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REVIEW

Millets across Eurasia: chronology and context of early records of the genera *Panicum* and *Setaria* from archaeological sites in the Old World

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Abstract We have collated and reviewed published records of the genera *Panicum* and *Setaria* (Poaceae), including the domesticated millets *Panicum miliaceum* L. (broomcorn millet) and *Setaria italica* (L.) P. Beauv. (foxtail millet) in pre-5000 cal B.C. sites across the Old World. Details of these sites, which span China, central-eastern Europe including the Caucasus, Iran, Syria and Egypt, are presented with associated calibrated radiocarbon dates. Forty-one sites have records of *Panicum* (*P. miliaceum*, *P.* cf. *miliaceum*, *Panicum* sp., *Panicum* type, *P. capillare* (?) and *P. turgidum*) and 33 of *Setaria* (*S. italica*, *S. viridis*, *S. viridis/verticillata*, *Setaria* sp., *Setaria* type). We identify problems of taphonomy, identification criteria and reporting, and inference of domesticated/wild and crop/weed status of finds. Both broomcorn and foxtail millet occur in northern China prior to 5000 cal B.C.; *P. miliaceum* occurs contemporaneously in Europe, but its significance is unclear. Further work is needed to resolve the above issues before the status of these taxa in this period can be fully evaluated.

Keywords Millet · Early Neolithic · Eurasia · Chronology · Archaeobotanical methodology

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Introduction

Two cereals with an unusual geographical pattern in the archaeobotanical record are the temperate Eurasian millets *Panicum miliaceum* L. (broomcorn, proso or common millet) and *Setaria italica* (L.) P. Beauv. (foxtail millet). Both species are known from a number of sixth and seventh millennium B.C. sites in the Yellow River valley and other regions of north China; *P. miliaceum* has been reported from approximately contemporary sites in eastern Europe and the Caucasus, while *S. italica* appears in the same broad region later, around the 5th/4th millennium B.C. (Gumelnitsa culture) (Zohary and Hopf 2000; Jones 2004). Neither species has so far been recorded from the intervening central Asian region until the mid-2nd millennium B.C., when *P. miliaceum* is found in the Bronze Age site of Tahirbaj Tepe (Nesbitt 1994). Several hypotheses have been proposed to explain the disjunct distributions of these two millet species: a single domestication in either northern China or eastern Europe followed by rapid spread across the central Asian steppe, or multiple domestications that could either represent two discrete events at either end of the region, or diffuse domestication across the steppe zone as a whole (Jones 2004). A resolution to this uncertainly has significant implications for our understanding of interactions between early farming societies across Eurasia.

Pan-Eurasian summaries of the archaeobotanical evidence for broomcorn and foxtail millet have previously been published by Marinval (1995), Zohary and Hopf (2000) and Jones (2004).The data for Europe (including the Caucasus) is reviewed in Lisitsyna and Prishchepenko (1977), Lisitsyna (1984), and Wasylikowa et al. (1991), and for China in Underhill (1997), Cohen (1998), Shelach (2000), Lu (2005) and Crawford et al. (2007). To date, however, there has been no comprehensive review of early sites with *Panicum* and *Setaria* which provides detailed information on sites, calibrated radiocarbon dates and archaeobotanical finds. Such a review is timely for a number of reasons: first, in both eastern Europe and north China a number of new excavations are taking place in which sediment is being floated for archaeobotanical remains, supported by direct dating of carbonized seeds. Second, a number of database projects are improving the international collation of archaeobotanical and radiocarbon dating information (see Shennan and Steele 2000; Colledge et al. 2004, 2005; Kroll 2005).

Our objective in this paper is to collate and present published records of the genera *Panicum* and *Setaria* prior to 5000 cal B.C., with details of sites and radiocarbon dates, as a reference source to enable assessment of the biogeography of these two millet taxa in the context of a unified chronology, and to consider the implications for research into the origins and spread of millet agriculture.

The foci of this review are the two principal Asian millet domesticates, *P. miliaceum* and *S. italica*. The primary archaeobotanical literature, however, records finds of the two genera along a continuum of within-genus identifications. In the case of *Panicum*, the continuum ranges from 'domesticated *P. miliaceum*' through '*Panicum* cf. *miliaceum*', '*Panicum* sp.', '*Panicum* ?', through to entirely distinct species (*Panicum turgidum*, not currently known to have any particularly close relationship to broomcorn millet). A similar spectrum exists for *Setaria*. This is one of the key factors that currently hinder evaluation of the age and geographical range of domesticated broomcorn and foxtail millet, particularly the former. To avoid the twin pitfalls of either potentially overrepresenting the record of securely identified domesticated forms, or excluding tentative or genus-level identifications that may in fact represent domesticates, we chose to report all finds within each genus, with their original identifications. Although this does result in the inclusion of some entirely different species, for example in North Africa, that are most unlikely to be related to the domestication history of the Asian millets, such an 'inclusive' strategy has the advantage of clear boundaries to the data set, and a transparency not easily achieved through attempting to fully subdivide each intrageneric continuum of attempted identifications.

Methodology and results

We have sought to collate all published records of *Panicum* and *Setaria* prior to 5000 cal B.C. This band of time, which encompasses early phases of food production across the area under review, is necessarily arbitrary, but we consider this circumscription to be more useful than for example 'Neolithic sites', since the Neolithic is defined differently in different parts of the world.

For the reasons outlined above, we have included any cited taxon within these two genera. We have not attempted to re-evaluate identifications based on morphological criteria. However, we have assessed the context of and grounds for each identification in terms of preservation type, nomenclature, and chronology.

