbaek may have been the first scholar to outline clearly the expectations for changes with the domestication of wheats and barleys (e.g. Helbaek 1959; 1960; 1969), and the importance of a pre-domestication stage. The first archaeobotanical work was carried out in the context of what can be called a formative *scientist-consultant* phase of archaeobotany, in that it lacked systematic sampling methods like flotation (see the histories of archaeobotany by Fuller 2002; Weber 2001; also, cf. Warnock 1998).

A real change took place with the development and application of water flotation for concentrating charred plant remains from archaeological layers. This was first applied in 1962-1963 at the Koster Site in Illinois, U.S.A. (Struever 1968), and in the Deh Luran plain,

Iran, the latter by Helbaek (1969). Also important was the early work W. Van Zeist from the late 1960s. Flotation became more widespread during the 1970s and 1980s on excavations in the Near East. As discussed in Fuller (2002), this precipitated the production much larger archaeobotanical datasets, and necessitated archaeological plant specialists (the *professionalization of the archaeobotany*). The impact of this can be seen in a consideration of published archaeobotanical reports. Figure 1 charts the growth of archaeobotanical evidence from the Neolithic Near East. What is apparent is the upsurge in evidence from the 1980s onwards, as new sites were published at a faster rate and these were mainly flotation samples. What might be considered a critical mass of floated sites has only become available in the past 10-15 years, and it should not be surprising therefore that our understanding of the processes involved in plant domestication have altered in the past decade. Also important, has been the publication of a number of particularly large datasets and site analyses that have heavily influenced thinking, such as Tell Aswad (Van Ziest and Bakker-Heeres 1986), Abu Hureyra (Hillman 2000), Netiv Hagdud (Kislev 1997), as well as the discovery of early epipalaeolithic Ohalo II (Kislev et al 1992). The last decade has also seen important discoveries in Cyprus (e.g. Peltenburg et al 2000; 2001a; 2001b), which lies outside the zone of potential domestication, and the first applications of the application of multivariate statistical approaches to datasets (e.g. Colledge 1998; 2001). Several of these latter studies have developed explicit concerns over the formation processes of samples and the potential to interpret archaeobotanical evidence as deriving largely from crop-processing waste and therefore representing crops and their weeds. This can be regarded as part of a larger process of archaeobotany becoming "self-critical" (Fuller 2002: 261). Another important development has been the coherent extension of the radiocarbon calibration curve back into the Late Pleistocene, allowing all the dates from this era to be calibrated (Stuiver et al. 1998). Throughout this paper we will use calibrated ages. It should also be noted that these recent advances mean that recent treatments in some Indian textbooks (e.g. Singh 1991; Possehl 1999) are now significantly out-dated.

Defining cultivation and domestication: Evolutionary Stages

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 or thousands of years, that led to the evolutionary changes of domestication. A key distinction must be made between *cultivation*, which is something that people do, and *domestication,* which is a quality or set of attributes of a plant (Helbaek 1960; Harlan 1995; Harris 1989; 1996). Cultivation is an activity; domestication is a genetic status, and this has evolved on account of cultivation. Cultivation usually involves soil preparation or tillage, although the earliest forms of cultivation may have simply involved sowing seeds by broadcasting; cultivation may also include adding to soil, such as fertilizing or irrigating. Cultivation is an important change in human strategy as people start to manipulate the soil and the composition of plants ahead of time in order produce yields of particular plants months later on. Domestication, on the other hand, is changes to the plant. In is important to note that the evolution of the domesticated plants is probably unintentional, and is due to what Charles Darwin (1883) called 'unconscious selection' (see also Zohary 1969; Harlan et al 1973; Hillman and Davies 1990a; 1990b). People did not set out to domesticate plants, but to manipulate productivity through cultivation. The new environment created by cultivation causes unintended evolution, and that is domestication.

A 'domestication syndrome' can be defined as a set of characters that differ between domesticated crops and their wild ancestors (Harlan et al. 1973; Hawkes 1983; Zohary and Hopf 2000; Gepts 2004). These characters can be related to different aspects of cultivation in terms of what causes them to evolve. It should be noted that the domestication syndrome differs for different kinds of crop-plants. Thus fruit trees and vines are not 'domesticated' in

the same was as grains crops such as cereals and pulses. For grain crops, the domestication syndrome usually includes:

1. Elimination/ reduction of natural seed dispersal, e.g. non-shattering rachis in cereals , non-dehiscent pod in pulses. This is often regarded as the single most important domestication trait. It makes a species dependent upon the human farmer for survival. It means that instead of shedding seeds when they are mature, a plant retains them. Instead those seeds must be separated by processing (threshing), i.e. by the addition of human labour, and then the seeds are dispersed by the farmer. This trait can only evolve under conditions of particular kinds of intensive harvesting that favour plants that retain their seeds, followed by sowing from the harvested seeds. All forms of cultivation will not select for this trait.

2. Reduction in seed dispersal aids. This is connected to the previous feature but is selected in a different way. Plants often have a range of structures that aid seed dispersal, this includes hairs, barbs, awns and the even the general shape of the spikelet in grasses. Thus domesticated wheat spikelets are less hairy, have shorter or no awns and are plump whereas in the wild they are heavily hairs, barbed and aerodynamic in shape. All of these tend be greatly reduced in the domesticated form. This can be considered to have come about by the removal of natural selection for effective dispersal, and once removed metabolic 'expenditure' on these structures is reduced.

3. Trend towards increasing seed/fruit size. This is likely to be selected for by open environments, and deep burial and disturbed soils. Comparative studies, for example between related species, show that larger seeds germinate more quickly and effectively than smaller seeds, and thus this should be selected for by tillage and cultivation generally.

4. Loss of germination inhibition. In the wild many seeds will only germinate after certain conditions have passed, conditions of day-length, temperature, or after the seedcoat is physically damaged. Crops tend to germinate as soon as they are wet and planted. This change is often signalled by changes in the seed, such as thinner seedcoats. This is also selected simply by cultivation, and sowing from harvested yield, since those seeds that do not readily germinate will not contribute to the harvest and the next planted generation.

5. Synchronous tillering and ripening, sometimes including a shift from perennial to annual. Planting at one time and harvesting at one time will favour plants that grow in synchronization.

6. More compact growth habit, e.g. reduction in branching, e.g. dense spikes or seed heads, e.g. from climbing habit to self-standing. Harvesting methods, like those that select for non-shattering types (no. 1, above) will also favour plants with single and compact parts to be harvested.

Of particular importance to the archaeobotanist are those changes which can be identified in archaeological material. This is likely to include numbers 1 through 4, although No. 4 is only preserved in certain kinds of seeds, and No. 2 may be difficult to recognize because hairs and often destroyed by carbonization. For this reason, especially for most cereals, it is criteria 1 and 3 which archaeologists look at. Grain size (no. 3) is made complicated because of the potentially wide range of variation in modern populations, and the effects of charring. If preserved, remains of the cereal ear rachis, provide clear evidence for mode of shattering (no. 1). In wild types there should be a smooth scar, indicating normal abscission, while in

domesticated (but also in very immature) plants the scar will rough because the ear has been broken apart by threshing.

The way in which such changes to the ear come about can be deduced from experiments with different harvesting methods applied to wild cereals (Hillman and Davies 1990a; 1990b; Willcox 1999). These experiments demonstrated how domesticated cereals dependent on human dispersal will evolve under a new ecology which includes human storage, planting and harvesting by particular techniques. Tough (or non-shattering) rachis ears occur as a rare genetic mutation in most wild grass populations (Kislev 1997). If wild cereals were harvested simply by shaking or beating ears to knock seeds into a basket then the shattering, wild type ears would be the ones to predominate in the next year's crop. By contrast, if people harvested with a sickle and cutting the entire ear, or pulling plants up from the roots, this would tend to disperse shattering seeds and retain all non-shattering mutants. Therefore, these could be replanted the following year and over time would be favoured and come to dominate the population at the expense of wild, shattering types. Of particular importance in this is the technique and technology of harvesting. By contrast grain size increase can be expected to evolve under tillage regardless of harvesting technique. The potential distinction between these two traits is something I will return to below.

