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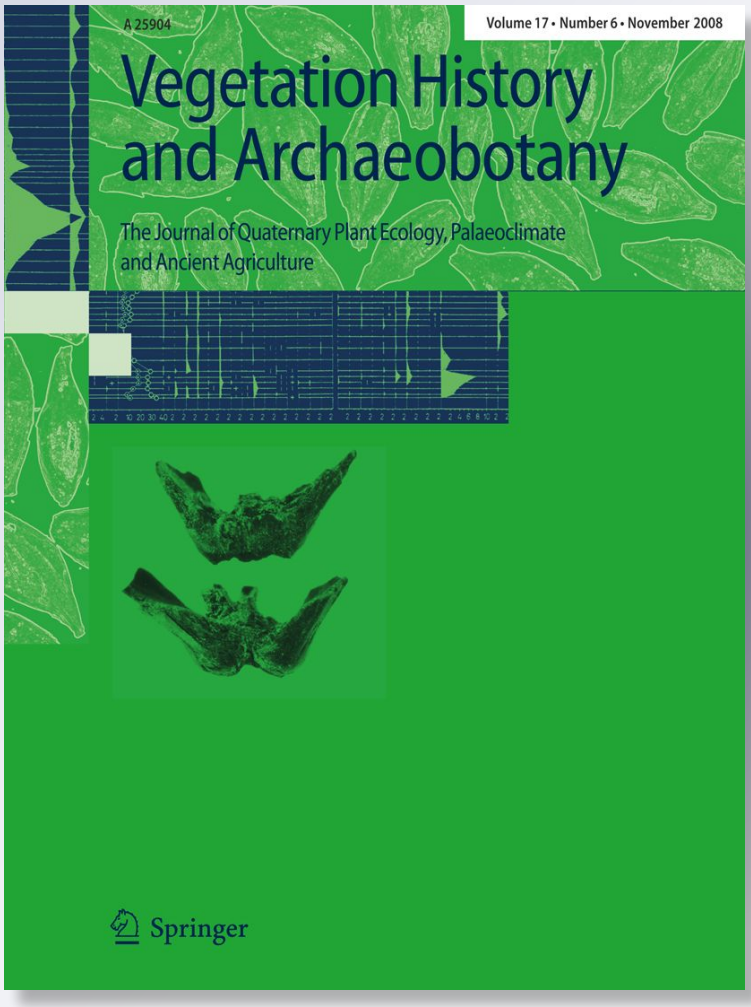

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ORIGINAL ARTICLE

Distinguishing wild and domestic wheat and barley spikelets from early Holocene sites in the Near East

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Abstract Identifying morphologically domestic cereals is essential to understanding the origins of agriculture. Charred spikelet bases provide the best evidence for distinguishing wild from domestic varieties of emmer, einkorn and barley; however until now, identification criteria have not been agreed upon or well established. We examined more than 20,000 remains of charred spikelets from eleven early Holocene sites in the Near East, classing them into nine groups. We show that damage and fragmentation of wheat spikelets probably due to dehusking makes identification problematic, and only when the abscission scar is well preserved is it possible to distinguish wild spikelets which shatter from domestic spikelets which adhere and separate during threshing. Barley spikelets were found to be less damaged and more easily identified, perhaps because the processing was less damaging. Einkorn was dominant over emmer on early sites, whereas on later sites emmer was dominant. Identifications presented here from eleven sites date from approximately 13000 to 8200 cal B.P. They give an incomplete picture, but no domestic cereals were identified during the PPNA (Pre-pottery Neolithic A). Early PPNB Aswad produced domestic barley but at other sites for this period the evidence is inconclusive. Unequivocal signs of domestic emmer spikelets appear during the Middle PPNB about 10,000 years ago but wild forms continue as part of the crop after this period. These conclusions are based on limited data. Future studies will undoubtedly produce a more accurate picture.

Keywords Wheat · Barley · Origins · Near East · Domestication · Agriculture

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Introduction

Identifying pre-domestic cultivation and morphologically domestic cereals is crucial to our understandings of the origins of agriculture in the Near East. Pre-domestic cultivation has been suggested for ten sites in the Near East (Colledge 1998; Edwards et al. 2004; Kislev 1997; Kuijt and Finlayson 2009; Meadows 2004; Weiss et al. 2006; White and Makarewicz 2011; Willcox et al. 2008). Domestication of wild cereals involved selection of traits favoured under the conditions of cultivation. Two of these traits can be identified in the archaeological record: changes in grain size and a change in the dispersal mechanism from shattering wild types to non-shattering domestic types. It is the latter which is the subject of this article.