For Europe and southwest Asia, we have drawn extensively on the databases compiled by Colledge et al. (2004, 2005), Shennan and Conolly (2007) and Kroll (1996, 1997, 1998, 1999, 2000, 2001, 2005). The latter also provides information from beyond this region. For sites in the northern Black Sea region and the Caucasus, we have worked from Lisitsyna and Prishchepenko (1977), Lisitsyna (1984), Wasylikowa et al. (1991), Kotova (2003) and references therein, in addition to Helmut Kroll's database.

For China, a number of English- and Chinese-language references (Crawford 1992; Underhill 1997; Shelach 2000; Liu et al. 2004a; Lu 2005; Crawford et al. 2007; Lee et al. 2007) provide information on sites with millet. We have consulted the primary excavation reports for details of most of these sites, relying on secondary literature where these were not accessible.

Radiocarbon dates were calibrated using OxCal 4.0 (Bronk Ramsey 2001). We report confidence intervals to 2σ. Included in the data table (Table 1) are all sites with at least one date whose earliest boundary falls before 5000 cal B.C. Where no radiocarbon dates were available, we have reported available chronological information.

Sites producing *Panicum* and/or *Setaria* spp. are mapped in Fig. 1, and their details listed in Table 1. We report a total of 41 sites with *Panicum* identifications (including *P. miliaceum* and equivalent common names, *Panicum* cf. *miliaceum*, *Panicum* sp., *Panicum* type, *Panicum capillare* (?) and *P. turgidum*) and 33 with *Setaria* (*S. italica* and equivalent common names, *Setaria viridis*, *S. viridis/verticillata*, *Setaria* sp.). These totals include nine sites with taxa in both genera.

Detailed information on radiocarbon dates is given in the Supplementary Information (ESM) (Table 3).

Table 1 Sites with archaeobotanical evidence for *Panicum* and/or *Setaria* prior to 5000 cal B.C

Country (region/province)	Period	Culture	Site name	Type of site	Dating information	Context of find	Nature of find (no. of grains)	Identification	Reference
Europe (incl. Caucasus)									
Azerbaidjan	Late Neolithic	Shulaveri-Shomutepe	Kjultepe	Settlement	5th–4th mill. B.C.[a]			*Panicum miliaceum*	Lisitsyna and Prishchepenko (1977)
Bulgaria (southwest)	Late Neolithic		Drenkovo-Ploshteko	Settlement	Late 6th–early 5th mill. B.C.		Grain (4)	*Panicum miliaceum*	Kreuz et al. (2005)
Bulgaria (south)	Early Neolithic	Karanovo 1	Kapitan Dimitrievo				Grain (134)	*Setaria viridis/verticillata*	Marinova (2001)
Bulgaria (south)	Middle Neolithic	Karanovo 2–3	Karanovo		5200–4800 B.C. (2 dates)		Grain (10)	*Setaria viridis/verticillata*	Renfrew (1969), Hopf (1973), Thanheiser (1997), Marinova (2001)
Bulgaria (southwest)	Early Neolithic	Karanovo 1	Kovacevo		6000–5500 B.C. (2 dates)		Grain (62)	*Setaria viridis/verticillata*	Marinova (2001)
Bulgaria (west)	Early Neolithic	Karanovo 1	Slatina		5900–5600 B.C. (8 dates)		Grain (36)	*Setaria viridis/verticillata*	Dontscheva (1990), Marinova (2001)
Cyprus (north)	PN		Ayios Epiktitos Vrysi		5000–3700 B.C. (16 dates)		Grain (1)	*Setaria* spp.	Kyllo (1982)
Cyprus (south)	Khirokitian		Khirokitia		6900–6000 B.C. (2 dates)		Grain (2)	*Setaria* spp.	Waines and Stanley Price (1977), Miller (1984), Hansen (1989, 1994)
Czech Republic (northern Bohemia)	Early Neolithic	LBK	Březno u Louny		Second half of 6th mill. B.C.		Grain (13)	*Panicum miliaceum*	Tempir (1979)
Czech Republic (central Bohemia)	Early Neolithic	LBK/Stichbandkeramik/Lengyel?	Bylany	Settlement	5400–4300 B.C. (9 dates)		Grain	*Panicum miliaceum*	Tempir (1979)
Czech Republic (northern Moravia)	Early Neolithic	LBK/Moravian Painted Pottery?	Mohelnice	Settlement	5600–5000 B.C. (6 dates)		Grain	*Panicum miliaceum*	Tempir (1979)
Georgia	Late Neolithic	Shulaveri-Shomutepe	Arukhlo 1	Settlement	5th–4th mill. B.C.[a]			*Panicum miliaceum*, *Panicum capillare*?	Lisitsyna and Prishchepenko (1977)
Georgia	Late Neolithic	Shulaveri-Shomutepe	Dikhi-Gudzuba	Settlement	5th–4th mill. B.C.[a]			*Panicum miliaceum*	Lisitsyna and Prishchepenko (1977)
Georgia	Late Neolithic	Shulaveri-Shomutepe	Imiris-gora	Settlement	5th–4th mill. B.C.[a]			*Panicum miliaceum*	Lisitsyna and Prishchepenko (1977)
Germany (southwest, Hessen)	Early Neolithic	LBK	Bruchenbrücken		5200–4800 B.C. (1 date)		Grain (1)	*Panicum miliaceum*	Kreuz (1990)
					5600–4800 B.C. (8 dates)		Grain (47)	*Setaria* spp.	
Germany (north-central, Harz mountains)	Early Neolithic	LBK	Eitzum 2		5500–4700 B.C. (3 dates)		Grain (2)	*Panicum miliaceum*	Kreuz (1990)
							Grain (3)	*Setaria* spp.	
Germany (southwest, Hessen)	Early Neolithic	LBK	Goddelau		5700–5100 B.C. (5 dates)		Grain (1)	*Panicum miliaceum*	Kreuz (1990)

