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Geographical variation in major cereal components and evidence for independent domestication events in the Western Asia

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Abstract: Cereal assemblages identified from Late-Pleistocene and Early-Holocene sites in Western Asia are compared. These assemblages show considerable differences between sites from different regions and different periods. This is particularly pronounced in terms of presence/absence. For example barley is the major component at Jerf el Ahmar and Netiv Hagdud, emmer at Aswad, two-grained einkorn at Mureybet and one-grained einkorn at Nevali Cori. The possible reasons for these differences are discussed and it is concluded that local variation in wild populations accounts for the differences. Geographically independent domestication events can be discerned for each species. Einkorn domestication appears to be restricted to Southeast Anatolia. But for emmer and barley, domestication may have advanced independently in different regions. These conclusions are discussed in the light of evidence from genetics and DNA fingerprinting on modern cereals which tends to corroborate the archaeobotanical findings. Well-established domesticates start to spread at the end of the 10th millennium. Finally, evidence for the disappearance of two cultivars, rye and domestic two-grained einkorn, is discussed.

Introduction

Over the last decade much new archaeobotanical data has become available for Late-Pleistocene and Early-Holocene sites in southwest Asia, which allows us to compare the results from sites in different regions. The new evidence suggests that the transition to agriculture was a gradual process occurring in the Fertile Crescent between 11,000 and 9000 (BP non-cal.; dates in the text are given in BP non-cal.). The presence of weed assemblages suggests that pre-domestic agriculture occurred on a number of 10th millennium sites prior to the appearance of morphological domestication, and regional diversity was also noted using correspondence analysis applied to wild/weed taxa (Colledge, 1998; Willcox, 1999; Willcox & Fornite, 1999). The question of whether cereals were taken into cultivation in one place at one time or whether they were taken into cultivation independently in different regions has not been approached from the archaeobotanical of point view. Daniel Zohary in an important article (1996) discussed the available genetic evidence for monophyletic and polyphyletic origins of individual crop species which have survived to the present day, and he concludes that "emmer wheat, ..pea and lentil were each taken into cultivation once, or at least only a few timesin barley..there (is) an indication that this crop has been taken into cultivation more than once" (Zohary, 1996: p. 155). The archaeobotanical data presented here demonstrates that the domestication of each species was a geographically independent event. And that in the case of emmer and barley they could have been domesticated independently in different regions. Recent evidence from DNA fingerprinting suggests monophyletic origins for present day populations of *Triticum monococcum* (Heun *et al.*, 1997) while new results for barley (Badr *et al.*, 2000) are not so clear-cut. Even if modern populations indicate monophyletic origins this does not exclude the possibility that the same species was taken into cultivation on a number of occasions in different regions, because resulting cultivars may have not have survived competition from better adapted varieties. Evidence presented here (Table 1), indicates that cereals taken into cultivation at geographically widely separated sites dated to before the 9th millennium, came from local populations. Prior to the appearance of more tolerant domestic strains, local cereals would have been better adapted to local climatic and edaphic conditions than those from other regions with different environmental requirements. It is during the 9th millennium that we see the spread of more tolerant crops in the form of emmer, barley and naked wheat, which were better adapted to cultivation and differing climatic conditions.

Materials and methods

Data on cereal identifications was collected from publications and is presented in Table 1. Chaff material was not included because it was absent or poorly represented on some sites and researchers did not systematically adopt identification to species level. Sites which had not undergone extensive sampling are not included, for example, Jericho PPNA, and Hayonim (Hopf, 1983, 1987). Wild and domestic morphological types have been taken as one group because their separation on morphological grounds is not always satisfactory. The problems of identifying morphological domestication in hulled wheats have been addressed by Kislev (1989) and by Nesbitt & Samuel (1996). In contrast, the distinction between two-grained and single-grained einkorns as two distinct taxa is feasible and the results significant.