Identifying the earliest domestic spikelets and comparing data from different sites in the Near East is problematic due to (a) lack of agreed identification criteria, (b) lack of direct AMS dating on cereal remains and (c) poorly preserved archaeobotanical material. In this study we attempt to consolidate the data presented in a previous article (Tanno and Willcox 2006). Tracking the earliest domesticates is under constant revision due to new or revised identifications.

For the PPNA period non-shattering domestic types were reported from PPNA Aswad and Iraq ed-Dubb

(Nesbitt 2002; Colledge et al. 2004). However at Aswad direct AMS dates on the grains and recent excavations by Stordeur have demonstrated that the samples and the layers from which they were recovered date to the early PPNB (10500 cal B.P.) (Stordeur et al. 2010). At Iraq ed-Dubb identification needs to be confirmed by direct dating and re-examination of the material: contamination from later material from higher levels cannot be ruled out (Nesbitt 2002). The low frequencies of domestic barley at PPNA Netiv Hagdud are not evidence for domestication (Kislev 1997). Kislev's (1989) detailed study of the anatomy of the dispersal mechanism showed that wild populations of barley may contain 10% of domestic types which come from the basal spikelet. This is about the quantity found at Netiv Hagdud. At the time of writing there are no finds from the PPNA in the southern or in the northern Levant with more than 10% domestic spikelets.

For the early PPNB, domesticated hulled wheat was reported from Cayönü and Mylouthkia but no firm criteria were given, indeed identification may have relied on the tear-off scar which as we explain below is not an indication of domestication (Murray 2003; van Zeist and de Roller 1994, Figs. 8, 2–6 and 9, 3–3). For PPNB Jericho the sample was too small and like Cayönü there were no direct AMS dates on the grains. Early reports from Nevali Çori (Pasternak 1998) suggested morphological domestication; this was confirmed by Nesbitt and Willcox, who examined the material at the IWGP meeting in Innsbruck in 1995. However further examination of the material in 2005 and again with colleagues at the IWGP in Kraków in 2007 showed that the identification was not clear-cut for reasons that will be described below. At Cafer Höyük for which identifications are more precise, 60% of the spikelets were domestic in levels XII-IX, dated to about 10000 cal B.P. Barley in the northern Levant, for example at Cayönü during this period is wild (van Zeist and de Roller 1994, Figs. 8,7). In the southern Levant however it was domesticated at Aswad and at Wadi el Jelat 7 where finds date at the earliest to the early PPNB, c. 10500 cal B.P.

In this study we attempt to clarify the situation by suggesting rigorous identification criteria and new data. However because of the inherent problems of the material, the scant archaeological record and difficulties in dating, it is not possible to provide an accurate record of domestication for each species.

Data from grain measurements indicates that an increase in size started before the appearance of a change in the dispersal mechanism during the PPNA (Fuller 2007; Willcox 2004). This increase in grain size could result from morphological domestication, but at present it is not possible to rule out the possibility of phenotypic changes resulting from improved growing conditions.

Materials and methods

Archaeological sites

Archaeological sites from which we examined charred spikelets include Dederiyeh (unpubl.), a cave site dating to the Natufian period situated in north-west Syria (Fig. 1). Also in northwest Syria, Tell Qaramel, an open air site with round houses, is dated to the Khiamian and PPNA. Further east on the Euphrates the PPNA site of Jerf el Ahmar and the early PPNB site of Dja'de produced evidence of pre-domestic agriculture (Willcox et al. 2008). To the north in southeast Turkey, Nevali Çori is also dated to the early PPNB and was re-examined following an initial study by Pasternak (1998), here we give the full results. Aswad in south Syria, of similar date, was first excavated in the 1970s and the plant remains were published by van Zeist and Bakker-Heeres (1984). Recent excavations by Stordeur have more accurately dated this site and produced more spikelet remains, which are reported here (Stordeur et al. 2010). Late PPNB sites include Seker al-Aheimar Khabur in northeast Syria and Ramad in south Syria. Pottery Neolithic sites include Salat Cami Yanu in the Tigris valley in southeast Turkey and Tell el-Kerkh in northwest Syria. These sites represent a limited sample and it is hoped that in the future this study will include a wider range of sites.