Table 1 continued

Country (region/province)	Period	Culture	Site name	Type of site	Dating information	Context of find	Nature of find (no. of grains)	Identification	Reference
Germany (southeast, Bayern)	Early Neolithic	LBK	Hienheim		5300–4700 B.C. (5 dates)		Grain (33)	*Setaria viridis/ verticillata*	Bakels (1978)
Germany (southwest, Baden-Württemberg)	Early Neolithic	LBK	Hilzingen		5400–4400 B.C. (9 dates)		Grain (47)	*Setaria viridis/ verticillata*	Stika (1991)
Germany (west Nordrhein-Westfalen)	Early Neolithic	LBK	Langweiler 3		Second half of 6th mill. B.C.		Grain (1)	*Panicum* spp.	Knörzer (1972)
Germany (west Nordrhein-Westfalen)	Early Neolithic	LBK	Langweiler 8		6000–4800 B.C. (6 dates)		Grain (2)	*Setaria* spp.	Knörzer (1988)
Germany (south, Bayern)	Early Neolithic	LBK	Meindling		5600–4800 B.C. (4 dates)		Grain (48)	*Setaria viridis/ verticillata*	Bakels (1992)
Germany (south, Bayern)	Early Neolithic	LBK	Mintraching		Second half of 6th mill. B.C.		Grain (1)	*Panicum miliaceum*	Kreuz (1990)
							Grain (1)	*Setaria* spp.	
Germany (northwest, Nordrhein-Westfalen)	Early Neolithic	LBK	Wanlo		Second half of 6th mill. B.C.		Grain (25)	*Setaria* spp.	Knörzer (1980)
Greece (Thessaly)	Early Neolithic	Protosesklo	Argissa Magoula	Settlement	6500–6200 B.C. (1 date)		Grain (1)	*Panicum miliaceum*	Hopf 1962, Kroll 1981, 1983
Greece (Thessaly)	Middle Neolithic	Sesklo	Otzaki Magoula		1st half of 6th mill. B.C.		Grain	*Panicum miliaceum*	Kroll 1981, 1983
Greece (Boeotia)	?Early Neolithic		Toumba Balomenou		6th-5th mill B.C.		Grain (1)	*Panicum* spp.	Sarpaki 1995
Italy (north)	Early Neolithic	Fagnigola	Sammardenchia		5600–4900 B.C. /EMPHASIS> (5 DATES)		Grain (3)	*Setaria* spp.	Rottoli 1999
Moldova (Prut-Dniestr rivers)	Early Neolithic	LBK	Denchen 1	Settlement	2nd half of 6th mill. B.C.		60 Imprints in pottery	*Panicum miliaceum*	Larina (1999)
Moldova (Prut-Dniestr rivers)	Neolithic	LBK	Durlesht I	Settlement	Second half of 6th mill. B.C.		1 Imprint in pottery	*Panicum miliaceum*	Larina (1999)
Moldova (Prut-Dniestr rivers)	Early Neolithic	LBK/Cris	Sakarovka	Settlement	Second half of 6th mill. B.C.		97 Imprints in pottery	*Panicum miliaceum*	Larina (1999)
Poland (southeast)	Early Neolithic	LBK	Olszanica		7000–4206 B.C. (8 dates)		Grain (2)	*Panicum* spp. (impressions)	Ford (1986)
							Grain (5)	*Panicum miliaceum* (impressions)	
Romania	Early Neolithic	Starčevo-Criş	Glăvăneştii Vechi	Settlement	1st half of 6th mill B.C.			*Panicum* sp.	Comşa (1996)
Romania	Neolithic	Vinča	Liubcova		Second half of 6th mill. B.C.			*Panicum miliaceum* L.	Comşa (1996)
Romania	Neolithic	Vădastra	Vădastra		Second half 6th-1st half 5th mill B.C.			*Panicum* sp.	Comşa (1996)