This has one very important implication for archaeologists: the origins of agriculture is a multi-stage process, and the human practices of cultivation cause the changes in plants that we call domestication. This is usefully summarized in a diagram by David Harris (Figure 2), which distinguishes four general stages, wild plant food procurement (true hunting and gathering), and wild plant food production (the very beginnings of cultivation) and systematic cultivation, and finally agriculture based on domesticated plants. The domestication results from the earlier wild plant food production, making crops more dependent on humans for survival but also more productive. Through all of these stages people are putting in increasing labour effort on a single unit of land and single field of crops, in other words this is intensification of production. But the reward is increased productivity of that land, and the ability to produce large surpluses, to feed more people, or to utilize for social and economic relations, i.e. for trade and the like.

The Ohalo warning: cereals do not mean agriculture

Before looking at the evidence for the beginnings of agriculture, it is worth briefly introducing a site that is *not* agricultural, Ohalo II. This is a site discovered at the end of the 1980s when particularly harsh drought conditions lowered the level of Lake Galilee in Israel and revealed an archaeological settlement along its banks, which included the remains of brush huts, and abundant plant and animal remains (Nadel et al. 1995; Simmons and Nadel 1998; Nadel and Werker 1999). Faunal remains indicate important catching of shallow water lake fish and catching of waterfowl, as well hunting of larger mammals. The plant remains from this site include fruits and nuts, like grapes and almonds, but also acorns which are often a storable staple food for hunter-gatherers (Kislev et al 1992). But particular attention has been given to evidence for wild emmer and barley in substantial quantities from Ohalo II in Israel (Kislev et al 1992; Weiss et al. 2004; Piperno et al. 2004). This means that use of the wild cereals preceded cultivation by more than 10,000 years! This evidence includes not just grains but quantities of rachis remains amongst which the wild (smooth scar) type greatly predominates. It should be noted, however, that small quantities of rough scar types occur, but these are likely to represent the rare 'domestic'-type mutants that occur in nature, or result from immature harvesting. This indicates the need for evidence from cereal rachises to also be considered quantitatively in studies of agricultural origins. Grinding stones from the site have been studied for starch grains, which indicate that wild barley was indeed ground for flour (Piperno et al. 2004). Ohalo is an important warning to archaeologists that hunter-gatherers may have utilized the wild forms of crops without cultivation and without any move to

cultivation! This indicates that there is no necessary trajectory from wild cereal use to cultivation. Therefore we need to explain the beginnings of cultivation through social and/or environmental factors.

Situating domestication in Southwest Asia: biogeography and climate change

First we must understand the ecological distribution of the wild ancestors of crops, and how these distributions were affected in the past by climate change. In the case of southwest Asia there are a number of crops which occur wild in the transitional zone between the Mediterranean oak woodlands, and open grassland steppe, in a zone that averages 400-600mm of annual rainfall (Zohary and Hopf 2000). The wild wheats (*Triticum* spp.) and barley (*Hordeum vulgare*) occur in the slightly drier, more open parkland steppe with dispersed shrubs, wild almond trees and oaks, while the wild beans of southwest Asia, including lentils (*Lens culinaris*), peas (*Pisum sativum*), chickpeas (*Cicer arietinum*), grasspea (*Lathyrus sativus*), broad bean (*Vicia faba*) and other vetches (*Vicia ervilia* and *Vicia sativa*), occur in the clearings of nearby woodlands. There are some subtle but significant differences in the ecological preferences and tolerances of the wild cereals, with wild rye occurring at wetter and generally higher elevations than wild wheats, while wild barley tolerates a drier range of conditions; in addition there are differing distribution of one-grained and two-grained subspecies of wild einkorn (Willcox 2005). Thus the wild cereals today, and in general the beans/pulses, are distributed in the arc of foothills in the Near East known as the "Fertile Crescent" (Figure 3). While this suggests the general region in which plants were domesticated, we also need to take account of the effects of climate change on their distribution in the past.

Climatic change and vegetation response in the Near East is well-documented from pollen cores, isotopic records in cave speleothems, and lake level data (Robinson et al. 2006). While during the last glacial maximum (18000 years ago) southwest Asia was a much drier place, after that as the world warmed up, rainfall increased. This led to the expansion of the moisture-dependent vegetation zones and the retreat of desert and steppe zones. The vegetation changes and the expansion of the Mediterranean forest and oak woodlands can be traced in the few pollen cores available from the region and most importantly the core from Lake Huleh in Israel (Figure 4). What can be clearly seen is the dramatic increase in forest cover indicated by total tree pollen, which when examined in detail includes a large component of oak. Based on this and other pollen cores, Gordon Hillman (1996; 2000) reconstructed the likely extent of major vegetation zones, as can see in Figure 4 (top) at about 13,500 years ago. On these diagrams the likely distribution of wild wheat, barley and rye is indicated by the dots in the area of transition from the open oak woodland to the more sparsely wooded steppe. Also indicated on these maps is the location of the important archaeological site of Abu Hureyra. What is striking is that the resource-rich ecosystems (the Mediterranean forest, oak woodlands and cereal zones) all become increasingly widespread between 13000 and 11000 years ago. After 11000 years ago (or 11000 BC calibrated), according to some of the most recent dating evidence, a dramatic reversal occurred which is known as the Younger Dryas from the glacial sequence in northern Europe (Roberts 1998). This climate event of cooling and drying was a global shift as is documented in the Greenland ice-cores (e.g. Roberts 1998; Alley 2000; Gasse 2000; Robinson et al. 2006), In southwest Asia it is easily seen in the Lake Huleh pollen diagram (Baruch and Bottema 1991), framed by two radiocarbon dates. Its likely impact on the vegetation has been reconstructed by Hillman (2000; Hillman et al. 2001). There would have been a retreat in woodland, forest and grassland zones with marked vegetation dying off in the previously green woodland and steppe. Not all plants would have died, however, as many of the plants of these regions can survive several years of drought, particularly trees, and rainfall would have been channelled under the influence of local topography into the soils of local depressions, which could have maintained at least for a period of time pockets of the pre-existing vegetation. After approximately 1000 years the Younger Dryas ended, rainfall returned and the environment

retuned to the state it had been before the onset of the Younger Dryas. Unambiguous village populations appeared throughout the area during the Pre-Pottery Neolithic A Period (9700-8700 BC), and many of them appear to be cultivators. Finds of domesticated plants are generally widespread during the subsequent Pre-Pottery Neolithic B (8700-6200 BC), especially by the end of this period, and it is by this period that they began to spread beyond the domestication zone into central Turkey, Cyprus, Crete and southern Greece. Domesticated animals first occur about 8200 BC at the start of the Middle Pre-Pottery Neolithic B (Garrard 2000; Bar-Yosef 2003; Colledge et al. 2004; Byrd 2005).