A proposition for the classification of charred wheat and barley spikelet fragments from early Neolithic sites in the Near East

In this study we classified spikelets into nine groups depending on whether they were wild or domestic and how they become fragmented (Fig. 2). This classification is based on both modern and charred material. Spikelets consist of the rachis internode with an upper and lower abscission scar. In wheat, the glumes are often partially preserved and form what are often called spikelet forks. Charred spikelets or fragments of spikelets from archaeological sites would have undergone harvesting, threshing (separation of spikelets, removal of straw), followed by dehusking to separate the grains from the glumes, lemma and palea. Conditions of charring and burial would also affect the specimens. Frequently the more fragile parts of the spikelets such as hairs, lemmas and upper parts of the glumes do not survive. Complete spikelets with unbroken rachis internodes are very rare; the fragile lower part is frequently missing. Longitudinal fragmentation results in glume bases which are not diagnostic. We examined 20,887 spikelet remains of hulled wheat and barley from the above-mentioned sites. We recognized nine types of remains for hulled wheat and seven for barley which are described below. This variety of forms or types results

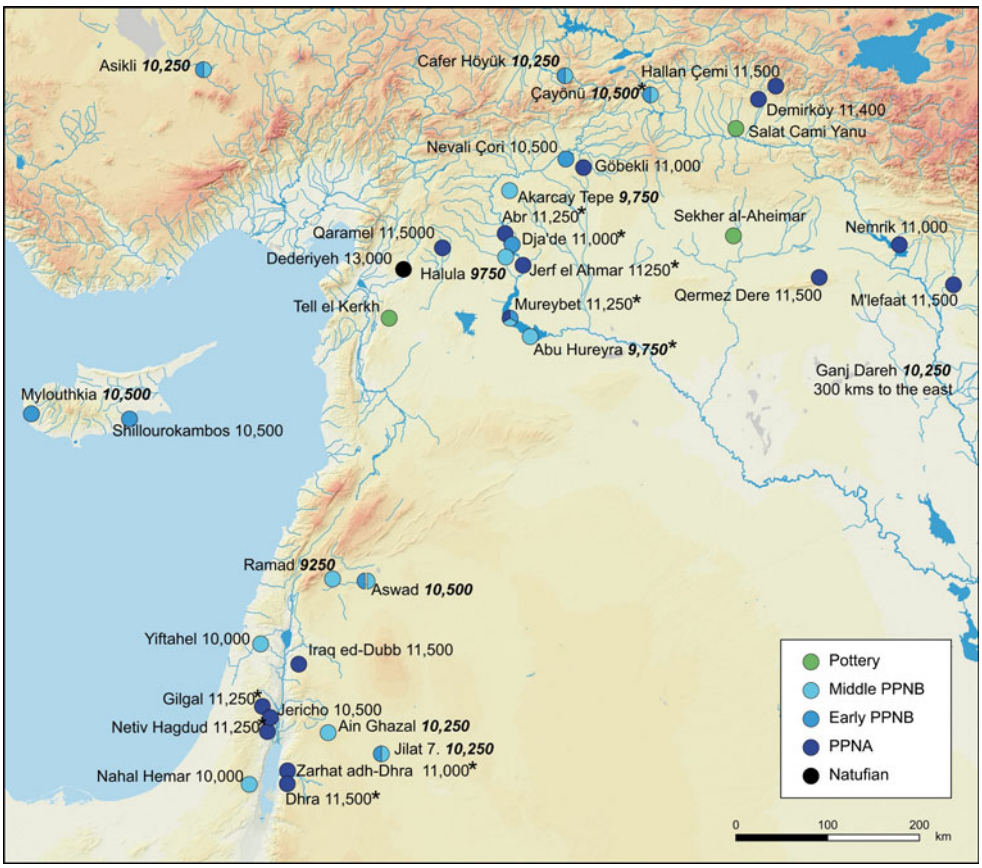

Fig. 1 Locations of major sites with dates. Sites with pre-domestic cultivation are marked with *. Dates given in bold italic indicate early finds of domestic spikelets. For the dates of other sites see Tables 1 and 2

from a combination of fragmentation and wild as well as domestic types.

(1) Glume bases of hulled wheat (Fig. 2a).

