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Pre-agricultural plant management in the uplands of the central Zagros: the archaeobotanical evidence from Sheikh-e Abad

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Abstract
Prior to the emergence of agriculture in southwest Asia, sedentarising human communities were experimenting with a diverse range of wild plant species over a prolonged period. In some cases, this involved the cultivation of species that would go on to be domesticated and form the foundation of future agricultural economies. However, many forms of plant use did not follow this trajectory, and in multiple places farming was only taken up later as an established 'package'. In this paper, we present new archaeobotanical evidence from the Early Neolithic site of Sheikh-e Abad in the central Zagros of western Iran. Sheikh-e Abad is unique in being the only settlement known to date within southwest Asia that lies at an altitude above 1000m and which has occupation spanning the agricultural transition (9800–7600 BC). Thus, it provides a rare opportunity to examine pre-agricultural plant management strategies in an upland zone. Our analyses of the plant remains from Sheikh-e Abad suggest that from its earliest occupation inhabitants were 'auditioning' a suite of locally available wild grasses, which ultimately were never domesticated. We discuss the possible reasons for this from a socio-ecological perspective, considering both the biology and ecology of the plant species in question, as well as the ways in which they were potentially managed.

Keywords
Southwest Asia, Neolithic, Origins of Agriculture, wild grasses, pre-agricultural plant management strategies,

Introduction

It is increasingly accepted that agriculture had multiple 'centres of origin' within southwest Asia (Salamini et al. 2002; Fuller et al. 2012; Willcox 2013). This perspective is supported by a growing body of archaeobotanical data that documents the independent development of cultivation, and domestication of plants, in disparate regions during the earliest phases of the Neolithic, and possibly as far back as the Late Palaeolithic at Ohalo II (Snir et al. 2015). Pre-domestication cultivation — the cultivation of wild crop progenitors — has been proposed for fourteen archaeological sites to date (Hopf 1983; van Zeist and de Roller 1994; Kislev 1997; Colledge 1998; Hillman 2000; Colledge 2001; Edwards et al. 2004; Weiss et al. 2006; Willcox et al. 2008; Kuijt and Finlayson 2009; Willcox 2012a; White and Makarewicz 2012; Arranz-Otaegui et al. 2016b), including recently for the first time in the eastern Fertile Crescent (Riehl et al. 2013) (Fig. 1a). However, pre-domestication cultivation represents only one strategy within a spectrum of possible pre-agricultural plant management strategies; moreover, the species that were domesticated and form part of the 'Neolithic crop package' (Zohary and Hopf 2000; Weiss and Zohary 2011) account for only a small number of the wild plant resources that people were gathering, consuming and potentially managing during this time.

While the process of domestication can be documented via morphological markers (e.g. tough rachis, seed size) (Harlan et al. 1973; Nesbitt 2002; Fuller 2007), and the identification of arable weed floras used to infer the cultivation of wild crops (Colledge 1998; Weiss et al. 2006; Willcox 2012a), other potential plant management strategies may have involved markedly different forms of crop-husbandry and methods of wild plant food production, including practices for which we have no modern analogues. Thus, reconstructing 'nondomestication' pre-agricultural plant management strategies remains problematic, especially given the complex nature of archaeobotanical assemblages and the multiple routes by which plants/plant parts may arrive at archaeological sites. Moreover, charred plant assemblages are known to significantly underrepresent wild plant resources (Matthews 2010, 2016; Colledge and Conolly 2014).

The interpretation of wild plant foods at Early Neolithic sites cannot rely on the uncritical assumption that the plant remains within an archaeobotanical assemblage are representative of those consumed. However, this inference may be strengthened if a species is recorded in large numbers and when other routes of entry into the assemblage are excluded e.g. dung burning, crafts, construction. Data provided by modern ethnographic studies (e.g. Ertug-Yaras 1997) and information on the use of taxa recorded within regional floras, can also help direct interpretations of wild plant foods, while more robust arguments may be made on the basis of archaeological evidence for food processing. For example, at Jerf el Ahmar the remains of charred seed cakes of *Brassica/Sinapis* sp. have been identified *in situ* on a saddle quern (Willcox 2002), suggesting their use as a food and/or oil. Similarly, at Ohalo II, the clustering of the remains of several wild grass species around a grinding stone has been cited in support of their interpretation as processed/staple foods at the site (Weiss et al. 2008). Morphological evidence for grains being broken prior to charring, consistent with the processing of cereals for consumption (e.g. by grinding), has also been reported at a number of sites across the region (Willcox 2002; Arranz-Otaegui et al. 2016a). In the absence of direct evidence for consumption (e.g. gut contents, coprolites), none of these lines of evidence demonstrate unequivocally that a plant species was used and managed as a food, but such inferences may be substantiated on the basis of multiple lines of evidence.