Sites such as Nativ Hagdud, Jerf el Ahmar, Abu Hureyra, Dja'de, Mureybet and Nevali Cori have undergone extensive sampling. Flotation was carried out on archaeological contexts where charred material had gradually accumulated and sample numbers were large. If samples had been obtained from storage structures where different cereals were stored separately this could bias results, but no burnt storage structures are known for this period. However, very high counts of two-grained einkorn from two samples at Mureybet were excluded on the basis that they could have been from storage structures. That the results are not biased in terms of relative frequencies is demonstrated by the fact that frequencies are remarkably similar from sample to sample and repeatedly show the same proportions of cereals. This recurrence of the same results within individual sites is a good sign of their reliability. Another possibility is that some archaeobotanical assemblages represent the unwanted part of the crop; here again in some cases it is possible to compare the unwanted chaff frequencies with grain frequencies and the quantitative similarity tends to support the hypothesis that the major grain fraction represents the major crop.

Results

Presence/absence and quantitative data are given in Table 1. Relative frequencies have been presented elsewhere (see Willcox, 2000a,b), however in some cases the data is not quantitatively significant. For the location of sites, see Fig 1.

At Mureybet (10,200-9600 BP) the charred cereal remains are characterised by high frequencies of two-grained einkorn, low frequencies of wild barley and some rye (Van Zeist & Bakker-Heeres, 1984; Willcox & Fornite, 1999). Einkorn, which is absent from the region today, may have occupied deep rich soils which occur in the side valleys or on the Pleistocene terraces above the flood plain situated not far from the site. Similar finds came from the Natufian site of Abu Hureyra located in the same general environment (Hillman, 1996, 2000). The presence of these two cereals this far south implies a much cooler and moister climate for this period.

Jerf el Ahmar (9700-9200BP), situated 60 km upstream from Mureybet, is contemporary with the latter's level III. In contrast to Mureybet, Jerf el Ahmar is characterised by high frequencies of barley compared with einkorn, which is rare (Willcox, 1996; Willcox & Fornite, 1999). The site is situated in a narrow part of the valley where there are no Pleistocene terraces. The surrounding land is made up of soft chalk with thin calcareous soils, which are not favourable for einkorn but support wild barley today, as no doubt they did in the past.

A similar situation occurs at Dja'de (9500-9000 BP) which is a little later in date than Jerf el Ahmar and situated some 25 km farther north (Willcox, 1996; in preparation). Barley is dominant and einkorn is rare, despite the Pleistocene terraces in the area. Still farther upstream the situation changes again at the site of Nevali Cori (9200-9000 BP), dated to the end of the 10th millennium (Pasternak, 1998). It is in a higher rainfall area. Here the archaeobotanical remains are dominated by what appears to be single-grained einkorn, which grows today in this region (some emmer may be present).

Farther north in Anatolia at Cafer Höyük and Çayönü the earliest levels sampled probably date to the mid-10th millennium (Van Zeist & De Roller, 1994; De Moulins, 1997). However these levels are poor in plant remains. For the later part of the 10th millennium and early 9th millennium these sites have similar frequencies of emmer and einkorn while barley is rare at Çayönü (9250-8500 BP) and absent at Cafer Höyük (9200-8800 BP). Here again this appears to reflect the present day situation where mixed stands of emmer and einkorn occur and barley is less competitive, being better adapted to a drier and warmer climate.

To the south, cereal remains dated to the 10th millennium have been found at Aswad I, situated in the internal drainage area of the river Barada near Damascus (Van Zeist & Bakker-Heeres, 1982). Level I produced a mixture of barley and emmer, einkorn is absent. Basalt lava flows in the area provide ideal soils for emmer but today it grows some seventy kilometres farther south in a higher rainfall area. In later levels where the number of samples is more significant, emmer appears to dominate.

Still farther south, the site of Netiv Hagdud in the Jordan valley and the much earlier site of Ohalo II have rich samples (Table 1) which indicate that barley was dominant and emmer is present but at lower frequencies

(Kislev *et al.*, 1992; Kislev, 1997). At these more southern sites einkorn only appears for example at Aswad and Jericho in the 9th millennium and then only at low frequencies. It may have been introduced from farther north.

In summary, the geographical differences in the major cereal components as seen particularly from presence/absence between sites can be explained by the differing natural conditions, which can be seen in the vicinity of each site today. At sites such as Aswad, Mureybet and Abu Hureyra the presence of ancient cereals that do not correspond with today's ecological conditions could be explained either by climatic change or by the introduction of crops (see below).