Glume bases are common on archaeological sites. They cannot be used to distinguish wild and domestic forms. In this study 9,317 or about 50% of the total remains were glume bases (Table 1). This type does not apply to barley.

(2) Damaged upper portion of spikelet with tear off scar (Fig. 2b).

A typical example of a damaged spikelet base is shown in Fig. 3b. The damaged area around the abscission scar lacks the epidermis, exposing the underlying tissue. In the past these types have been identified as "domestic" with a "tear-off" scar which was supposed to have resulted from the tearing apart of two spikelets which were fused. These types were common at sites where only wild types had been identified, for example at Qaramel and Dyderiyeh. But they are also common at sites with domestication such as Salat Cami. This type is not suitable for identification. It is frequent on the early farming sites, making up 36.8% of the total spikelet fragments in our study. In contrast to the hulled wheat, this type was rare among the remains of barley. This will be discussed below.

(3) Terminal spikelets (Fig. 2c).

Figure 2c shows a terminal spikelet. In this case the abscission scar has not survived so it is not possible to distinguish between wild and domestic. The terminal spikelet is the first to be lost when wild plants reach maturity. Theoretically in archaeobotanical assemblages consisting of wild populations the terminal spikelet should be less frequent than in a domestic population. Our results support this hypothesis because the terminal spikelets increase proportionately with the domestic types (Table 1). No terminal spikelets were recognized among the barley remains.

(4) Wild type spikelet upper scar (Fig. 2d).

Wild type spikelet bases of wheat and barley have an abscission scar which exposes the vascular bundles (see Fig. 2d). The scar is concave because it was connected to the lower end of the above spikelet which has a convex scar. For the identification to be secure the original surface of the abscission scar must be present. It is smooth and the perimeter is clearly defined. The abscission layer is wider with more vascular bundles when the spikelet comes from the lower part of the ear, whereas nearer the apex there are fewer vascular bundles and it is narrower (Whingwiri et al.

Fig. 2 Nine categories of charred hulled wheat spikelets: **a** glume base; **b** damaged spikelet base with tear-off scar; **c** terminal spikelet; **d** upper scar, wild type; **e** upper scar, domestic; **f** possibly domestic; **g** lower scar, wild; **h** lower scar, domestic; **i** lower scar, possibly domestic; **j** modern wild; **k** modern domestic

1981). However, in the present study it was not possible to arrange spikelets in the order of their position on the ear because of phenotypic and genetic variation.

(5) Domestic type spikelet upper scar (Fig. 2e).

The domestic type scars (Fig. 2e) in hulled wheat and barley retain a fragment of the lower portion of the neighbouring spikelet above. It can be quite obvious as in Fig. 2e or it can take the form of a raised lip on the perimeter, usually seen on the lower edge of the scar. Early domestic barley ears shatter in a similar way to einkorn and emmer with the break occurring at the join between the two spikelets, and only rarely do they break into rachis fragments.

(6) Possible domestic spikelet upper scar (Fig. 2f).

In this type the vascular bundles are not readily visible and the scar is not concave. The surface of the scar is not smooth. The perimeter is poorly defined. There is no clear fragment of the neighbouring spikelet above. This could be

Table 1 List of identifications of charred einkorn and emmer spikelets, including new data from Aswad and Asikli. * Samples from level 4 Asikli, 2010 excavations. ** Samples from Stordeur's excavation. *** emmer present in small quantities

	Emmer and Einkorn	Dederiyeh (einkorn***)	Qaramel (einkorn)	Jerf el Ahmar (einkorn)	Dja'de (einkorn)	Nevali Cori (einkorn***)	Aswad ** (emmer)	Asikli * (emmer)	Seker Aheimar (emmer)	Salat Cami (emmer)	el-Kerkh (emmer)	Total
Date (ka cal B.P.)		13	12	11.3	11	10.5	10.5	10.2	9.3	8.3	8.2	
Not identifiable	glume fragment	1	186			5,312	568	200	179	1,848	621	9,317
	damaged, indet.	4	88			2,285	1,262	193	70	1,268	860	6,464
	terminal spikelet					6	27	4	2	18	27	105
Upper part	wild		14	5	16	64	170	11	1	1	19	322
	possible domestic		4			38	50			12	23	250
	domestic					3	7	9	2	42	11	292
Lower part	wild					179	51	10	1		1	242
	possible domestic					35	16		1	8	5	66
	domestic					36	3		7	43	4	139
Total		5	292	5	16	7,958	2,154	426	263	3,240	1,571	17,196

a domestic spikelet with a damaged scar; however it might also be a wild spikelet's scar with an irregular protuberance. We included this type because it was quite frequent in the case of hulled wheat remains.