Table 1 continued

Country (region/province)	Period	Culture	Site name	Type of site	Dating information	Context of find	Nature of find (no. of grains)	Identification	Reference
Russia (Dagestan)	Early Neolithic		Chokh	Settlement	7th–early 6th mill. B.C.		Grain	*Panicum* sp.	Amirkhanov (1987)
Slovakia (southeast)	Early Neolithic	(eastern) LBK (Bukk)	Domica Cave	Settlement	5200–4800 B.C. (1 date)		Grain	*Panicum miliaceum*	Hajnalová (1989)
Slovakia (east)	Early Neolithic	(eastern) LBK (Bukk)	Šarišské Michal'any 2		Second half of 6th mill. B.C.		Grain (4)	*Panicum miliaceum*, *Panicum* cf. *miliacum*	Hajnalová (1993)
							Grain (2)	*Setaria viridis*	
Slovakia (southwest)	Early Neolithic	LBK (Zeliezovice group)	Štúrovo	Settlement	5500–4800 B.C. (2 dates)		Grain (l)	*Panicum miliaceum*	Hajnalová (1989)
Ukraine (central)	Middle Neolithic	Kievo-Cherkasskaya	Grini	Settlement	5200–4250 B.C.		3 Impressions in pottery	*Panicum miliaceum*	Kotova (2003)
Ukraine (northwest)	Middle Neolithic	Volynskaya	Krushniki	Settlement	5100–3850 B.C.		2 Impressions in pottery	*Panicum miliaceum*	Kotova (2003)
Ukraine (northwest)	Early Neolithic	Volynskaya	Mala Osnitsa	Settlement	5450–5100 B.C.		Impression in pottery	*Panicum miliaceum*	Kotova (2003)
Ukraine (northwest)	Early Neolithic	Volynskaya	Obolon	Settlement	5450–5100 B.C.		Impression in pottery	*Panicum miliaceum*	Kotova (2003)
Ukraine (western central)	Early Neolithic	LBK	Rovno	Settlement	5550–5150 B.C.		2 Impressions in pottery	*Panicum miliaceum*	Kotova (2003)
Ukraine (western central)	Early Neolithic	Bugo-Dnestrovskaya	Sokoltsy 2	Settlement	6300–6250 B.C. (2 dates)		Impression in pottery	*Panicum miliaceum*	Kotova (2003)
East Asia									
China (Hebei)	Early Neolithic	Cishan	Cishan	Settlement	6400–5700 B.C. (4 dates)	Pits	Grey Sediment with seed-shaped voids	cf. *Setaria italica*	Huang (1982), Tong (1984)
China (Gansu)	Early Neolithic	Dadiwan	Dadiwan	Settlement	5600–5400 B.C. (1 date)	Bottom of pit H398 (under a Yanshao house), burned soil	Grain (8)	*Panicum miliaceum*	GPICRA (2006)
China (Henan)	Early Neolithic	Peiligang	Peiligang	Cemetery/settlement	6500–4700 B.C. (3 dates)	Pits T1H1, T2H2 and H11	Grain ('a few')	"Su"	HWTN1IACASS (1983)
China (Henan)	Early Neolithic	Peiligang	Shawoli	Cemetery/pits	6000–5700 B.C. (1 date)	Sediment	Grain	"Su"	HWTN1IACASS (1984)
China (Henan)	Early Neolithic	Peiligang	Wuluoxipo	Test trenches	6000–5000 B.C.	Sediment	Grain (4)	Foxtail millet/grass	Liu et al. (2004b)
China (Inner Mongolia)	Early Neolithic	Xinglongwa	Xinglonggou	Settlement	6200–5600 B.C.	House floors	Grain (1500)	*Panicum miliaceum*	Zhao (2005)
							Grain (10)	*Setaria italica*	

Table 1 continued

Country (region/province)	Period	Culture	Site name	Type of site	Dating information	Context of find	Nature of find (no. of grains)	Identification	Reference
China (Liaoning)	Early Neolithic	Xinle	Xinle	Settlement	5600–4600 B.C. (4 dates)	House F2 floor and shallow pit near pillar	Grain and chaff	“Dacongshu”	OPAMS and SPM (1985)
China (Shandong)	Early Neolithic	Houli	Yuezhuang	Settlement	6060–5750 B.C. Lee et al. (2007)	Pits	Grain (1)	*Setaria italica* ssp. *italica*	Crawford et al. (2007)
						Pits	Grain (40)	*Panicum miliaceum*	
South and SW Asia and the Nile corridor									
Egypt	Neolithic		Abu Ballas	Settlement	6200–6000 B.P.		Grain (32)	*Panicum* sp.	Barakat and Fahmy (1999)
							Grain (13)	*Setaria* sp.	
Egypt	Neolithic		Farafra	Settlement	6000–5800 B.C. (1 date)	96E4, hearth	Grain (12)	*Panicum* cf, *turgidum* (1), *Panicum* type (11)	Barakat and Fahmy (1999)
							Grain (24)	*Setaria* cf, *viridis* (1), *Setaria* sp. (12), *Setaria* type (11)	
					6200–5600 B.C. (2 dates)	96F/1, hearth	Grain (8)	*Panicum turgidum* (5)	
							Grain (5)	*Panicum* sp. (3) *Setaria* type	
Egypt	Early Neolithic	El-Nabta	Nabta Playa	Settlement	7500–6500 B.C. (10 dates)	Hut F 2/90, middle level	Grain (‘numerous’)	*Panicum* (cf.) *turgidum* *Setaria* type *Panicum miliaceum*	Wasylikowa et al. (1995), Wasylikowa and Dahlberg (1999)
Iran (southeast)			Tepe Gaz Tavila (Dautalabad R37)		6th mill. B.C.				Meadow (1986)
Syria (Euphrates Valley)	Late PPNB/PN		Bouqras		7900–6000 B.C. (25 dates)		Grain (13)	*Setaria* spp.	Van Zeist and Waterbolk-van Rooijen (1985)
Syria (central part)	Final PPNB		El Kowm 2		7400–6100 B.C. (2 dates)		Grain (2)	*Setaria* spp.	De Moulins (1997)
Syria (Euphrates Valley)	(Early/)middle/late PPNB		Tell Abu Hureyra 2A		8800–7000 B.C. (20 dates)		Grain (18)	*Setaria* spp.	Hillman et al. (1989), De Moulins (1997), Hillman (2000)
Syria (Euphrates Valley)	Middle/late/final PPNB		Tell Abu Hureyra 2B		7900–6000 B.C. (8 dates)		Grain (5)	*Setaria* spp.	Hillman et al. (1989), De Moulins (1997), Hillman (2000)