A broader understanding of pre-agricultural plant management requires not only a critical evaluation of the archaeobotanical evidence available for wild plant food production, but also a consideration of the socio-ecological context in which experimentation with wild plant species took place. Variation in local climate, vegetation and socio-cultural practices would all have been key factors shaping early plant management, affording communities with different opportunities and constraints. In this paper, we present new evidence from the Early Neolithic site of Sheikh-e Abad in western Iran, where analysis of the charred macrobotanical assemblage has allowed us to trace long-term plant use over a 2200-year period, including a sustained focus on a suite of wild grasses with medium-sized grains as food. Notably, none of these wild grass species are crop-progenitors and domesticated crops are only adopted later in the site's occupation. At present, Sheikh-e Abad is unique amongst contemporary sites in southwest Asia, being the only settlement located in an upland zone (here defined as land above 1400m asl) with occupation spanning the agricultural transition (Fig. 1a). Furthermore, in contrast to other sites occupied during the initial phases of the Early Neolithic (i.e. PPNA or equivalent), Sheikh-e Abad is also located at a considerable distance from units of lower land. A straight-line distance of *ca.* 150km separates it from elevations consistently below 1000m (Fig. 1b). The results we present here are therefore significant for our understanding of local variability in pre-agricultural plant management strategies, particularly for upland zones which are not represented within current models of agricultural origins.

Environmental setting

Sheikh-e Abad is located on a fertile alluvial plain (1430m asl) in a semi-arid region of the central Zagros Mountains, 38km north of the modern city of Kermanshah, bounded by mountain peaks up to 3000m (Fig. 1a, b). The site lies at the boundary of the lower and elevated Zagros, providing access to a range of different environments. The climate of the study area is characterised as semi-arid with a Mediterranean component (Köppen-Geiger: Csa) and topography plays a key role in determining how this is expressed at a local level (Zohary 1973; Kehl 2009). Present-day precipitation around Sheikh-e Abad averages 437mm per year and is sufficient for dry-farming, with much of the land around the site currently under cultivation. However, this is unevenly distributed throughout the year, with no rain falling during the hot summer months (June to October). Average temperatures range from 25.9°C in July to a low of 1.3°C in January and between December and February minimum temperatures drop below freezing point.

Vegetation around Sheikh-e Abad is strongly influenced by the combined ecological factors of moisture and temperature, with both the cold winter period and hot dry summer inhibiting plant growth (Zohary 1973). In phytogeographic terms the study area falls into the xerophilous forest sub-division of the Irano-Turanian zone (Zohary 1973: 87; Badripour 2006). Here, remnants of Pistachio-oak forest steppe are observed, rich in herbaceous plants and wild grasses, particularly perennials which form the basis of the vegetation from *ca.* 1500m (Badripour 2006: 20). *Bromus* (*B. tomentellus, B. cappadocicus*), *Festuca* and *Stipa* (especially *S. barbata*) species are especially numerous, and other perennial grasses recorded here include: *Piptatherum holciforme* (syn. *Oryzopsis holciformis*), *Hordeum bulbosum, Hordeum fragile, Hordeum violaceum* and *Poa* spp. The annual crop progenitor *Hordeum spontaneum* (wild barley) is rare above 1500m due to its limited cold tolerance (Zohary and Hopf 2000: 67), and the Zagros Mountains represent a significant disruption in its natural range (Morrell and Clegg 2011). Wild einkorn (*Triticum boeticum*) and wild emmer (*Triticum dicoccoides*) also prefer lower elevations (Bor 1968), placing Sheikh-e Abad outside of their natural habitats, as illustrated in modern distribution maps for the wild cereals (Zohary and Hopf 2000; Willcox 2005; Fuller 2007).