(7) Wild spikelet lower scar (Fig. 2g).

Figure 2g is the lower portion of the internode with a wild type scar of hulled wheat. Barley produces similar remains, which may be difficult to distinguish from wheat. This lower convex scar fits into the concave scar of the upper portions where indeed they were joined. The shape is rounded, the surface smooth, and the vascular bundles are visible as is the perimeter of the scar.

(8) Domestic spikelet lower scar (Fig. 2h)

The domestic scar of the lower part of the spikelet is not rounded, it is broken off and part of it is missing, precisely the part which adhered to the upper portion. In place of the scar there is a jagged break.

(9) Possible domestic spikelet lower scar (Fig. 2i)

This type shows damage to the perimeter of the scar. The vascular bundles are not visible and it does not show the rounded form of the wild type. This could be a domestic type which has been damaged.

The nine types fall into three groups, the first group (Fig. 2a, b, c) was not informative for separating wild from domestic. The second group relies on the abscission scar on the upper portion of the spikelet (Fig. 2d, e, f); in this group wild and domestic can be readily distinguished when well preserved, but they are frequently damaged. The third group consists of the lower scar of spikelet (Fig. 2g, h, i); these rarely survive.

In the rare cases of whole spikelets with no breakage between the upper and lower portions of the rachis internode, the two scars were counted separately. In the case of barley, connected rachis fragments, common on later sites, were counted in the same way as wheat. The lower portions of the spikelets are rare compared to the upper portions. The former are smaller and less likely to survive, being more fragile, more easily consumed by fire and more difficult to recognize when sorting than the upper portions. They are also more likely to be damaged during sampling procedures. Despite this rarity, the identification of the lower portions is more straightforward.

Dehusking experiments on hulled wheats

Because we suspected that dehusking could damage spikelet bases, we carried out experimental dehusking using a wooden mortar and pestle on a population of wild einkorn grown at Jalès in southern France (Fig. 3a). Examination of the chaff that was obtained from dehusking revealed that spikelet bases were indeed damaged