Table 1 continued

Country (region/province)	Period	Culture	Site name	Type of site	Dating information	Context of find	Nature of find (no. of grains)	Identification	Reference
Syria (Euphrates Valley)	Late Epipalaeolithic/Khiamian/PPNA		Tell Mureybit 1		10500–9000 B.C.		Grain (12)	*Setaria* spp.	Van Zeist and Bakker-Heeres (1984), Willcox and Fornite (1999)
Syria (Euphrates Valley)	Late Epipalaeolithic/Khiamian/PPNA		Tell Mureybit 2		10500–9000 B.C.		Grain (26)	*Setaria* spp.	Van Zeist and Bakker-Heeres (1984), Willcox and Fornite (1999)
Syria (Euphrates Valley)	PPNA		Tell Mureybit 3		10500–9000 B.C.		Grain (28)	*Setaria* spp	Van Zeist and Bakker-Heeres (1984), Willcox and Fornite (1999)

Dating information—number of associated radiocarbon dates, with range of earliest lower 2σ bound—latest upper 2σ bound, rounded to nearest 100 years. See Electronic Supplementary Information (ESM) (Table 3) for details of radiocarbon dates. Dating information for sites with no associated radiocarbon dates is based on information given in archaeobotanical reports and/or cultural chronologies. Additional sources of radiocarbon dates: Shennan and Steele (2000), IACASS (1991), a current project of one of the authors (MV)

[a] No indication in original publication whether chronology represents calibrated or uncalibrated radiocarbon years. Following Wasylikowa et al. (1991), we have assumed uncalibrated (and hence earliest bound could fall before 5000 cal B.C.)

Discussion

Issues of taphonomy and identification

The data comprise evidence arising from a variety of site formation processes. Prominent among these are carbonization and impressions in either pottery or daub. From one site in China (Cishan) evidence comes in the form of 'grain-shaped voids' in sediment. In some reports the evidence of the form of preservation involved is incomplete or absent. The geographical distribution of the principal evidence types is patchy, reflecting different regional traditions of archaeobotany, for example in how widespread the use of flotation has been. Consequently, the presence of carbonized grain versus impressions most likely reflects regional differences in the history of archaeological practice rather than any original patterning in the data.

Various authors have discussed identification criteria for the caryopses of carbonized *P. miliaceum* and *S. italica* found in archaeological sites of a variety of dates (Knörzer 1971; Kroll 1983; Nesbitt and Summers 1988; Liu and Kong 2004; Fuller 2006; Fuller and Zhang 2007; Nasu et al. 2007). The last report presents excellent grain measurements and photographs of modern reference specimens of ten *Setaria* taxa. All other publications deal with both genera and mention that the caryopses of *P. miliaceum* and *S. italica* are different in general shape. Grains of *P. miliaceum* typically have a pointed distal ('top') end and relatively blunt proximal ('bottom') end, while grains of *S. italica* are gently rounded at both ends (Nesbitt and Summers 1988).

A second key identification criterion all the authors mention is the size of the embryo pit. Knörzer (1971) and Nesbitt and Summers (1988) recognize that the embryo pit of *P. miliaceum* is 'short and wide', 40–60% of grain length (maximum 70%). The groove of *S. italica*, however, is much longer and narrower than in broomcorn millet, almost always over 65% of grain length, usually averaging 70–80%. Kroll (1983) states that the embryo pit of *P. miliaceum* is smaller than half the grain length. Fuller (2006) generalizes that the embryo pit of *Panicum* spp. is around half of grain length, ranging up to two-thirds, while *Setaria* spp. are markedly longer than half, usually exceeding two-thirds.

A third criterion is the morphological pattern of lemma and palea under the microscope. In the earlier publications (Knörzer 1971; Nesbitt and Summers 1988), they state that the charred husk fragments of *P. miliaceum* are smooth and glossy, and the ones of *S. italica* vary from finely rugose to punctuate. The later references present good SEM images of husks (Fuller 2006). In addition, Nesbitt and Summers (1988) argued that in *P. miliaceum* the husks often adhere to the charred caryopses.