It is unlikely that modern vegetation around the site provides a direct analogue for the archaeological past, especially in light of human and animal activity, particularly agriculture, which has significantly altered the natural vegetation of the study area (Zohary 1973: 608–10). Recent studies have also emphasised the role of varying moisture and CO_2 availability in determining the distribution and yield of wild plants during the early Holocene (Cunniff et al. 2010; Riehl 2016). However, after the end of the Younger Dryas, as in the present day, wild grasses would have formed a major component of the vegetation across the Fertile Crescent (Riehl et al. 2012), replacing the existing chenopod-*Artemisia* steppe (Stevens et al. 2001). At the same time, pistachio (*Pistacia* spp.) and oak (*Quercus* spp.) pollen both appear in relatively low percentages in regional pollen cores, which correspond to those found today in the open woodland of the Zagros oak forest (Stevens et al. 2001), suggesting a similar level of arboreal cover.

Excavations at Sheikh-e Abad

Sheikh-e Abad was first recorded during a 2006 survey of the region by Yaghoub Mohammadifar and Abbass Motarjem and excavated in 2008 under phase 1 of the Central Zagros Archaeological Project (Matthews et al. 2013). At over one hectare in extent the site is dominated by the archaeological mound at its centre, which comprises approximately 10m of almost exclusively Early Neolithic deposits. Excavations in 2008 focused on three areas that span this sequence: Trench 1 at the base of the mound, Trench 2 halfway up the mound and Trench 3 on the mound's summit (Fig. 2a). Repeated layers of ash and debris from the earliest levels excavated attest to long-term continuity of activities at the site. Radiocarbon determinations on plant material from the lowest levels of Trench 1 returned a range of 9810–9240 cal BC — making occupation here broadly contemporaneous with the end of the Younger Dryas and the onset of the Levantine Pre-Pottery Neolithic A (PPNA) cultural period (Kuijt and Goring-Morris 2002) — while dates from Trench 2 (7960 cal BC) and Trench 3 (7590 cal BC) are coeval with the Levantine PPNB (Table 1). This makes the site one of the oldest Neolithic settlements in southwest Asia, and the only one currently in the central Zagros region to record occupation spanning the entire agricultural transition. Within the eastern Fertile Crescent only Chogha Golan (*ca.* 9700–7600 BC), *ca.* 170km away in the lower foothills of the southern Zagros, has provided similar dates (Riehl et al. 2013). Currently, the nearest sites to Sheikh-e Abad for which archaeobotanical remains have been analysed are Ganj Dareh (8240–7840 BC) and Abdul Hosein (8300–7800), both falling within the later phases of the Early Neolithic when we see the widespread emergence of farming across the region.

The plant macroremains analysed for this study were collected from deposits across all three trenches. Trench 1 (4.15m deep) and Trench 2 (2.5m deep), were both excavated as 2x2m step-trenches and represent stratigraphic sections into the mound. Samples from these areas derive from a range of deposit types, including external midden, possible areas of mudbrick/surface packing, deposits characterised by heavily burnt sequences of ash and charred plant remains and, in Trench 2, several deposits with pisé features interpreted as building debris/collapse. In Trench 3 (10x10m plus a 6x3m extension), where open-area excavations took place, a considerable expanse of architecture was uncovered including a T-shaped mudbrick building (Building 2; Fig. 2b). This single-roomed, arguably 'symbolic' building contained several significant features, for example, ground and unworked stone, a fire installation and most strikingly of all in its southeast an installation of wild sheep and goat skulls, one bearing traces of red ochre (Fig. 2c). A second building (Building 1) constructed of pisé was recorded to the east of the trench and includes an area (Space 8) used for penning animals, based on the identification of a sequence of inter-bedded layers of compacted herbivore dung in micromorphological thin-section (Matthews 2013; Shillito et al. 2013). Preliminary analysis of animal bones from the site documents the exploitation of goat and sheep and to a lesser extent red deer, cattle, fox and hare. Also, identified from the faunal assemblage at Sheikh-e Abad are birds, rodents, tortoise and crab (Bendrey et al. 2013).