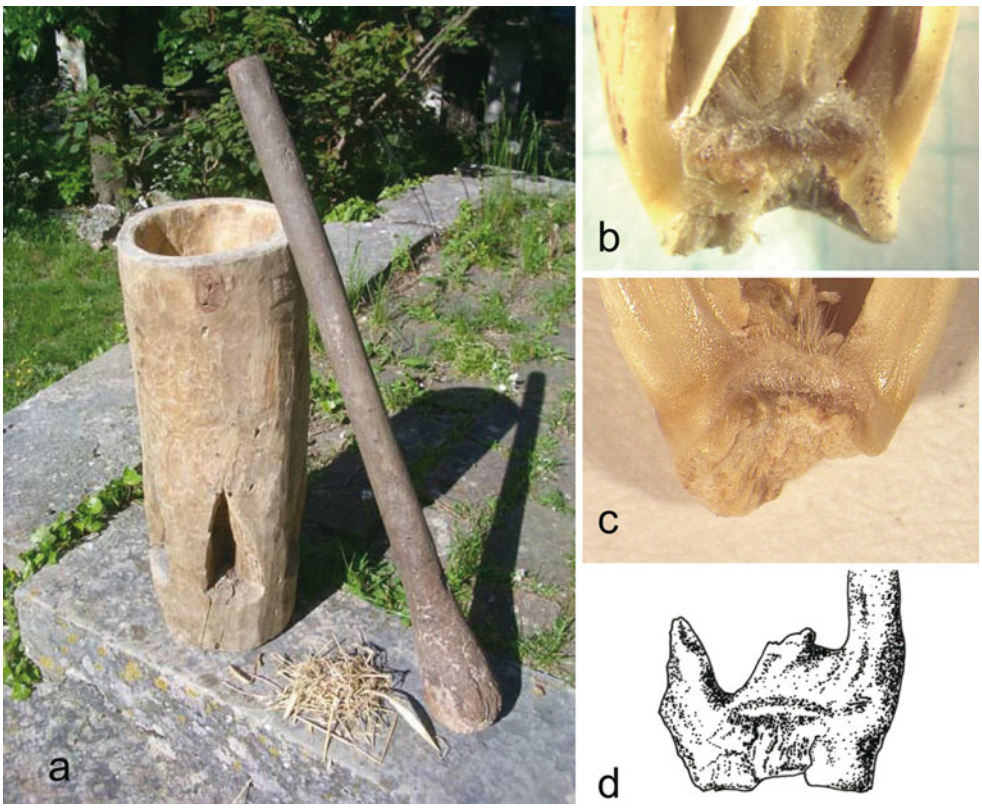

Fig. 3 Use of a wooden pestle and mortar in dehusking experiments: **a**, **b** damaged spikelet with tear-off scar from wild einkorn; **c** damaged spikelet with tear-off scar from a domestic population; **d** charred spikelet from Tell Qaramel

(Fig. 3b). These experiments were confirmed with domestic emmer and einkorn which produced the same tear-off scar. These damaged specimens were very similar to the unidentifiable types where the epidermis had been torn off, producing the so called tear-off scars formerly interpreted as being domestic (Fig. 3b, c and d). We conclude that this type of scar in most archaeobotanical specimens results from damage during pounding and could come from either wild or domestic ears.

Results

After examining 3,695 specimens of barley and 17,196 specimens of hulled wheat we classified them into the types mentioned above (Tables 1, 2; Figs. 4, 5). In addition, 677 identifications of barley spikelets from analyses by van Zeist are presented in the tables and figures (van Zeist and Bakker-Heeres 1984).

The wheat remains were fragmented; unidentifiable specimens including glume bases represent over 90% of the total study. In contrast, for the barley, unidentifiable remains represent less than 5% of the total study. At the four earliest sites there is no evidence of einkorn domestication.

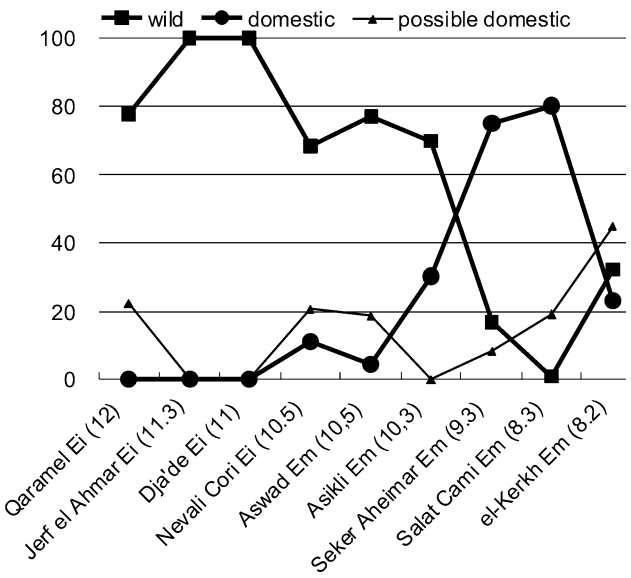

Fig. 4 Percentages of emmer and einkorn spikelets from sites in the study. Domestic types are present from about 10500 cal B.P. The irregularity in the graph results from geographical isolation which suggests that domestication proceeded at different paces depending on the site or region. The lowering in the frequencies of wild emmer between 10500 and 8300 B.P. suggests that selection against these types was not strong; *Ei* einkorn, *Em* emmer

Table 2 List of identifications of charred barley spikelets, including new data from Aswad and Asikli

	Barley	Jerf el Ahmar	Dja'de	Aswad (Willcox)	Aswad (van Zeist)	Asikli (Willcox)	Seker Aheimar	Ramad (van Zeist)	Salat Cami	el-Kerkh	Total
Date (ka cal B.P.)		11.3	11	10.5	10.5	10.2	9.3	9	8.3	8.2	
Not identifiable	damaged, indet.			14	14		24	84	8	15	159
Upper part	wild	3,325	153	23	80	11		186		2	3,780
	possible domestic			14			7			1	120
	domestic	8	2	18	34	2	52	269	11	1	397
Lower part	wild			12		12					24
	possible domestic			4							4
	domestic			1			2		4		7
Total		3,333	155	86	128	25	85	539	23	19	4,491