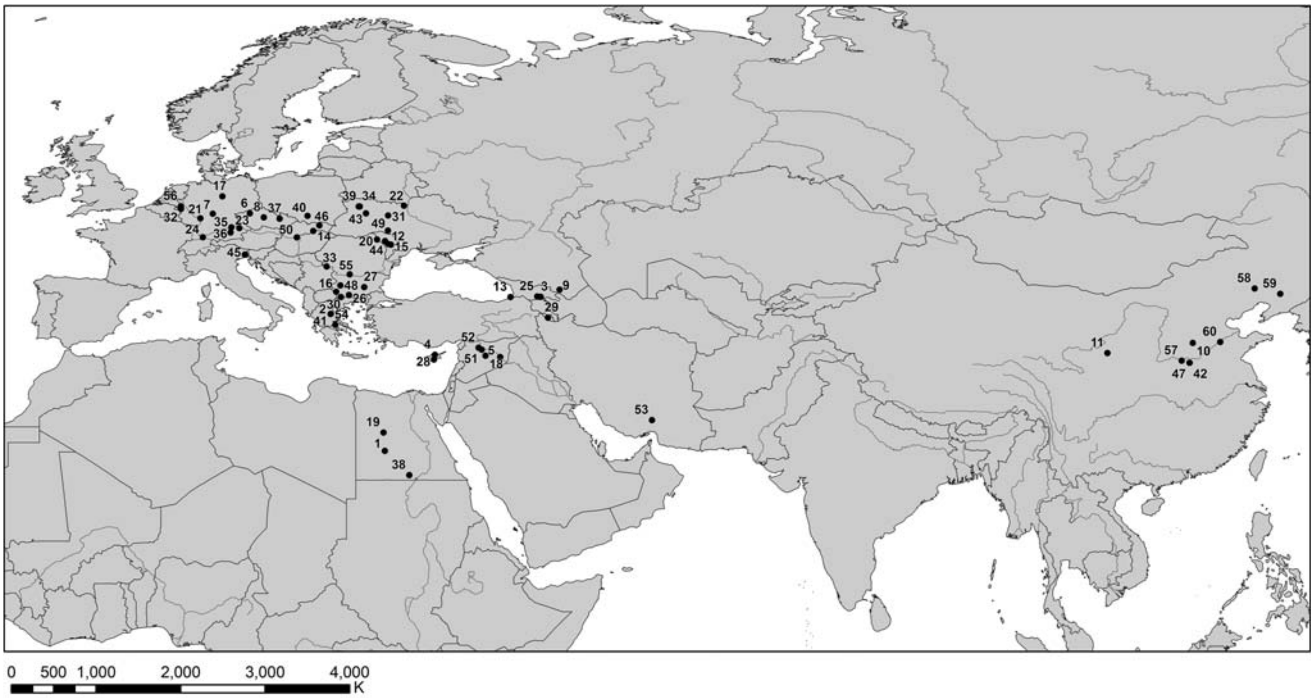

Fig. 1 Sites pre 5000 cal B.C. with archaeobotanical remains of *Panicum* and/or *Setaria*. *1* Abu Ballas; *2* Argissa Magoula; *3* Arukhlo 1; *4* Ayios Epiktitos Vrysi; *5* Bouqras; *6* Březno u Louny; *7* Bruchenbrücken; *8* Bylany; *9* Chokh; *10* Cishan; *11* Dadiwan; *12* Denchen1; *13* Dikhi-Gudzuba; *14* Domica Cave; *15* Durlesht1; *16* Drenkovo-Ploshteko; *17* Eitzum 2; *18* El Kowm 2; *19* Farafra; *20* Glăvăneştii Vechi; *21* Goddelau; *22* Grini1; *23* Hienheim; *24* Hilzingen; *25* Imirisgora; *26* Kapitan Dimitrievo; *27* Karanovo; *28* Khirokitia; *29* Kjultepe; *30* Kovacevo; *31* Krushniki 2; *32* Langweiler; *33* Liubcova; *34* Mala Osnitsa1; *35* Meindling; *36* Mintraching; *37* Mohelnice; *38* Nabta Playa; *39* Obolon1; *40* Olszanica; *41* Otzaki Magoula; *42* Peiligang; *43* Rovno; *44* Sakarovka; *45* Sammardenchia; *46* Šarišské Michal'any 2; *47* Shawoli; *48* Slatina; *49* Sokoltsy 2; *50* Štúrovo; *51* Tell Abu Hureyra; *52* Tell Mureybit; *53* Tepe Gaz Tavila (Dautalabad R37); *54* Toumba Balomenou; *55* Vădastra; *56* Wanlo; *57* Wuluoxipo; *58* Xinglonggou; *59* Xinle; *60* Yuezhuang

Numbers of identifications by nomenclature in this data set are summarized in Table 2. With a few exceptions, the reports relevant to the period covered by this paper do not allude to the above identification criteria, but simply present taxon names. Moreover, identification is not always reported consistently between (and sometimes even within) publications. For example, Lisitsyna and Prishchepenko (1977) list *P. miliaceum* L. at the Shulaveri-Shomutepe sites of Arukhlo I, Dikhi-Gudzuba and Imirisgora, but in a later review (Lisitsyna 1984), these identifications are revised to '*Panicum* sp.', without explanation. In a more common scenario, original genus-level identifications are elsewhere 'upgraded' to specific identification of a species of palaeoethnobotanical interest. For example, Barakat and Fahmy present a detailed table of the results of archaeobotanical analysis from Abu Ballas in which a total of 32 grains of '*Panicum* sp.' and 13 of '*Setaria* sp.' from a range of sediment samples are recorded (1999, Table 2, p. 39); however, a summary table (Barakat and Fahmy 1999, Table 3, p. 40) comparing grass taxa at multiple sites, and subsequent discussion, refer to '*P. turgidum*'; the same table refers to '*S. viridis*', but the text states that further morphological investigations are under way to identify the grains of

Table 2 Summary of identifications of *Panicum* and *Setaria* in the current data set by nomenclature

Identification	Number of ident.
Panicum miliaceum	31
Panicum cf. *miliaceum*	1
Panicum capillare?	1
Panicum turgidum	1
Panicum (cf.) *turgidum*	2
Panicum sp(p).	8
Panicum type	1
Dacongshu' (Chinese, 'onion broomcorn millet')	1
Setaria italica ssp. *italica*	1
Setaria italica	1
cf. *Setaria italica*	1
Su' (Chinese, 'foxtail millet')	2
Foxtail millet/grass	1
Setaria viridis	1
Setaria cf. *viridis*	1
Setaria viridis/verticillata	7
Setaria sp(p).	16
Setaria type	3

'*Setaria* type' from Abu Ballas accurately to species level. Such inconsistencies may seem trivial in the context of an individual report, but they have knock-on effects in the secondary literature. This is not to single out the authors above for particular criticism—there is a universal tendency to simplify the complex details of primary data sets to provide a concise synthesis.