Materials and Methods

A total of 57 soil samples from 50 contexts, with an average volume of 36.8 litres, were collected from Sheikh-e Abad in 2008, as part of a systematic sampling strategy in which every archaeological unit was sampled. Of these, 41 samples were analysed for this study, corresponding to 1893 litres of soil. Samples were processed by machine-assisted water flotation with the light fractions (flots) collected in a mesh with an aperture of *ca.* 250µm, while the heavy residues were collected in an internal mesh with an aperture of 1mm. Light fractions were air-dried in the shade and prior to sorting were separated by passing them through a stack of nested Endecott sieves with aperture sizes of 4mm, 2mm, 1mm and 0.3mm. Heavy residues were sorted separately and any plant material that had failed to float was removed and stored alongside its corresponding flot for further sorting and identification.

Analysis of samples was undertaken at the School of Archaeology, University of Oxford, using a stereomicroscope (Leica model EZ4HD or a CETI varizoom) at magnifications of x6–x40. Scanning Electron Microscopy (SEM model: Jeol JSM-5910) was employed to provide magnifications up to x250,000 where necessary. Identifications were made according to morphological characteristics, surface texture and size, and verified by comparison to modern reference material. Archaeological specimens were compared to both modern uncharred and modern charred material wherever possible, to take account of the potential effects of charring on seed morphology. Plant remains were quantified using the principle of recording the 'minimum number of individuals' (MNI) following Jones (1991). Taxonomy follows modern convention.

Similarities and differences in the botanical composition of samples were explored within correspondence analysis (CA) (Lange 1990; Jones 1991). Correspondence analysis was carried out within the CANOCO for windows package and the results plotted using CANODRAW (Smilauer 1992; ter Braak and Smilauer 1997). Axis 1 (which explains the most variation) was plotted horizontally and axis 2 vertically. To explore the possibility that wild taxa may have entered the archaeobotanical assemblage within animal dung burnt as a fuel, the bias that ruminant (sheep/goat) digestion imposes on the composition of plant remains surviving within dung was also considered. This has been demonstrated to be closely related to the size and hardness of plant remains (Wallace and Charles 2013). Wild plant taxa were classified as having a low, medium, or high likelihood of surviving in dung based on their toughness (e.g. the hardness/thickness of their seed coat and whether they are enclosed) and their size in relation to the reticulo-omasal orifice of the ruminant digestive system of sheep, with seeds less than 1.18mm in all dimensions considered to pass easily through this (Poppi et al. 1985). At present, no attempt has been made to include the complex factor of plant toxicity within out model.

Categorising wild grasses in the archaeological record

Within archaeobotanical reports, wild grasses are commonly referred to in terms of non-taxonomic groupings based on the relative size of their seeds (e.g. 'large-seeded' and 'small-seeded'). However, there is little uniformity in how these categories are applied, making comparisons problematic and leading to a degree of ambiguity in wider discussion. Some scholars have used the term 'large-seeded' to refer primarily to the wild progenitor species and – despite considerable variation in size - lumped all remaining taxa together as 'small-seeded' (e.g. Weiss et al. 2004; Savard et al. 2006). Elsewhere, 'large-seeded' has been employed to encompass a much broader category of wild grasses, including many non-progenitor species (e.g. *Taeniatherum caput-medusae*, *Bromus* spp.), with the 'small-seeded' category reserved for more minute grasses such as *Poa* spp. (Riehl et al. 2012, 2013; Spengler and Willcox 2013). In some publications a 'medium-seeded' category provides an intermediate class that bridges the divide between the large- and small-seeded types (Nesbitt 2006; Riehl et al. 2013). The criteria for these groupings and/or the full list of taxa that fall within them are rarely reported by authors.