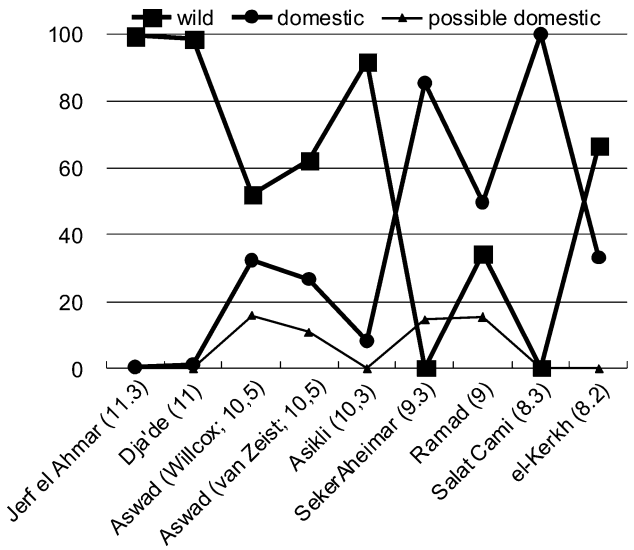

Fig. 5 Percentages of barley spikelets from sites in the study. Domestic types at Aswad are low, but a later increase can be seen at the nearby site of Ramad. Further north at Sekher al-Aheimar and Salat Cami Yanu, domestic types are dominant suggesting that domestication proceeded more quickly in this area, possibly because the sites were situated outside the natural distribution area of wild barley

At Nevali Çori (einkorn dominant) Aswad (emmer) and Asikli (emmer), dated to between 10500 and 9300 cal B.P., domestic types are present at low frequencies compared to wild types; the question of whether this represents a wild population is discussed below. At the later sites this is reversed and domestic types become more common than wild types. For barley the low frequencies of domestic types at the two early sites, Jerf el Ahmar and Dja'de, represent what would be expected in wild populations (Kislev 1989). At Aswad, there is evidence of barley domestication for the early PPNB with domestic types being present in the earliest samples dated to 10500 cal B.P. This is the earliest evidence for barley domestication in the Near East.

Discussion

Barley remains are better preserved than hulled wheat and so can be identified more reliably. At Aswad samples came from levels dated at the earliest to c. 10500 cal B.P. where wild barley types are slightly more common than the domestic types, but considerably more than the 10% one might expect in a wild population (see above). At the neighbouring site of Tell Ramad, dated at the earliest to 9300 cal B.P., domestic types are more frequent than wild types suggesting a gradual trend in the region towards domestication. At Seker Aheimer domestic barley types dominate. At Asikli preliminary results for barley are not conclusive. Reports from Ganj Dareh, Chogah Golan and Chia Sabz in the eastern Fertile Crescent suggest that mixtures of wild and domestic barley were present from about 10500 cal B.P., making these finds similar in date to those of the southern Levant (Riehl et al. 2011).

Einkorn spikelets are not numerous at the four earliest sites Dederiyeh, Qaramel, Jerf el Ahmar and Dja'de, and none were domestic. For the later sites Nevali Çori, Aswad and Asikli, the frequencies of domestic types are lower than 10%, so these may represent the small proportion of basal

spikelets which can be fused in wild populations (Kislev 1989). Lower frequencies of wild emmer compared to domestic and an increase in terminal spikelets at the sites of Seker Aheimar, Salat Cami and Tell el-Kerkh confirm that morphological domestication of emmer was established.

Why is barley chaff less fragmented than wheat chaff? The morphology of the barley spikelets is similar to that of hulled wheat. However an important difference is that barley has awn-like vestigial glumes whereas wheat has thick glumes which clasp the grains and require rigorous dehusking to separate grains and chaff. The low frequencies of damaged spikelets in barley compared to hulled wheat may due to different processing techniques. In hulled wheats the spikelet remains intact during threshing, the grains remaining tightly held between the glumes. However, with barley during threshing the glumes and the spikelet bases separate easily from the grain, which remains fused with the lemma and palea. The hulled wheats require further treatment, that is, rigorous dehusking after threshing, in order to separate the grain from the glumes and the rachis internodes. It is probably the dehusking which leads to damage, whereas barley spikelet bases are subject to less pounding. Natufian spikelets from Dederiyeh produced the damaged tear-off type which suggests that similar dehusking methods were used at this early period. The damage at Salat Cami Yanu was apparently more severe than at other sites (see above). These observations suggest that future studies of spikelets may yield information about dehusking techniques.