Agriculture as part of intensification

The beginnings of cultivation can be seen as one of several interrelated practices by which human groups came to exploit the environment more intensively, to produce more food out of the same amount of land. Intensification is seen in increasingly stable, sedentary communities, and in the increasing use of pounding and grinding technology to extract more calories through processing. This process begins in the Late Pleistocene, in what is known archaeologically as the Epipalaeolithic period. In the southern Levant (the southwestern fertile crescent) this period is known as the Natufian culture. The evidence from Natufian sites indicates clear investment in home base sites which could have been inhabited all year round (Bar-Yosef 1998; 2003), although these site do not have as permanent structures as later periods. Many Natufian sites of the southern Levant occupied caves and the terraces in front of the caves, where houses and burials are both found. Natufian sites consisted of clusters of round buildings built on stone foundations, like those from the site of Mallaha, reconstructed as having timber posts to hold up a perishable superstructure. Burials were closely associated with the edges of these settlements. Not only were the dead buried at the villages, but also in some cases their skeletons were subsequently dug up, some skulls removed and then treated with plastering and perhaps used in ceremonies. Such skulls have been found on or buried under the floors inside the houses. This suggests a concern with ancestors and ancestral claims to the particular place of the settlement and we can suggest that this is connected with definition of group territories and permanence of occupation. During the course of the subsequent periods, Pre-Pottery Neolithic A and Pre-Pottery Neolithic B, sites would become larger and more elaborate architecturally, suggesting more permanence. Of particular importance may be the transition from round houses of the PPNA to rectilinear house of the PPNB. This transition is preserved in stratigraphic succession at sites such as Jericho and Jerf el Ahmar (Stordeur et al. 1997; Kuijt and Goring-Morris 2002). This transition, as we will see, seems to correspond roughly to the transition from early cultivation of morphologically wild cereals to agriculture based on fully domesticated cereals.

The artefacts of the Natufian attest to a wide range of techniques developed to exploit efficiently the available resources. The main lithic types are geometric microliths which were probably made into compound tools such as barbed arrows. In addition bone tools are common, especially points, perhaps for spears or harpoons used for small game, birds and fish (all of which are indicated from the animal bone record). One important technological development in the Natufian were the sickles, indicated by special stone blades which have been found on some sites (such as Wadi Hammeh), mounted in bone to form harvesting tools. These blades are a very minor component of the lithics. This is important in relation to the role of harvesting methods in plant domestication discussed earlier. In the earliest period of these tools it is just as likely that these were used for gathering plants such as reeds and sedges used in house construction and for matting as used for harvesting food plants. Analyses of the microscopic traces on these tools from a range of sites suggests had previously been though to reflect early cereal harvesting while cereals were still green, although use on other grasses, such as reeds, cannot be ruled out (Unger-Hamilton 1989; Anderson 1992; but on the limitations of such data, see Len-Salal 1996), but they might also be used for wetland plants like reeds, other grasses and sedges. The advantage of harvesting

wild cereals while still green, i.e. not yet fully mature, is that it minimizes loss of grain by natural shattering but also it will not create a strong selection for a change to domestic morphology.

Another prominent part of the archaeological finds represents grinding equipment, especially mortars and pestles and less frequently querns. The occurrence of grinding equipment from before, during and after the Natufian attests to an increasing efficiency in processing plant seed foods, including cereals, for better digestion of calories (Figure 6). By breaking down seeds into smaller pieces, their surface area increases and more of them can be absorbed by the digestive system. By grinding them into flour even more can be absorbed. Two chronological trends in the Levant attest to such an intensification of the use of food resources through their processing (Wright 1994): The increase in mortars and grinders in the Natufian and subsequently the Neolithic, and the increase in querns as opposed to mortars during the Neolithic by comparison to the Natufian. This implies that one of the concerns during this period was to extract more calories from the same amount of plant foods, which might be connected to increasing population density.

One thing that is striking about the Natufian is that whilst most of our well-dated sites come from the early Natufian, much fewer have definite late Natufian occupation. This might suggest a less sedentary lifestyle, either due to population decline or else increased mobility in response to the changed climatic conditions of the Younger Dryas. Analysis of faunal remains suggests subsistence intensification during the Early Natufian, inferred from the increasing importance of less-valuable prey, such as hares, i.e. those that are less energy efficient in terms of the trade of capture effort for nutritional yield (Munro 2004). By contrast during the Late Natufian, it was possible to rely more on the more rewarding prey, such as easy to catch tortoises, suggesting that there was less competition or reduced impact from human population density. The late Natufian coincides with the dry and cold spell of the Younger Dryas.

Interestingly, it is amongst some sites that are occupied during this period that the earliest probably evidence from cultivation comes from. One site which continues from the Epipaleolithic (equivalent to the Early Natufian) into the Younger Dryas period is Abu Hureyra, while another site, Mureybit, appears to be inhabited mainly during this period. These sites are important because they provide some the earliest likely evidence for cultivation, but also for pre-domestication cultivation.

Abu Hureyra in particular had intensive sampling of all archaeological contexts and subsequently the flotation for the recovery of charred plant remains (Hillman 2000). For the early Natufian levels there have been identified 157 wild plant species, most probably used for food, amongst which are wild barley, wild einkorn wheat and wild rye. An important change in the plant remains is indicated during the late Natufian (Younger Dryas) when most species associated with the oak woodland-steppe decline while there are increases in more arid-tolerant, steppe-desert transition species (Figure 7). There are two sets of exceptions to these trends. First, wild cereals maintain significant levels, and second a select group of herbaceous woodland edge species, today known to be weeds of cultivation. This suggests that these species were increasingly maintained in a new environment, that of the cultivated field (see also Hillman et al 2001). It is particularly striking that in Abu Hureyra and now in three other well-documented, but somewhat later sites from the same region (Mureybet, Jerf el Ahmar, D'jade), that wild cereals are found associated with known weeds of cultivation, an indication for the cultivation of cereals but without the morphological changes attributed to domestication (Willcox 1999; 2004; Tanno and Willcox 2006a). Similarly, weed floras have been identified at sites in the Southern Levant (Colledge 2001), while other sites have assemblages that might be reconsidered as pre-domestication cultivation weed floras (e.g. Netiv Hagdud). Multivariate statistical analyses of seed assemblages support the identification of weed floras at these earliest sites, suggest general similarities to subsequent clearly

agriculture sites, while indicating subtle ecological differences between sites (Colledge 1998; 2002). Thus some human communities adapted to the harsher climatic conditions of the Younger Dryas by maintaining certain species of food plants through cultivation, while other groups (e.g., most of those inhabiting southern Levant) may have reverted to increased seasonal mobility. The long-term effect of this shift in the northern Levant was the reduction in the diversity of plants utilised for food and the intensification of effort on a few species, which were bound to become the major crops.

Domestication syndrome evolving: contrasting grains and rachises

Near Eastern archaeobotany now allows the outline of a phased evolutionary process through which changes in human practices (cultivation) and changes in plant morphology (seed size increase and domestic-type seed dispersal) evolved over an extended period of perhaps two millennia. Evidence for pre-domestication cultivation has been recognized through the statistical composition of wild seed assemblages, for nearly 10 years (Harris 1998; Colledge 1998; 2001; 2002; Hillman 2000; Hillman et al. 2001; Willcox 1999; 2002). Important evidence seems to be in the contrast between the timing of increases in grain size and the appearance of the first tough (domesticated) rachises.

There is a growing morphometric database for wheat and barley from the Near East (Colledge 2001; 2004; Peltenberg et al. 2001b; Willcox 2004). This indicates that wheat and barley grains increased in size starting in the Pre-Pottery Neolithic A (PPNA) and earliest Pre-Pottery Neolithic B (PPNB). This is before clear and widespread evidence for tough rachises and loss of natural seed dispersal. It is well known that wild and domesticated cereal grains differ in size and this has been used to infer the domesticated status of cereals, already in the PPNA and the earliest PPNB, including sites from the Jordan Valley, the upper Euphrates in Syria, and the first settlements on Cyprus (Colledge 2001; 2004). This evolutionary shift can be illustrated from evidence from individual site sequences, such as at Jerf el Ahmar (Willcox 2004). In Figure 8a, can be seen the contrast between the barley grains from the early phase at Jerf el Ahmar (9500-8800 BC) and the much later Chalcolithic site of Kosak Shamali (ca. 5000 BC), in which all of the grains are larger and comparable to the domesticated size range inferred from modern material. If we look at the later phase at Jerf el Ahmar (ca. 8500 BC), however, it can be seen that many of the grains are of the larger size (Figure 8b). This implies evolution towards larger grain size during the occupation of this site, but recovered rachis remains indicate that ears were still of the wild, shattering type. A similar pattern is found for the einkorn wheat grains (*Triticum monococcum*), which also include some mixture of rye (*Secale cereale*) (Figures 8c-8d).