Within this paper, we explicitly differentiate between five groups of wild grasses (small-, medium(small)-, medium(medium)-, medium(large)- and large-seeded) based on their relative grain size. Grain size was calculated from measurements of modern uncharred specimens reported by Nesbitt (2006) (Fig. 3), in order to avoid potential inconsistencies resulting from the morphological effects of charring (Charles et al. 2015) and volume was chosen in preference to length as a comparative measure, due to the latter placing undue emphasis on a single dimension, which can be misleading; for example, *Bromus* and *Stipa* grains tend to be long and thin, meaning that length measurements overestimate their relative size (Fig. 3). Ellipsoid volume was selected as the most appropriate volume determination for grass caryopses following Forster et al. (in prep) and was calculated using the following formula:

$$V = \frac{4}{3}\pi abc$$

where:

$$a = \frac{length}{2};\ b = \frac{breadth}{2};\ c = \frac{thickness}{2}$$

While still subjective, the five groupings we propose provide a more nuanced categorisation of wild grasses that avoids giving undue prominence to wild crop progenitors and also recognises the wide range of seed sizes found within the Poaceae family. This final point is of particular significance when considering how seeds were potentially collected, processed and regarded by people in the past. Large-seeded grasses (mainly crop progenitors) still form a distinct group, but other grasses are now divided between four groups, with only the most minute of these (e.g. *Poa*, *Crypsis*, *Puccinellia*, *Sporobolus*) afforded the label small-seeded. Grasses whose grain falls between these size divisions are referred to as medium-seeded grasses, within one of three sub-divisions (small, medium and large), with the largest of these also including crop progenitors (e.g. *Secale*) and progenitor related taxa (e.g. *Aegilops*).

Results

For the present study, approximately 13,044 charred plant macroremains, representing 130 different taxa/types, were identified across the 41 samples analysed from Trenches 1, 2 and 3 at Sheikh-e Abad (Table 2). Preservation is good and in some cases exceptional. Dominating the assemblage in terms of both frequency and abundance are the wild grasses (67.2 % of the assemblage), followed by other wild and weedy taxa (29.4 %). Crops — namely domestic-type barley (*Hordeum vulgare*), glume wheat (*Triticum dicoccum*/'new-type') and a range of pulses including pea (*Pisum sativum*), lentil (*Lens* spp.) and bitter vetch (*Vicia ervilia*) — represent only a minor component of the plant remains recovered, together accounting for just 2.7 % of the total Sheikh-e Abad assemblage (355 out of 13,044 items). Moreover, these are restricted to Trenches 2 and 3 at the site, with no evidence of crops or their wild progenitors recovered from earlier Trench 1 deposits. Also present at low levels across the assemblage, although recorded in over half of all samples, are the remains of nut/fruit taxa (1.7 % of the assemblage), including both almond (*Prunus amygdalus*) and pistachio (*Pistacia* sp.).

Within the wild grass category, small-seeded grasses (*Poa* spp., *Crypsis* sp. and *Sporobolus* sp.) are particularly abundant, occurring in 68.3 % of samples and accounting for *ca.* 50 % (6250) of all the macrobotanical items identified at the site. However, there are clear differences in the distribution of small-seeded grasses through time, with the lowest proportions found within Trench 1 and the highest in Trench 3, where they dominate every sample analysed (Fig. 4a). Medium-seeded grasses, meaning those within the small, medium and large subdivisions (see Fig. 3), are attested repeatedly through the site's occupation but are particularly numerous prior to the establishment of crops (Fig. 4a). Together they account for 25.4 % of all the plant remains recovered from Trench 1, 22.8 % of plant remains from Trench 2, but only 1.7 % of plant remains across Trench 3. Four species in particular dominate the assemblage in terms of both ubiquity and abundance: *Lolium perenne/rigidum* (ryegrass), *Piptatherum holciforme* (ricegrass), *Taeniatherum caput-medusae* (medusa-head grass) and *Stipa* spp. (feathergrass). None of these taxa formed part of the canonical 'founder suite' of domesticated cereals that emerged by the 8th millennium BC across the Fertile Crescent.