DNA fingerprinting

How does the archaeobotanical evidence compare with results from DNA fingerprinting? Analyses carried out on a large sample of present-day domestic and wild einkorns by the Max-Plank Institut für Züchtungsforschung near Cologne suggest monophyletic origins for present-day domesticates (Heun *et al.*, 1997), with the ancestral population localised in the Karaçada region of south-east Anatolia. The archaeobotanical record agrees with these findings because the only site (Nevali Cori) known at present with high frequencies of single-grained einkorn is to be found about 150 km away. Work carried out more recently on barley populations by the same laboratory (Badr *et al.*, 2000; Salamini, pers. comm.) indicates that ancestral populations came from the southern Levant. Archaeobotanical results indicate that barley was the principle cereal at sites such as Netiv Hagdud (Kislev, 1997) and probably Jericho. This does not exclude other domestication events for barley during the early stages because not all domesticates may have survived in the long term. Some may have been rapidly selected out once they came into contact with more competitive strains.

Morphological domestication has been reported for 10th millennium levels at Aswad, Nevali Cori, Cafer Höyük and Çayönü. There is no evidence for domestication at Nativ Hagdud and Mureybet or at Jerf el Ahmar and Dja'de, but these last two sites are still under analysis. Unequivocal evidence for morphological domestication only occurs by the beginning of the 9th millennium with naked wheats and solid rachis barley.

For 9th millennium sites, sampling was less extensive and produced fewer plant remains. Naked wheats appear in the Damascus basin and in the Euphrates valley with the first signs of six-row hulled barley. The composition of the assemblages becomes more homogenous with the spread of well established domesticates. Thus we see that barley increases in Anatolia, presumably by diffusion, and einkorn appears for the first time in the southern Levant. Two-rowed barley remains more frequent at sites in drier areas such as Abu Hureyra, Aswad, and Jericho. Sites such as 'Ain Ghazal, Halula, Magzalia, Aşıklı, Ghoraifé, Jilat 7 and Can Hasan III (French *et al.*, 1972) were settled for the first time during this period, and here we see the spread of established domesticated cereals including naked wheat, emmer and six-row-hulled barley. Single-grained einkorn, although spreading southwards, is rare compared to emmer or barley.

Discussion

The geographical variation in terms of presence/absence and frequencies of cereal assemblages found on the thirteen sites (Table 1) does not appear to result from sampling bias as argued above. The reasons for the geographical variability appears to be environmental and linked to the edaphic and climatic requirements that favour one species over another. Climatic change could also affect the presence of cereals. Indeed this could account for the disappearance of rye after the 10th millennium in the Syrian Euphrates.

The most obvious way that crop assemblages will be affected is by the introduction of cultivars from other areas by man. As stated above the spread and diffusion of well established domesticates is clearly seen during the 9th millennium. But did human induced introductions occur during the phases of pre-domestic agriculture? Importation or introduction has been suggested for the 10th millennium in the Euphrates valley. Van Zeist (1970: p. 172) mentioned the possibility of einkorn at Mureybet being imported from farther north. He suggests this because under present-day climatic conditions einkorn cannot grow in the area of the site. More recently Salamini (2000) has also suggested, for the same reason, that cereals might have been introduced to the Syrian Euphrates from farther north. Given that archaeological evidence for transport in raw materials such as obsidian, shells, stone, bitumen and perhaps wood is well documented for this period, the transportation of cereals and pulses is a real possibility. However with regard to introduction in the Euphrates most researchers now prefer to explain the presence of rye and wild einkorn outside their contemporary distribution limits by a more favourable climate that existed in the past. And there is indeed now some information that points to cooler, more humid conditions (Hillman, 2000). The early introduction of crops is seen on the island of Cyprus where barley, emmer and einkorn have been found for the end of the 10th millennium. The latter two, which have no wild equivalents on the island today, are considered to be introductions, but their status as domesticates is unclear for the moment (Willcox, 2000c).