Thus we can now see that a key change in human behaviour was cultivation, but that this did not immediately, nor inevitably, lead to biological domestication and full dependence on agriculture. The practices of preparing land (tillage), planting seeds from stores, and tending plants was an important change in strategy amongst certain hunter-gatherer groups. In this context, we can imagine that groups experimented with a range of potential plants that could be cultivated, and it was during this period that the cereals, pulses (like peas, lentils, chickpea and vetch—see Tanno and Willcox 2006b), and flax were explored as cultivars. It should be noted, however, that early pulse finds do not indicate any significant increase in size (cf. Zohary and Hopf 2000), and clearly enlarged pulses seed sizes come only from much later Pottery Neolithic and Bronze Age contexts. As suggested recently on the basis of the evidence from Indian mungbeans there may be a long lagtime of millennia between the beginnings of pulse cultivation (and probable domestication in terms of seed dispersal and germination) and the seed size increase (Fuller and Harvey 2006). There is also recent evidence that during this period some people began to transplant cuttings of trees and shrubs that were useful, such a fig trees (Kislev et al. 2006) and, perhaps, almonds. Unlike cereals which evolved gradually into domesticated forms, "domestication" for species of fruit tree, like the fig, involved simply the identification of a promising mutant in nature and its vegetation propagation (from cuttings) and tending by people. This is quite different from

gradual evolution of domesticated cereals, but equally indicates the key change in human behaviour that occurred first.

The evolution of non-shattering ears was also a gradual process. Although theoretically it could have happened very quickly, as demonstrated under ideal experimental conditions (Hillman and Davies 1990a; 1990b), the archaeobotanical evidence indicates a gradual evolution non-shattering ears. A quantitative assessment of the proportions of wild and domesticated einkorn wheat spikelet forks and barley rachis remains indicates the gradual increase to dominance of the domesticated types by the Late Pre-Pottery Neolithic B, as opposed to partial presence in the Early PPNB and near absence from the PPNA (Figure 9). Nevertheless, there is significant inter-site variability, which may relate different degrees of continued reliance on gathering from wild stands as well. At Wadi Jilat 13, for example, specimens are almost entirely of wild type, despite the relatively late date of this site. This could be due to predominance of a gathering strategy at this site, which can also be suggested from a diverse range if other plant remains including evidence for wild edible tubers (*Cistanche* sp.) (Colledge 2001). The overall regional pattern however is the replacement of entirely/predominantly morphologically wild barley and predominantly domesticated barley by the end of the pre-pottery Neolithic periods, a domestication processing taking perhaps 1500-2000 years (see also Tanno and Willcox 2006a; Weiss et al 2006; Hartmann et al. 2006), and if we infer that the beginnings of wild plant food production (pre-domestication cultivation) began, as at Abu Hureyra, as early as 10500 BC, then the whole evolutionary process from gathering wild wheats to agriculture dependent on fully domesticated wheat might have taken closer to 3000 years. There is, however, need for further research and discussion on this matter. While the predominance of domesticated type barley on most Near Eastern sites may have waited until ca. 7000 BC or after, by this period crops has dispersed towards Europe, reaching mainland Greece and Crete (see Colledge et al. 2004; 2005), where fully domesticated form dominate. Even earlier by 8000 BC cereals had been transferred to Cyprus, where domesticated chaff remains also dominate. This may suggest that could mean that local bottleneck effects sped up the domestication in dispersing crops, full domestication occurred during the less well-documented middle PPNB, or rate appear slower in the centres of origin because of wild-gathered or weedy barley entered the archaeological record in this region of the wild progenitor. What is clear, however, is that with an increasingly robust archaeobotanical, domestication can be documented as a process of change in plant populations responding to cultural behaviour.

Breaking down the fertile crescent: emerging sub-centers

Textbooks and summaries often talk about the 'Fertile Crescent' or the Levant as *the* place where agriculture originated, but in fact this region needs to be broken into a number of distinct micro-centres (perhaps 3). This is a contention that remains a centre of fierce debates that draw on varying evidence from genetics, biogeography and archaeology. While reductionist views, often associated with particular types of genetic analyses (AFLP diversity analyses and neighbour-joining tree cluster analysis), often favour single centres (e.g. Lev-Yadun et al. 2000; 2006; Salamini et al. 2002). While botanical and genetic evidence have long support a very limited number of domestications for each crop species, in many cases perhaps only one (or two) (Zohary and Hopf 2000), these need not mean that they all come form the same place. Foci of domestication suggested from DNA diversity studies (assuming modern distirbiutions are repsentative) have been positied for (one-grained) einkorn wheat (Heun et al. 1997) and barley (Badr et al. 2000) (see Figure 3). Researchers starting from the geographical and chronological distribution of archaeobotanical data, together with considerations of the biogeogeography of wild progenitors tend to favour multiple localized places of domestication (e.g. Willcox 2005; Tanno and Willcox 2006b; 2006c; Weiss et al. 2006; Hartman et al. 2006; see also Jones and Brown 2000 on genetic support; and Allaby and Brown 2003 on concerns with the neighbour-joining tree methodology.). These debates indicate the vibrant state of research on Near Eastern agriculture origins, the significance of

recent methodological developments in both genetics and archaeology, and need for further data gathering.

Archaeological evidence currently favours two or three sub-centres of early plant cultivation and domestication (Figure 10: shaded areas). A number of advances in recent years have made it increasingly clear that separate histories need to be traced for different sub-regions, which were separate in as much as the beginnings of agriculture relied on different species, which much have been taken separately from the wild into cultivation. Also of significance is the growing evidence for some extinct early crops, that is species or varieties that featured in early agriculture which cannot be found in cultivation today. In others there is lost biological diversity from early agriculture, a process akin to the lost of genetic diversity amongst many crop today. The evidence for this comes from the gradual accumulation of more archaeobotanical data but also from significant methodological advances in the genetic analysis of modern plants and in the refinement of archaeobotanical identification criteria.

Advances in genetics have been important for identifying evolutionary lineages of crops which are indistinguishable on morphological grounds. This was first achieved through 'traditional' plant genetics based on cross-breeding and the identification variant recessive genes that control for the same morphological result. For examples in barley (*Hordeum vulgare*) two variant genes control whether or not the ear shatters. A recessive mutation in either gene locus leads to the domesticated condition, while the dominant variant at either locus confers wild-type shattering ears (Zohary and Hopf 2000: 59-60). The existence of these two variants argues for two domestications for barley, although these need not both come from the wild barleys of Southwestern Asia (*Hordeum spontaneum*), as eastern wild barleys (of Eastern Iran through Central Asia) and landraces in these regions and eastwards in the Himilayas are quite genetically distinct (Morrell et al 2003; cf. Badr et al. 2000). Other approaches have included the examination of chromosomal form, or variation in seed proteins. Chromosomal variants help to localize the closest ancestors of domesticated peas (*Pisum sativum*) with wild populations in central Turkey and Israel rather than other wild pea population spread throughout Turkey and the fertile crescent (Zohary and Hopf 2000: 105). More recently, however, it has become possible to identify distinct evolutionary lineages through the sequencing of parts of the DNA in crops and wild relatives to more closely pin down the likely ancestral populations and the number of domestications. Recent work on emmer wheat has identified two different lineages of a gluten gene which are so different that they are estimated to have evolved apart 100,000's of years ago, and thus amongst wild emmer wheat, long before domestication. Such evidence implies two separate domestications of emmer (Allaby et al 1999: 305; Brown 1999; reviewed in Jones and Brown 2000).