In some cases the specificity of identification may have arisen from a circular argument—that *Setaria* sp. remains from Neolithic China may be discussed as possible cultivated foxtail millet, *S. italica*, because we expect to find this taxon there, whereas *Setaria* sp. identifications from Egypt are assumed to be part of a different archaeological 'story', and ignored in the former context. The lack of photographs or morphological details in reports from excavations of the 1970s/1980s in the key regions of China and the Caucasus makes it difficult to assess these records critically. Some authors have arrived at their own judgements on which records are dubious and should be discounted (see, for example, Nesbitt and Summers 1988). A further problem is posed by reports where botanical identifications are only given in the vernacular. The excavation report for Peiligang (HWTN1IACASS (Henan Working Team No. 1, Institute of Archaeology, Chinese Academy of Social Science) 1983) notes the presence of *su*—(*S. italica*, foxtail millet), while a Chinese book of the same year, *The history of Chinese Cultivated Plants*, reports that grains shaped like *ji*, which the author defines as sticky-type broomcorn millet, were found at Peiligang (Li 1984). Subsequent papers quoting both *S. italica* and *P. miliaceum* at Peiligang (Ren 1995; Underhill 1997) may represent an amalgamation of these two contemporary Chinese sources. We have listed *Setaria* only at Peiligang, in keeping with the primary report. At Cishan, *S. italica* was identified on the basis of seed-shaped voids in sediment (Huang 1982), of which no record has been kept. In the last decade, the introduction of flotation to Chinese archaeology, for example by Zhao (2004) at Xinglonggou and Crawford et al. (2007) at Yuezhuang, has resulted in substantially more robust evidence with the recovery and direct dating of broomcorn and foxtail millet macrofossils.

Identifying domestication, cultivation and crop/weed status

Setaria viridis has been conclusively identified as the wild ancestor of *S. italica* on the basis of morphology, interspecific crosses and AFLP analysis (Le Thierry d'Ennequin et al. 2000), but the wild ancestry of *P. miliaceum* remains uncertain. The most plausible candidate is a weedy taxon, *P. miliaceum* ssp. *ruderale*, which grows as a weed of maize and millet crops in China today. According to Zohary and Hopf (2000) this taxon grows west to the Aralo-Caspian basin, but a morphologically similar weed is found in central Europe (Scholz and Mikoláš 1991). Whether *P. miliaceum* ssp. *ruderale* constitutes a genuinely wild species or is a feral derivative of domesticated broomcorn millet, or whether, as these authors suggest, further taxonomic division of this subspecies is needed, remains an open question.

In the absence of secure knowledge about the wild ancestor, authors have speculated about familiar domestication markers such as grain size and shape. Zhao (2005) has tentatively related the wild/domesticated status of some of the *P. miliaceum* finds in northern China to variation in seed size. However, as Fuller et al. (2007) have shown for rice, grain size and shape need to be interpreted in the context of an understanding of panicle maturation patterns and the morphometry of seeds at different stages of maturity.

The clear taxonomic and morphological differentiation of domesticated *S. italica* and the wild annual weeds *S. verticillata* and (ancestral to *S. italica*) *S. viridis* leaves less room for ambiguity than in *Panicum* regarding the inferred wild/domesticated status of the finds. Crawford and Lee (mentioned in Liu et al. 2004b) assessed grains from Wuluoxipo as potential intermediates in the transition from wild to domesticated foxtail millet on the basis of dorsal flattening of the grain. The dataset contains a number of identifications of '*Setaria* spp.' in Epipalaeolithic and Neolithic Syria, Cyprus, and central Europe. These are usually assumed (explicitly or otherwise) to represent one of the two wild species above, since there is no concrete evidence for *S. italica* until the Iron Age in the Near East (Nesbitt and Summers 1988) and until the Bronze Age in central Europe (Zohary and Hopf 2000).

In contrast, the only non-*miliaceum* species-level identifications of *Panicum* are *P. turgidum* in Egypt, of palaeoethnobotanical interest in its own right but distinct from broomcorn millet domestication history, and a tentative identification of *P. capillare* in the Caucasus (Lisitsyna and Prishchepenko 1977). *P. capillare* is a native of North America naturalized in Europe (Tutin 1980), so unless this find represents an intrusion or the chronology is wrong, this identification is unlikely to be correct. The *Panicum* flora of Europe is species-poor (*Panicum* is primarily a tropical genus) and only one native wild species, other than *P. miliaceum* ssp. *ruderale*, is widespread in Europe, *P. repens* (Tutin 1980). Probably for this reason, there has been no discussion to date of the morphology of wild *Panicum* species or their possible presence as weeds in assemblages, although such a study would be pertinent to China, which has a number of native wild *Panicum* species (Wu and Raven 2007). While the presence of *S. viridis* and *S. verticillata* as natives throughout much of Europe makes this the 'default' interpretation for records of *Setaria* sp., the absence of clear-cut wild *Panicum* species (given the uncertainty of the status of *P. miliaceum* ssp. *ruderale*) accounts for the recurrent inference that generic level archaeobotanical identifications of *Panicum* sp. represent domesticated broomcorn millet. Explicit discussion is needed on morphology of *Panicum* and allied genera to clarify which species might potentially be indicated by an identification of '*Panicum* sp.'