Table 1. Presence/absence, ubiquity and absolute totals of charred cereal grains found on Late-Pleistocene/Early-Holocene sites in Western Asia. These results show that cereal assemblages vary from site to site in terms of both presence/absence and the frequencies of the major cereal components.

Site	Units	Date BP	Einkorn 1g	Einkorn 2g	Emmer	Barley	Rye
Southern Levant							
Ohalo II	1	19,000	**0**	**0**	21	629	
Wadi Hammeh 27		12,200-11,920	**0**	**0**	0**	p	
Netiv Hagdud	8	9900-9400	**0**	**0**	27(4)	541(8)	
Aswad I	9	9800-9200	**0**	**0**	23(6)*	32(6)*	
Middle Euphrates and Iraq							
Abu Hureyra	24	11,500-10,000	**0**	>500(21)	**0**	**0**	p*
Qermez Dere		10,100-9700	**0**	0**	**0**	p	
Mureybet I-III	56	10,200-9600	**0**	744(23)	**0**	116(17)	p
Jerf el Ahmar	69	9700-9200	**0**	197(25)	**0**	1132(69)	p
Dja'de	18	9500-9000	**0**	309(16)	**0**	662(18)	
Eastern Anatolia							
Cafer Höyük XII XIII		9400-8800	p	p	p*	0**	p
Çayönü phases g, bp, ch		9250-8500	p	p	p*	p	
Nevali Cori	1	9250-9000	661*	p	129	89	
Cyprus							
Mylouthkia/Shillourokambos		9250-9000	p	p	p	p	

Units = number of samples; numbers not in brackets = absolute numbers of grains identified; numbers in brackets (00) = number of samples in which a taxon is present; * = possible domestication at this site; ** = absence not significant; bold = absence significant. The preliminary results of Jerf el Ahmar and Dja'de are from author's unpublished data.