Another source of evidence for multiple domestication of the "same" (or similar) crops comes from refinements in archaeobotanical identification criteria. Thus, for example, it is possible on the basis of grain shape to distinguish einkorn wheat (*Triticum monococcum*) with single-grained spikelets from einkorn with two-grained spikelets. Modern domesticated einkorn (*T. monococcum*) is normally one-grained. This is a trait derived from one-grained wild einkorn populations (*Triticum boeoticum* subsp. *aegilopoides*). There are also wild two-grained forms (*T. boeoticum* subsp. *thaudar* and *T. urartu*). Archaeobotanical evidence indicates the presence of one of these two grained forms as a wild cereal from the late Pleistocene in Syria (Hillman 2000; Willcox 2002; 2005), and later as a domesticated cereal in Syria, Turkey and into Neolithic Europe. It persists in prehistoric Europe at least through the Bronze Age (Kreuz and Boenke 2002; Kohler-Schneider 2003), and disappears in its Syrian homeland during the Chalcolithic (Van Zeist 1999). This implies that in addition to the einkorn domestication that is ancestral to the single-grained einkorn found in cultivation today (but rare), there was an additional two-grained einkorn domestication but this crop went extinct in prehistory.

Similarly there is now evidence for an extinct emmer-like wheat (Jones et al. 2000; Kohler-Schneider 2003). As already indicated, genetic data suggests two domestications to account

for the emmer wheat races in cultivation today. However, it has become clear that there is a distinctive prehistoric wheat chaff type (glume bases) which are consistently distinct from emmer, einkorn, or spelt wheats and therefore must derive from another, extinct wheat, which we might call "emmeroid". This extinct cereal is known from Neolithic sites in Turkey, Djeitun in Turkmenistan, southeast and central Europe. It persists in parts of central Europe as late as the Bronze Age on current evidence (Kohler-Schneider 2003). In addition early sites in Syria appear to have cultivated a local form of rye (*Secale* cf. *montanum*), but rye did not become a major crop of the Neolithic Near East despite occasional later finds (Hillman 2000: 392); and was probably a different species from the later European rye (*Secale cereale*), domesticated from a field weed in Late Bronze Age or Iron Age times (ca. 1000 BC) (Küster 2000). Taken together the archaeobotanical morphotypes and genetics suggest a minimum of 7 domestications of wheat and barley in the Near Eastern Fertile Crescent region, and there is no reason to attribute them all to a single micro-region or a single process of agricultural origins.

As data has accumulated in recent years is has become clear that the earliest agriculture in the Near East was based on differing sets of crops in different parts of the Near East. This is especially clear with the cereal crops (Figure 11), different kinds of wheat, barley and rye, but some patterns may also be present in the pulses. This has been highlighted in particular by Willcox (2002; 2005). In the Southern Levant (Israel and Jordan), early cereals were barley and emmer wheat (*Triticum diococcum*) (Colledge 2001), whereas in the northern Levant (Syria), early cereals included rye, two-grained einkorn wheat and barley. In Turkey, by contrast, the early one-grained einkorn occurs, together with emmer and barley. The latter case is best-known from the site of Nevali Cori. Peas (*Pisum sativum*) were probably domesticated in the South and chickpeas (*Cicer arietinum*) in the north. This indicates that the earliest cultivation, at roughly the same time (PPNA to early PPNB), differed in different parts of the western Fertile Crescent. Thus archaeobotanical data, together with genetic evidence, converge to suggest multiple domestication centres in Southwest Asia.

Packages dispersing: different Neolithic crop packages in Europe

As is well-known the early agriculture in Europe was based on crops originating in the Near East, which spread to Europe by processes of diffusion (e.g. via trade) and/or migration of farmers. An ongoing area of debate amongst European archaeologists is the relative role of migration versus cultural diffusion in spreading crops, and domesticated animals, to different regions of Neolithic Europe (e.g. Price 2000; Scarre 2003; Zvelebil 2003). Also of interest is the probable existence of different pathways of migration and diffusion overland and via the Mediterranean sea. Our ability to track these dispersals and to understand what they mean in terms of the transmission and transformation of agriculture has continued to improve through increased archaeobotanical sampling and the integration of data in interregional comparative analyses that consider weeds as well as crops (Colledge et al. 2004; 2005; Colledge and Conolly 2006; Bogaard 2004; 2005).

An important contribution has come from refinements in identification. As discussed above, it has become possible to distinguish emmer wheat from an ancient 'extinct' emmer-like wheat ("striate emmeroid"). These species have different distributions (Figure 12). While true emmer went everywhere the primary dispersal of Near Eastern crop went, including to South Asia, Egypt and all parts of Europe, the "striate emmeroid" is found only in central and Eastern Europe as well as Turkey and Anatolia, suggesting a distinct dispersal history. Another set of different dispersal histories can be seen for early free-threshing wheats. Free-threshing wheats are those that have evolved under domestication to be easier to process, producing clean grain after the initial threshing and winnowing rather than requiring an additional de-husking and winnowing. There are two different genetic groups of free-threshing wheats, tetraploid *Triticum durum* types, used traditionally in Europe for pasta and in North Africa for couscous, and the hexaploid *Triticum aestivum* types, bread wheats, which

include the only wheats found in East Asia. Although the grains of both groups are indistinguishable, subtle by consistent differences exist in the chaff (rachis) parts that can also be preserved by charring (cf. Zohary and Hopf 2000; Fuller 2002: 273-277). These differences were first recognized in the late 1970s and early 1980s and their routine application by archaeobotanists in Europe has gradually increased. It is now possible to see that the earliest free-threshing wheats in Eastern and Central Europe were included hexaploid bread wheats, *Triticum aestivum,* as well as some tetraploids (although these were a minor crop, or perhaps even a "weed" in systems dominated by emmer and einkorn) (Bogaard 2004; Kreuz et al. 2005; Colledge et al. 2005). By contrast in the Western Mediterranean Neolithic, including Spain, and extending northward through France to Switzerland, free-threshing wheats were predominantly tetraploid, *Triticum durum* (Zapata et al. 2004; Maier 1996). There were also differences in terms of companion crops, with peas, lentils and bitter vetch spreading through Southeast Europe to Germany, while chickpeas and common vetch (as well as lentils) were important in the Mediterranean. Central Europe also saw the addition of common millet (*Panicum miliaceum*), which had not originated in the Near East and must have diffused from Asia north of the Black Sea via the Ukraine region. The same may also be true for another kind of wheat, spelt (*Triticum spelta*) (cf. Zohary and Hopf 2000).

The growth of archaeobotanical research has been even more rapid in Europe than in the Near East As a result it is now possible to trace the spread of crop and weed packages from the Near East and how these were progressively modified by processes of ecological and/or cultural selection as the agricultural way of life moved across Europe (see Colledge and Connelly 2006; Colledge et al. 2005; Bogaard 2004; 2005).

Conclusion

There have been important advances in the archaeology, and especially archaeobotany of the Near East, in recent years. These have come about through quantitative increases, with more sites, samples and researchers contributing, but also through methodological advances. This has included increased attention to quantification, larger scale studies of grain measurements and improved appreciation of the distinctions in charred chaff remains and in the contribution of weed flora studies. As a result we can now begin to trace the evolutionary process that saw hunter-gatherers turned into cultivators and selected wild species transformed into domesticated plants, marked by distinctive features of the domestication syndrome.

Acknowledgements

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Figure 1. The progress of archaeobotany of the Near Eastern Neolithic, charted by the cumulative number of sites with published archaeobotanical data in five year periods. The upper line charts the total number of published sites, while the lower line indicates the overall proportion that had been sampled by flotation for more systematic recovery. (These data derived from a database on Near Eastern and European archaeobotany compiled by Colledge; cf. Colledge et al 2004; 2006).