Why do wild types persist after the appearance of domestic types? Wild and domestic types are very similar morphologically and difficult to distinguish, making their separation difficult. Indeed this continued admixture of wild types and low frequencies of einkorn in emmer fields suggests that for early Neolithic farmers non-shattering and shattering forms were part of the same crop, whereas today, wild einkorn and wild barley in the Near East are treated as weeds when they invade fields. It is possible that early farmers renewed their seed stock from wild populations when harvests failed. The occurrence of occasional failed harvests would have been inevitable given the climatic conditions that existed in the eastern Mediterranean. But the continued long term occurrence of wild types with einkorn/emmer mixtures suggests that farmers did not consciously select.

Why not? Plants with vegetative reproduction such as tubers or fruit trees can be cloned. Selection in the case of annual grain crops, such as the founder crops of the Near East, is not a simple matter. Domestic traits in these crops are not readily visible to the naked eye. This aside, the only effective way to select consciously is to build up a single line population from a single plant. This would be difficult because it requires keeping the descendents isolated from other plants. Even if selection could have been attained, a hypothetical single-line population would have had the disadvantage of reducing genetic diversity, which was necessary to create healthy crops with stable year-to-year yields. Non-industrial farmers generally appreciate variety and diversity in their crops, perhaps they understood that healthy crops consisted of numerous landraces, each with its own advantage. In addition early farmers no doubt felt secure and confident with their crops, and without the hindsight of a plant breeder it did not occur to them to attempt crop improvement. Early farmers may have chosen specific crops, for example wheat over barley, or they may have exchanged crops, but this is not selection.

Conclusion

This investigation into identifying domestic charred spikelets demonstrates that in the case of the hulled wheats only a small proportion of specimens are identifiable with any certainty. They can be classified into nine groups; only well preserved specimens will allow separation between wild and domestic. These new results complement those of a previous publication (Tanno and Willcox 2006) but they also underline the problems associated with identifying the timing of domestication. The data is incomplete with immense geographical and chronological gaps in the archaeobotanical sequence. In addition, in the case of hulled wheat the unidentifiable types make up 92.3% of the sample. The outcome of these results will no doubt be modified with new sites and observations. A critical re-examination of material in the light of the criteria presented here from sites such as Cayönü and Cafer Höyük should help clarify the domestic status of the hulled wheats.

An increase in the frequencies of emmer compared to einkorn over time can be seen in Table 1. This trend is prevalent across the Near East and indicates that the larger-grained emmer became the major wheat while einkorn with few exceptions was a minor component. As hulled wheats spread into new areas such as Cyprus and Europe, einkorn became a major component in some areas.

The earliest signs of domestication from the data in this study come from barley found in levels dated to 10500 cal B.P. at Aswad in the southern Levant. Recent finds from level 4 at Asikli dated to 10250 cal B.P. point to emmer being in the process of domestication. However these conclusions will require consolidation from future results. Domestication at the so-called mega sites such as Aswad, Halula, Abu Hureyra II, Asikli for the middle PPNB is not in doubt because naked wheats are also present. At these sites wild types continued to be present. These sites proliferated in the Middle PPNB but the early levels, which may be critical for the understanding of domestication, are

often inaccessible because they are covered by later levels and thus poorly understood.

Finally what conclusions can be drawn about the origins of agriculture from the results presented here? It is now agreed by archaeologists and archaeobotanists that pre-domestic cultivation occurred during the PPNA (and perhaps before) over a wide area including the northern and southern Levant. Crops from the south, for example from Netiv Hagdud, would not be adapted to climatic conditions of the high Anatolian plateau in the north, for example at Cayönü or Göbekli. Nor would the crops from the north be adapted to conditions in the lowlands of the south. Thus crops taken into cultivation at PPNA sites were probably local. These crops show a continuity into the succeeding period (early PPNB) when contemporary sites are found over a wide area of southwest Asia including Ganj Dareh in Iran, Aswad in southern Syria, Asikli in central Anatolia, Cayönü and Cafer Höyük in eastern Anatolia, and Jericho in Palestine. These sites have domestic cereals, but wild forms are still very common which implies that genetic input from wild populations continued independently at geographically widely separated sites suggesting that cereals evolved independently in different regions.

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