A closely related issue to that of wild/domesticated plant forms is whether the millets were being cultivated as crops or alternatively existed as weeds. Some authors have explicitly interpreted rare or solitary finds as arable weeds, and/or only inferred intentional cultivation where large quantities of grain are present. (Nesbitt and Summers 1988; Kreuz et al. 2005). The latter authors consider that the presence of *P. miliaceum* from four LBK sites in Germany as only single seeds reflects its status as a weed of the major crops (einkorn and emmer wheat), introduced in seedcorn. *P. miliaceum* ssp. *ruderale* and similar types with wild-type seed dispersal behaviour are significant arable weeds in several parts of the world today: China, central Europe (Scholz and Mikoláš 1991), and North America (Bough et al. 1986). It is plausible that such types were also weeds in prehistory, either as truly wild taxa, or derived from domesticated non-shattering *P. miliaceum* by back-mutation. However, grain quantities have at best an indirect relationship with grain use, let alone grain domestication. Our growing awareness of taphonomy and site formation processes has brought to light a range of quite separate factors that may determine numerical composition of assemblages (Hubbard and Clapham 1992). We should also bear in mind that the sharp distinction in modern agriculture between 'crop' and 'weed' need not necessarily have been as sharp, or indeed applied at all, among Neolithic people.

Implications for the origins of domesticated broomcorn and foxtail millet

More can currently be said with confidence about the origins of domesticated *S. italica* than *P. miliaceum*. The distinction between domesticated foxtail millet and its wild relatives is established, and, as argued above, this has knock-on effects for nomenclatural clarity and the botanical framework in which identification of archaeological samples is carried out. Although the progenitor *S. viridis* is widespread in Eurasia, and this appears to have been the case in prehistory too, *S. italica* is found before 5000 cal B.C. only in China. Unfortunately, the records from the two most widely mentioned sites, Peiligang and Cishan, are enigmatic (see above). However, new site excavations at Xinglonggou and Yuezhuang attest to the presence of *S. italica* as early as the late seventh millennium B.C. in northern China. Analysis of intraspecific genetic polymorphisms at ribosomal and mitochondrial loci supports eastern Asia as a centre of origin of foxtail millet (Fukunaga et al. 2002, 2006; Fukunaga and Kato 2003). The genetic data also indicate an independent domestication of landraces in Afghanistan and north-western Pakistan (Li et al. 1995; Fukunaga et al. 2006). An independent origin of foxtail millet landraces in tropical eastern Asia, including Taiwan and the Philippines, is also possible, but the complicated evolution of the ribosomal markers used in this study means that this is still uncertain (Fukunaga et al. 2006). The discovery of foxtail millet at Chengtoushan at 3850 cal B.C. has also led to the hypothesis that it was domesticated separately in south-central China, alongside rice (Nasu et al. 2007).

Polymorphic genetic markers that have the potential to reveal geographic patterns in *P. miliaceum* have not yet been described in the literature. We are currently undertaking marker development to address this problem. The most plentiful early records of broomcorn millet appear in two regions. Xinglonggou, Yuezhuang and Dadiwan in northern China have yielded 1500, 40 and 8 carbonized grains, respectively. Pottery from two sites in Moldova, Denchen and Sakarovka, has, respectively, produced 97 and 60 impressions. We note that a great number of the remaining early records are of single grains, which, as mentioned above, have prompted some authors to speculate on its status. Whatever that status might be in different regions, crop, weed or intermediate form, the question of its dispersal across Eurasia remains. Crucial to answering this are the status and chronology of finds from the northern Black Sea region and the Caucasus, which require re-evaluation.

Ecological considerations

We would infer from the geographical distribution indicated in Map 1 that the great majority of domesticated millet records prior to 5000 B.C. could have arisen from rainfed summer crops, without the need for any form of irrigation. Such an inference demands closer scrutiny of records from southeastern Europe and southern Iran. Four records from Bulgaria and Greece specify either *Panicum* or *P. miliaceum*. The varied topography around each of the sites concerned does permit a combination of seasonal sowing patterns, and the most southerly of these records, from Toumba Balomenou, Chaeronia, Greece, occurs in conjunction with weed evidence of summer sowing of at least some crops (Sarpaki 1995). The Iranian record from Tepe Gaz Tavila is more anomalous in ecological terms.

This record has not however yet reached primary archaeobotanical publication.

Conclusions

Archaeobotanical data underpins a range of recent and ongoing complementary archaeological science projects researching the origins of millet agriculture: stable isotope analysis (Hu et al. 2006), genetics (Fukunaga et al. 2002, 2006; Fukunaga and Kato 2003) and lipid analysis from sediment cores (Jacob et al. 2008).

The data assembled here have emphasized the contrasting patterns for the two principal Eurasian millets, *P. miliaceum* and *S. italica*. Both occur prior to 5000 cal B.C. in North China, but only *P. miliaceum* occurs prior to 5000 cal B.C. in western Asia and Europe. Within the *P. miliaceum* distribution, there is a marked contrast in numerical abundance between records, which some authors have related to crop/weed status. This review emphasizes the need for researchers across diverse disciplines to engage with the complexities and points of debate in the archaeobotanical data that pertain to the agrarian prehistory of these crops.

Not all domestication events need be associated with a pre-5000 cal B.C. archaeobotanical signature—independent domestications may have happened at a later date. However, discussion of millet domestication has stemmed largely from the geographical distribution of the earliest finds, which, given their rarity at this early date and the obscurity of some records, renders them critical.

The current archaeobotanical record does not allow discrimination between hypotheses of single versus multiple domestications, or of subsequent diffusion pathways, of *P. miliaceum* and *S. italica*. The key issues for future archaeobotanical research on these crops are the need for unified and transparent criteria for taxonomic identification, the more consistent application of flotation techniques, and the need to fill gaps in the record, particularly over large areas of central Asia.

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