Figure 2. The idealized evolutionary spectrum from pure foraging to agriculture based on domesticated crops, indicating the significant stages of wild plant food production and pre-domestication cultivation (after Harris 1989; 1996). On the rows at the base of the chart the inferred presence of these stages in the Near East (see discussion in this paper).

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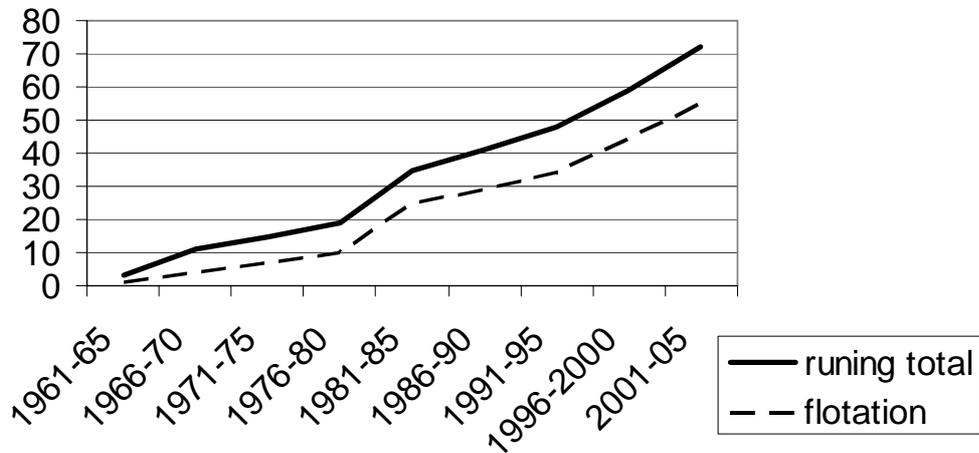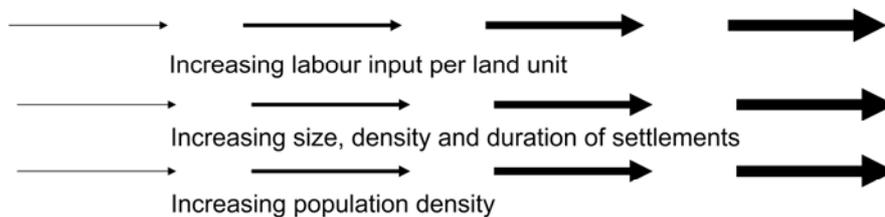**Near Eastern archaeobotany:
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Increasing labour input per land unit

Increasing size, density and duration of settlements

Increasing population density

Wild plant food procurement	Wild plant food production	Cultivation with systematic tillage	Agriculture: cultivation of domestic crops
Gathering burning tending	Replacement planting, harvesting, storage	Land clearance, tillage	**D**

South-west Asia	Foragers using wheat/barley (e.g. Ohalo, Natufian)	management of dwindling Wild cereals (inferred) (Abu Hureyra)	Emergence of arable weed flora (assemblage change); evolution of larger grains (PPNA)	Occurence of domestic type rachis (PPNB)