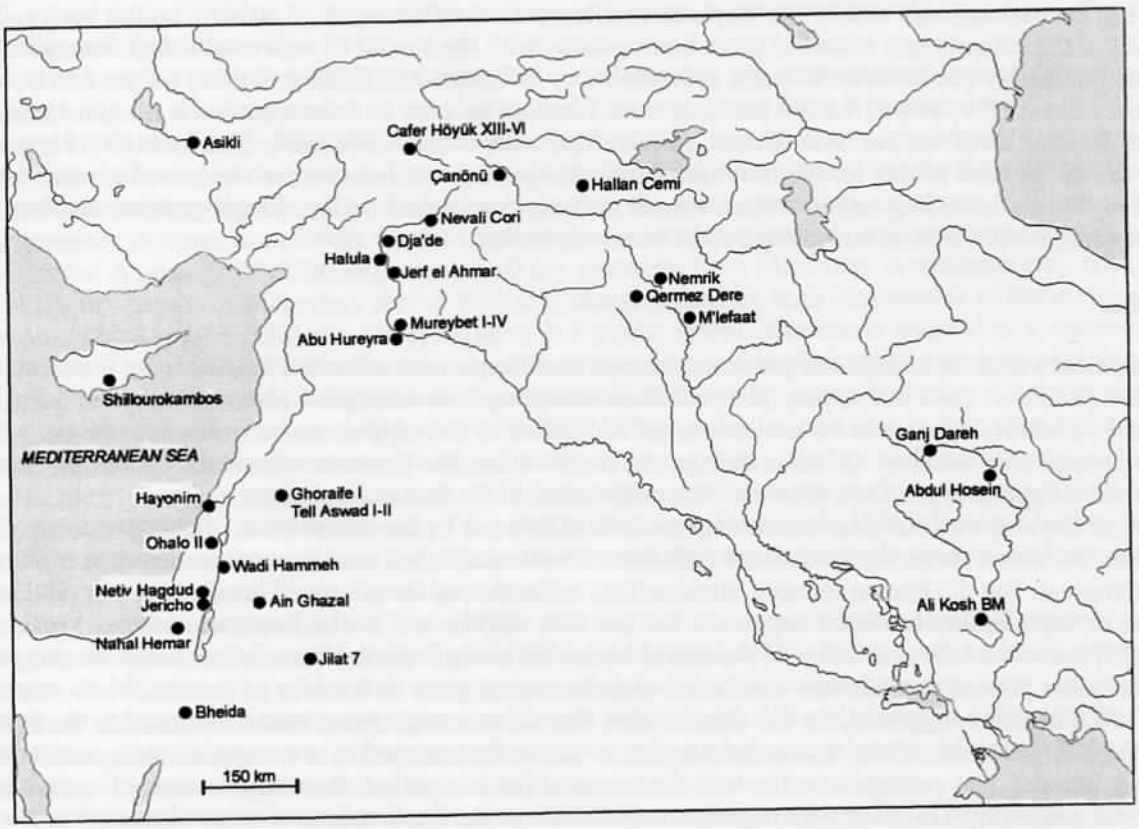

Figure 1. Site location map giving principal sites mentioned in the text and in Table 1. Dates in BC cal.

At nine of the thirteen sites (Table 1) the major cereal component corresponds to the most common wild cereal in the present-day local vegetation, thus availability appears to offer a convincing explanation, at least for these nine sites. This demonstrates that the inhabitants relied on the local cereals (being the best adapted to the local conditions). A number of these sites were occupied continuously for more than a millennium. Unfortunately in many cases the earliest basal levels were poorly sampled, but it seems probable that initially the cereals were gathered, then cultivation would have progressively replaced gathering (the reasons for this were probably multiple and not necessarily the same for each region). This taking into cultivation of local populations independently would favour the possibility of independent domestication events. A glance at the map (Figure 1) shows us that the distribution of sites fits into three clusters: the southern Levant, the middle and upper Euphrates and northern Iraq with the western slopes of the Zagros. The eastern cluster has very few plant remains, yet it is clear that wild cereals were exploited by the end of the 11th millennium at Qermez Dere and perhaps Nemrik and by the beginning of the 10th millennium at M'lefaat (Nesbitt, 1992, 1995). Thus, within the region as a whole the transition to cultivation appears to have been broadly contemporary in that it took place during the 10th millennium. The very wide geographical area and the long time span provided a vast arena for potential domestication events. With a long period of pre-domestic agriculture, over a wide area, the probability of multiple domestication events must have been high. In fact at sites with long chronological sequences, such as Aswad, Çayönü, Cafer Höyük, Nevali Cori, Abu Hureyra and Jericho there are arguments for independent domestication events.

Possible archaeobotanical evidence for the domestication of the major cereals

Archaeobotanical material provides evidence for independent domestication events for each cereal species. The earliest is rye at Abu Hureyra (Hillman, 1996, 2000). Another possible example is single-grained einkorn, which has been found as a dominant at only one early site, Nevali Cori. Spikelet bases and grains from Nevali Cori examined at the IWGP meeting in Innsbruck in 1995 were considered to be mainly from single-grained einkorn. At Cafer Höyük in the same general region single-grained einkorn frequencies increase in the 9th millennium. At 9th millennium sites outside this area single-grained einkorn represents a minor component. Only at later dates in Europe, Cyprus and Central Asia did einkorn become a major cereal component. High frequencies of einkorn from Mureybet and Abu Hureyra are frepresented by the two-grained type.

In the case of barley the situation appears more complex. The archaeobotanical evidence indicates that barley is dominant at sites in the southern Levant, for example 10th millennium Netiv Hagdud and 9th millennium Jericho, where it is already domesticated. Farther north large amounts of barley rachis segments from sites in the Damascus basin provide evidence for a progressive increase in domestic types. Results from Aswad I and II (9700-8500 BP) and Ramad (8200-7800 BP) indicate that wild fragile rachis types were very gradually replaced by solid forms. Of all the rachis fragments from Aswad, 62.5% are wild, 26.6% domestic and 10.9% unidentified. By the end of the 9th millennium at nearby Ramad, 35.3% are wild, 48.8% are domestic and 15.9 are unidentified (Van Zeist & Bakker-Heeres, 1982). This appears to be evidence of gradual *in situ* selection for a solid rachis in wild barley in this area. Further north still at Jerf el Ahmar and Dja'de high frequencies of barley grains with a rounded ventral furrow have been found on 10th millennium sites (Willcox, 1996; in preparation) but grain morphology alone is not considered at present a reliable criterion for domestication. The rachis fragments remain of fragile wild type. Barley is rare or absent from early sites in Anatolia. Farther east in the Zagros area it is common, and the earliest domestic barley is not much later than in the southern Levant (beginning of the 9th millennium) suggesting the possibility of an independent domestication.