When comparing the relative proportions of these four taxa over time at the site (Fig. 4b), it is clear that *P. holciforme, T. caput-medusae* and to a greater extent *L. perenne/rigidum,* all decline through time relative to *Stipa* spp.; *L. perenne/rigidum* is absent from Trench 3 deposits altogether. Other medium-seeded grasses, including *Bromus* spp. (brome grass), are found more frequently within later levels at the site, as is the large-seeded crop progenitor *Hordeum spontaneum* (wild barley)*,* which first appears alongside domesticated crops in Trench 2 (Fig. 4a). In addition to grain, fragments of *Stipa* awn (Fig. 5a) and *T. caput-medusae* rachis (Fig. 5b) have also been recovered within samples from Trenches 1 and 2, suggesting these grasses were brought to the site prior to processing, while *Aegilops* sp. is represented solely by spikelet bases. Some wild grasses, for example specimens of *Stipa*, also show clear evidence for having been broken prior to charring, as demonstrated by the distinctive 'oozing' of the endosperm and bulging-smooth appearance of the grain at the broken facets (Fig. 5c) — a pattern that is consistent with these being processed for consumption (Willcox 2002; Antolín and Buxó 2011; Valamoti 2011). *P. holciforme* grains meanwhile, are noted as having a distinct tapering appearance that is not observed in modern uncharred material (Fig. 5d). Experimental charring undertaken by the authors suggests this is a result of the grains being charred in their chaff, plausibly as a result of parching to release grain as documented ethnographically for species of the *Piptatherum/Oryzopsis* complex (Adams 1999).

Other wild taxa identified at Sheikh-e Abad that are significant in terms of their ubiquity and/or abundance include *Bolboschoenus glaucus* (tuberous bullrush), and *Chenopodium* spp. (chenopods), both of which decline proportionally through later levels of the site (Fig. 4a). In contrast, the mustards *Brassica/Sinapis* sp. and *Neslia paniculata* (ball mustard), as well as *Papaver* spp. (poppy) all increase through time (Fig. 4a), a pattern that may relate to their role as arable weeds during later occupation. Figure 6 illustrates the bi-plot for a CA run on all taxa and types occurring in three or more samples (44) — after first removing any outliers that obscured underlying trends — and all samples with three or more items of these (14); Figure 6 clearly shows that these three taxa form a group with crops and other wild species that we interpret as arable weeds, based on this association and their fruiting times which suggest they would have been in seed at the time of harvest (Townsend et al. 1966). Several of these weedy taxa (*Bellevalia* sp., *Papaver* spp., *Vaccaria pyramidata, Glaucium* sp. and *Coronilla* sp.) also correspond to the potential arable weed taxa listed by Willcox (2012b) for southwest Asian Neolithic assemblages. In contrast, *Chenopodium* spp. and *B. glaucus* separate out from crops along the first (horizontal) and second (vertical) axis, suggesting they did not arrive on site as part of this crop/weed package. This inference is further supported in the case of *B. glaucus* by its fruiting period, which falls outside of the assumed harvest period (Townsend et al. 1966). Also, diverging from this crop/weed group along the first axis are medium-seeded wild grasses, which form a distinct group in CA unrelated to most other taxa. This suggests they did not arrive on site as crop weeds or (annual) cultivars, since cultivation would have entailed regular tillage and re-sowing, creating a cultural niche for ruderal species to invade. However, we do not rule out other forms of crop-husbandry (e.g. watering and weeding), especially for perennial species that may have suited alternative management strategies.

Several non-botanical remains have also been identified at Sheikh-e Abad, including amorphous charred matter, which requires further investigation, and charred rodent pellets. Charred rodent pellets are restricted to Trench 2 and found in association with crops (Fig. 4a), suggesting that crops/crop-products were being stored at the site during this time. The remains of potential sheep/goat dung have also been recovered from Trench 2, and are identified in morphological thin-section across Trench 3 along with traces of herbivore and omnivore faecal material identified by GC-MS (Matthews 2013; Shillito et al. 2013).

The burning of animal dung as fuel is a major route by which plant remains can enter a charred macrobotanical assemblage (Miller 1996; Charles 1998; Matthews 2010). At present, there is no unequivocal evidence for any plant remains having a dung origin at Sheikh-e Abad (i.e. no plant macrofossils have been identified within whole dung pellets). However, when considering seeds' potential for surviving in dung (see Table 3), it is plausible that many wild plant species could have entered the archaeobotanical record in this way. This is particularly the case for those taxa that are unlikely to have arrived as arable weeds based on their seasonality and divergence from the crop/weed group in CA, and for which another explanation is therefore required (e.g. *Chenopodium* spp., *B. glaucus*). Similarly, small-seeded grasses, including *Poa* spp. which dominates the assemblage, are also ranked as having a high chance of surviving ruminant digestion intact. The dominance of small-seeded grasses within the upper levels of Trench 2 and across Trench 3 (Table 2; Fig. 4a) may relate to an increasing intensity of animal management at the site, corresponding with more widespread trends in the management and emergence of domestic livestock across southwest Asia in the Early Neolithic (Zeder 2011). In contrast medium- and large-seeded wild grasses are increasingly less likely to have entered the assemblage within animal dung. Furthermore, in the case of specimens that were broken prior to charring (e.g. *Stipa* grains), and which are therefore reduced in size, it remains unlikely these have a dung origin, as despite their endosperm being exposed they are clearly undigested.