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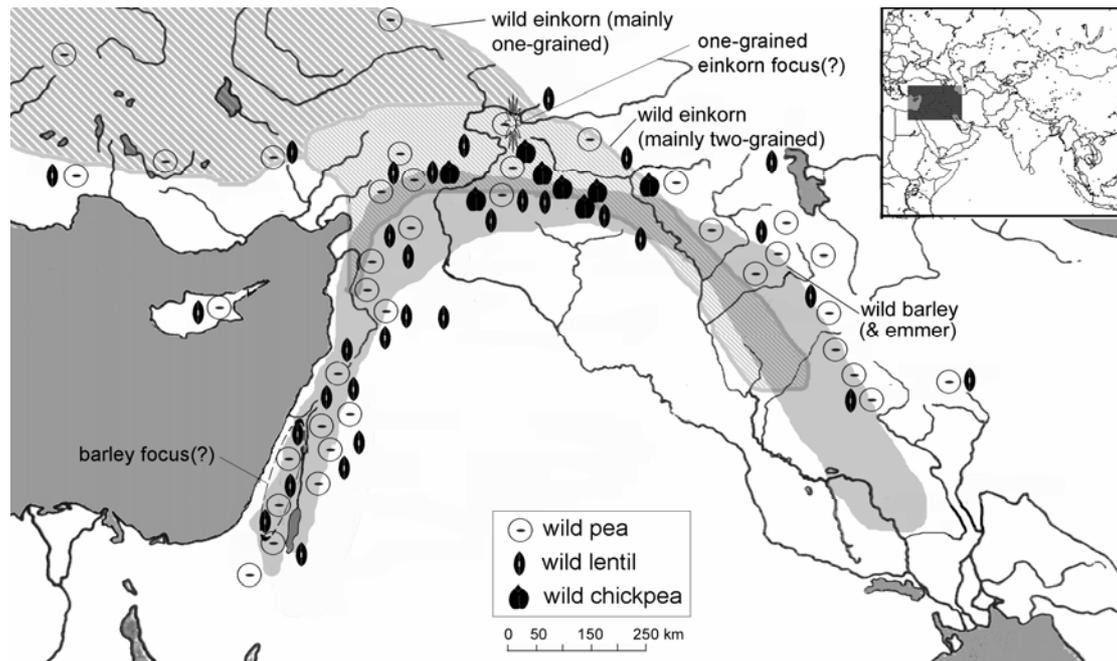
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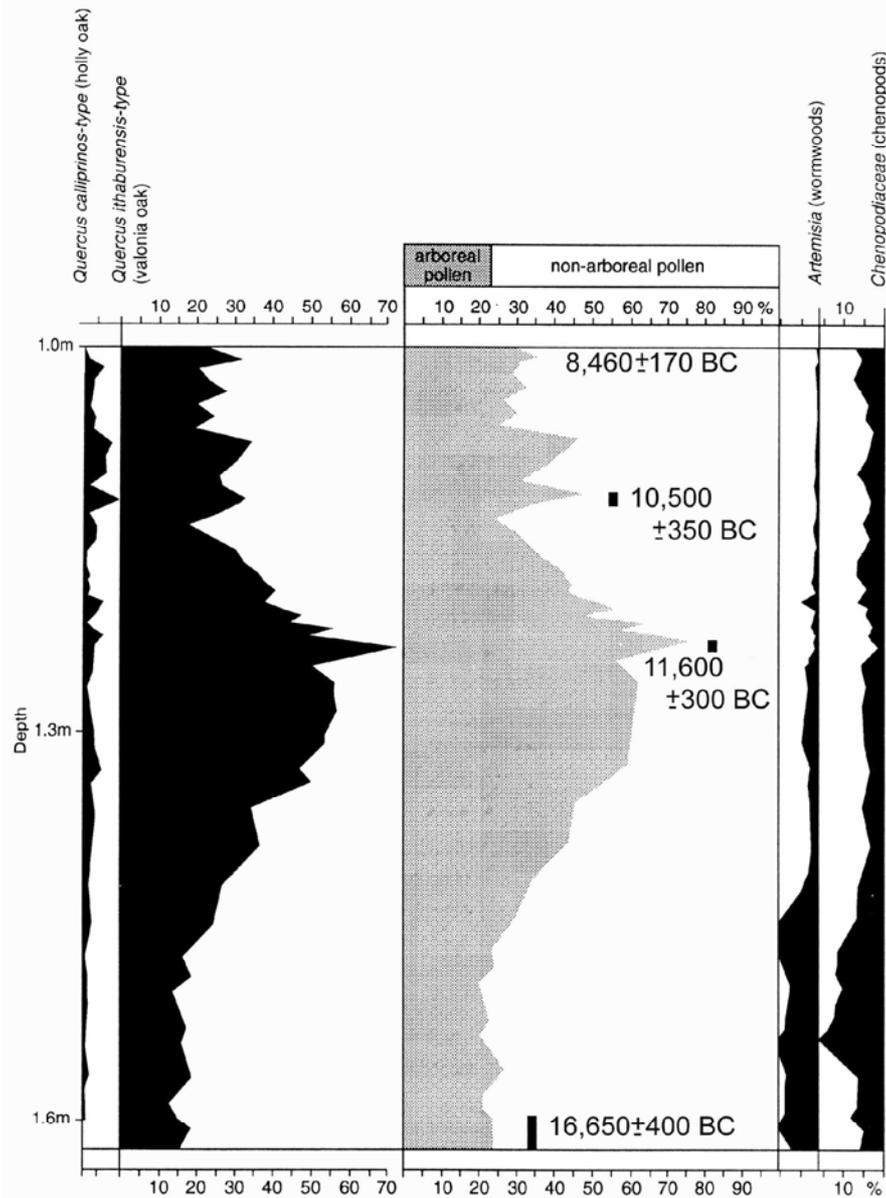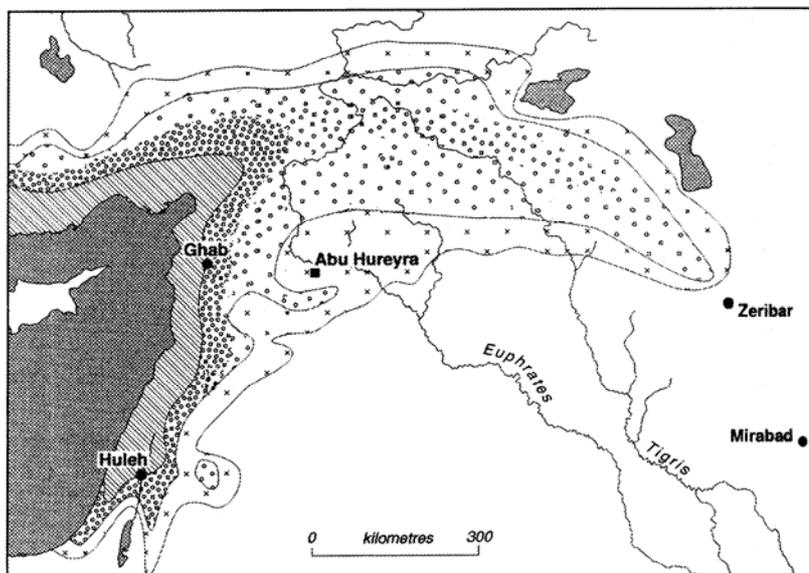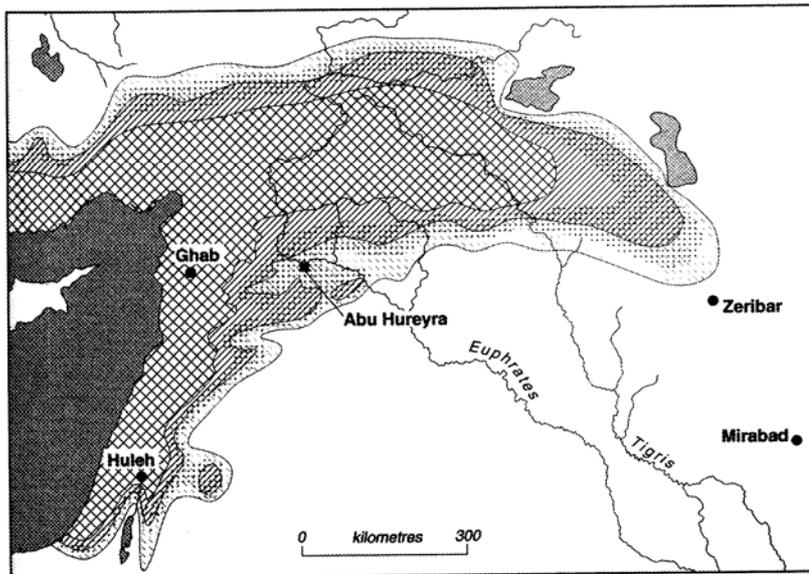
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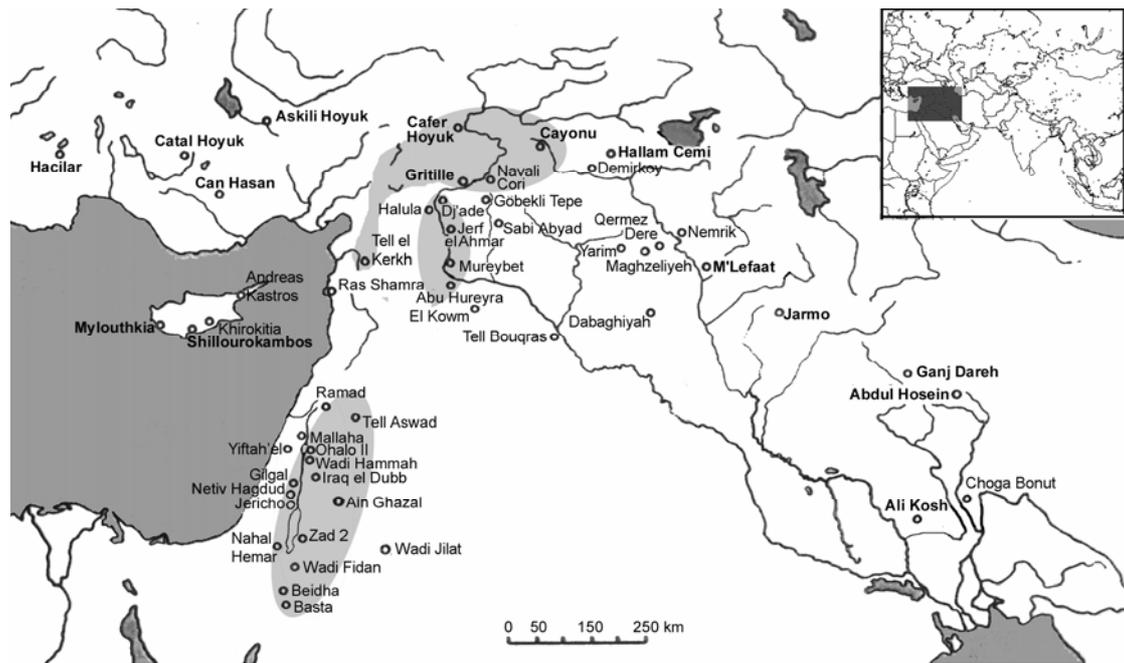**Figure 6**. Map of Southwest Asia, showing the locations of sites with archaeobotanical evidence that contribute to understanding the origins and spread of agriculture.