Evidence for the local domestication of emmer is fairly strong at the site of Çayönü. The earliest levels do not have diagnostic remains, but *Triticum* was identified. Spikelet fragments of emmer from later 9th millennium levels are reported as domestic, and in terms of the grains Van Zeist states that in the course of the occupation of the site wild type emmer grains were replaced by forms with a distinct domestic grain morphology. Further south, Aswad I has also produced early finds of domestic emmer.

New evidence from Cyprus at Shillourokambos (Guilaine *et al.*, 1997; Willcox, 2000c) and at Mylouthkia (Peltenberg *et al.*, 2000) indicates that barley, emmer and einkorn are present at the end of the 9th millennium. The barley is wild at Shillourokambos, but it is not possible to tell whether the wheats are domesticated or not. If wild forms were introduced into Cyprus, the possibility of an inde-pendent domestication on Cyprus could be considered.

That at least two domesticates died out is demonstrated by the evidence of rye domestication at Abu Hureyra during the 11th millennium which did not survive (Hillman, 2000) into the 10t and 9th millennia and by two-grained einkorn found at Tell Sabi Abyad (Van Zeist & Waterbolk-van Rooijen, 1996) and Kosak Shamali (Willcox, unpublished report) which also did not survive into the Bronze Age.

Conclusion

After comparing available data from a wide range of sites it appears that the domestication of each species was a geographically independent event, for example:

- rye at Abu Hureyra (identified from grain material only) and later at Can Hasan III;
- barley in the southern Levant and perhaps in the east in the Zagros, although this not supported by DNA data;
- emmer in the northern Levant (Çayönü) and possibly independently in the southern Levant (Aswad, Jericho);
- einkorn in south-eastern Anatolia, in the region of Nevali Cori.

Domestication appears to be a gradual process because wild cereals were not always rapidly replaced by their domesticated counterparts; mixtures have been observed at most sites. Evidence that some early domesticates became extinct may be seen in two species which are readily distinguished, rye and two-grained domestic einkorn. Different varieties of emmer and einkorn may have also died out, but this is difficult to demonstrate because one cannot recognise different varieties in the archaeobotanical material. The archaeobotanical evidence agrees broadly with conclusions based on DNA and genetic studies but in addition it provides a geographical and chronological framework.

Gathering of wild progenitors occurred over several millennia and over a wide geographical area from Greece (wild barley at Franchthi [Hansen, 1991] and at Theopetra [Kyparissi-Apostolika, 1998]) to Iraq and as far south as the southern Levant. The earliest known site (at present) where wild cereals were found to be exploited is Ohalo II, which dates to 19,000 BP. By the 11th millennium we see the first possible evidence for a domestication event on the Euphrates. Evidence from weeds suggests that cultivation may have occurred sporadically on 10th millennium sites with local wild cereals, which in some cases led to morphological domestication. However, selective pressures were not always sufficiently high to lead to domestication. By the 9th millennium agriculture became progressively more organised into a production economy with an increase in selective pressures in favour of domesticates. It is only at this point that we see the consistent appearance of domestication with the spread and introduction of emmer, naked wheat and domestic barley at sites such as Halula, 'Ain Ghazal, Abu Hureyra, Akl and others. These sites show a dramatic increase in surface area (Molist & Stordeur, 1999) which would appear to reflect an increase in population resulting from the adoption of a fully established production economy. This new more developed agricultural economy may have lead to the extinction of less productive domesticates.

Future research will no doubt reinforce or refute these interpretations. The basal levels of a number of sites need to be re-examined, in particular at Çayönü, Aswad, and Jericho. More work needs to be carried out on the morphology of domestication. Accurate chronological correlation between sites is problematical and so more dating, directly from the seed material rather than from wood charcoal, could to provide a more accurate framework.

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