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Site	BC cal.	einkorn 1g	einkorn 2g	rye	emmer	naked wheat	barley	flax	lentil	pea	chick pea	grass pea	bitter vetch	broad bean
Southern Levant (Israel, Jordan, Palestine)														
Ohalo II	**20000**	*0*	*0*	*0*	X	*0*	XXX		x		*0*			
Wadi Hammeh 27	**12200-11800**	*0*	*0*	*0*		*0*	x				*0*			
Gilgal	**9700-9200**	*0*	*0*	*0*	x?	*0*	XX				*0*			
Netiv Hagdud	**9500-9000**	*0*	*0*	*0*	XX	*0*	XXX		x		*0*		x	
Zad 2	**9400-8900**	*0*	*0*	*0*	x	*0*	x				*0*			
Iraq-ed-Dubb	**9250**	?	*0*	*0*	x?	*0*	XX				*0*			x
Tell Aswad I	**8700-8000**	*0*	*0*	*0*	XX	*0*	XX		x		*0*		x	
Wadi Jilat 7	**9000-7500**	x?	*0*	*0*	x?	*0*	XX				?			
Jericho II	**8400-7500**	X	*0*	*0*	XX	*0*	XX	x	x	x	?			X
Beidha	**8400-7500**	*0*	*0*	*0*	XX	*0*	XX				x		x	
Nahal Hemar	**8400-7500**		*0*	*0*	x	*0*	x		x					
Yiftah'el	**8200-7500**		*0*	*0*		*0*			x		*0*			X
Ain Ghazal	**8300-7000**	*0*	*0*	*0*	XX	*0*	XX	x	x	x	x			
Basta	**7500-7000**	x	*0*	*0*	x	x	x		x	x			x	
Wadi Fidan A & C	**7500-6500**	X	*0*	*0*	XX	*0*	XX							
Wadi Jilat 13	**7000-6500**	X	*0*	*0*	XX	*0*	XX							
Middle Euphrates (Syria and Iraq)														
Abu Hureyra 1	**11500-9600**	*0*	XX	XX	*0*	*0*	*0*	x	x	*0*			x	
Mureybet I-III	**10200-8500**	*0*	XX	XX	*0*	*0*	XX	x	x	*0*			x	
Jerf el Ahmar	**9700-8500**	*0*	XX	XX	*0*	*0*	XXX			*0*			x	
Dja'de	**9000-8000**	*0*	XX	X	?	*0*	XXX			*0*			x	
Abu Hureyra 2A-C	**7800-6500**	?	XX	X	X	X	XX	x	x	?	x	?	?	X
El Kowm	**7500-6800**	?	XXX	X	XX	XX	X							
Tell Bouqras	**7400-6600**	?	X	X	X	XX	XX	x	x	x				
Sabi Abyad II	**7500-6500**		X		XXX	XX	XX	x	x					
Tell Ramad	**7500-6500**	?	X	X	XXX	X	X	x	x	x	x			
Eastern Anatolia (E. Turkey)														
Göbekli Tepe	**8900-8800**	*0*	XX	?	*0*	*0*	XXX			*0*				
Cafer Höyük IX-XIII	**8300-7700**	XXX	x	X	XX	x	X		x	*x*		x	x	X
Cayönü (g, bp, ch)	**8700-7500**	X	x	X	XX		XX	x	x	x	x	x	x	X
Nevali Cori	**8500-7500**	XXX	X	X	XX		X		x	x	?	x	x	X
Asikili Höyük	**8400-7500**	X	?	*0*	X	X	X		x	x	?		x	
Hacilar	**8000**	XX	?	*0*	XXX	X	X		x					
Catal Höyük	**7400-6800**	X	?	*0*	XXX	XX	XX		x	x	x		x	
Can Hassan III	**7500-6500**	X	?	*0*	XX	XXX	XX		x				x	
Cyprus and Coastal Syria														
Tell el-Kerkh	**8600-8300**	X	*0?*	?	X	*0*	?			*0*	x			X
Mylouthkia	**8600-8000**	x	x		x		x							
Shillourokambos	**8200-8000**	x	x	x	x		x							
Cap Andrea-Kastros	**6900**	?	XX?	?	XXX		XX	X	X	?				?
Khirokitia	**6300**	?	X?	?	XXX	X	XX		X	X	?			?
Ras Shamra	**7500-6100**	X?	X?	?	XXX	X	XX	X	X	X		x		
Northern/Eastern Fertile Crescent														
Qermez Dere	**10100-9300**	*0*	*0*	*0*	*0*	*0*	X		X				x	
Demirkoy	**10000**	*0*	*0*	*0*	*0*	*0*	X		X					
Hallam Cemi	**10000-8900**	*0*	*0*	*0*	*0*	*0*	*0*			?		?	?	
Nemrik	**9600**					*0*		X	X					
M'Lefaat	**9300-8900**	x?	x?			*0*	XX		X				x	
Ganj Dareh	**8100**					*0*	XXX		X	X				
Ali Kosh (Bus Mordeh phase)	**7900-6900**	X			XXX	*0*	XX	X						
Tell Maghzaliyeh	**7600-6400**	XX			XX		XX	X	X					
Tell Abdol Hosein	**8000-7400**				XX		XX		X					
Jarmo	**7500**	X			XX		XX		X	X		x		
Choga Bonut	**7600-6900**	XX			XXX		XX		X					
Umm Dabaghiyah	**6900-5500**				XX		XX							
Yarim Tepe I	**6900-5500**				X	X	XX							
Mehrgarh I (Pakistan)	**7000?-6000**	x?			X	XX	XXX							

x=present, unquantified   For cereals only, semi-quantitative ranking

?= possibly present   XXX =highly frequent/ dominant   XX =frequent   X =present, low frequency

0 = absence considered significant   [X] =domesticated   [X] =partial domestication syndrome, e.g. size (status of early *Vicia faba* unresolved)

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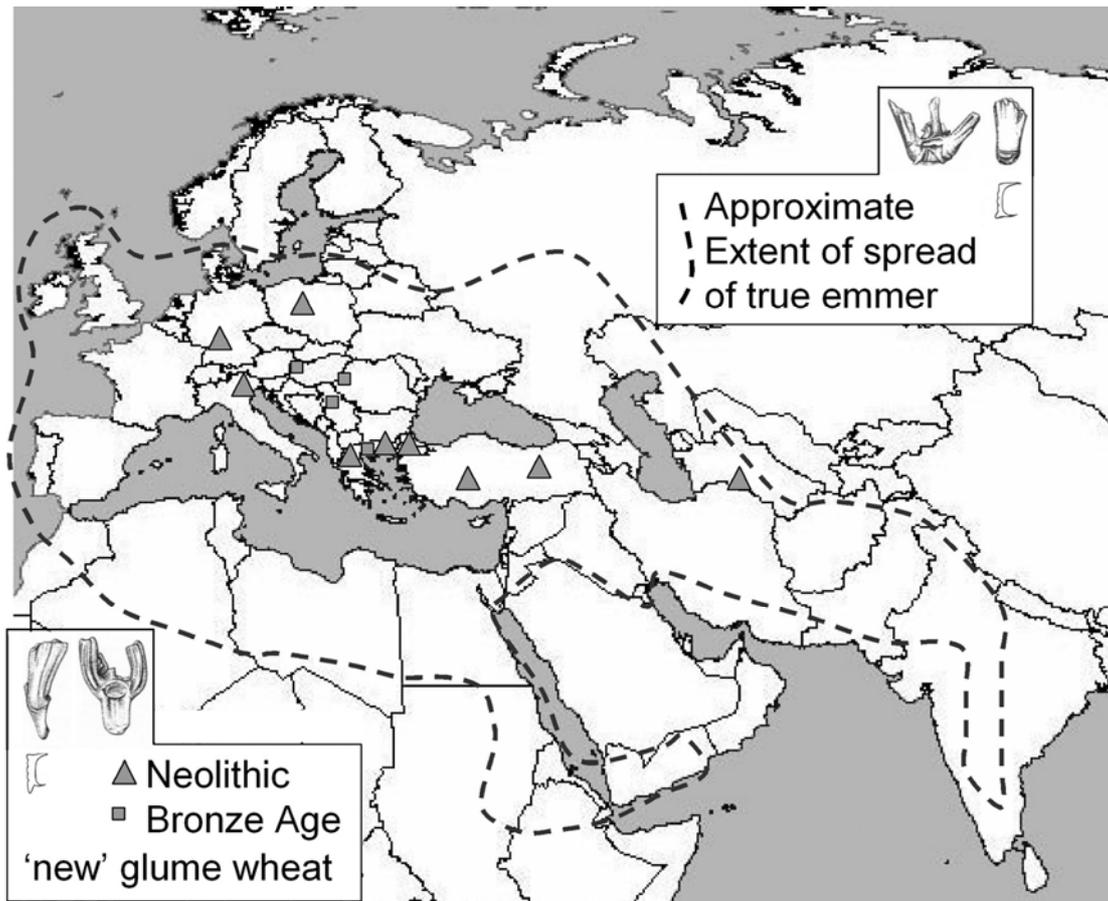
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