Discussion

Identification of wild plant foods

Analysis of the plant remains from Sheikh-e Abad clearly demonstrates that a diverse range of wild taxa were utilised at the site, including a suite of medium-seeded wild grasses that were most likely gathered for consumption. Four taxa — *Lolium perenne/rigidum*, *Piptatherum holciforme, Taeniatherum caput-medusae* and *Stipa* spp. — account for the majority of medium-seeded wild grasses recovered, both in terms of ubiquity and abundance, and we interpret these as staple foods at Sheikh-e Abad based on the following five lines of independent evidence: (1) their frequent occurrence across the assemblage and presence in significant numbers (e.g. 100 or more specimens of a single taxon within a single sample); (2) their incompatibility as crop weeds, given their ripening times in comparison to the harvest period and/or their divergence from crops and crop weeds in CA; (3) their low likelihood of surviving animal digestion intact and having entered the assemblage within animal dung burnt as a fuel, (4) morphological evidence for grains being processed in a manner consistent with their consumption (i.e. ground, parched) and (5) the decrease in these taxa (excepting *Stipa* spp.) through later levels of occupation following the appearance of domesticated crops.

Other potentially edible wild plant foods attested within deposits at Sheikh-e Abad include the nut-fruit group (primarily composed of *Pistacia* sp. and *Prunus amygdalus*), *Chenopodium* spp. and also *Papaver* spp., the seeds of which are commonly used as a condiment. *Bolboschoenus glaucus* may also have been collected for this purpose and has been cited as a major food source at other Early Neolithic sites in the region e.g. Qermez Dere and Hallan Çemi in southeast Anatolia (Savard et al. 2006). Experimental work on the tubers of this species has also demonstrated how these might have been processed for consumption (Wollstonecroft et al. 2008). Meanwhile, the mustards *Brassica/Sinapis* sp. and *Neslia paniculata* could have been used as flavouring and/or for their oil, with charred plant assemblages from Neolithic sites in western Asia providing evidence for mustard seeds being stored and processed for these reasons (Willcox 2002; Bogaard et al. 2009). We use the phrase 'potentially edible' here, as unlike the medium-seeded wild grasses discussed, there is no convincing evidence to support the hypothesis that these wild taxa were consumed. Indeed, many may have entered the assemblage via other routes, with *Papaver* spp., *N. paniculata,* and *Brassica/Sinapis* sp. all noted as potential crop weeds, while *Chenopodium* spp. and *B. glaucus* may have a dung origin. If this latter inference is supported, this would have significant ramifications for our understanding of fuel use and animal management during the earliest phases of the Neolithic, given the ubiquity of these taxa in Trench 1 deposits at the site (10th millennium BC) and current debates regarding the availability of dung fuel during this time (Hesse 1984; Miller 1996). We also leave open the possibility that these wild taxa may have arrived on site in myriad ways, have been utilised for multiple purposes simultaneously (including for medicine or crafts) and that their use(s) could have varied over time. Nor do we exclude the possibility that other taxa attested at the site might have been consumed.

Pre-agricultural plant management strategies and 'auditioning' of medium-seeded wild grasses

The medium-seeded wild grasses, *Lolium perenne/rigidum, Piptatherum holciforme, Taeniatherum caput-medusae,* and *Stipa* spp., form a significant component of the Sheikh-e Abad assemblage, both in terms of their ubiquity and abundance, and are most reasonably interpreted as processed/staple foods. This repeated and intensive focus on these wild grass species over a prolonged period of time is, we argue, consistent with the concept of 'auditioning' (Smith 2007, 2011, 2016), insofar as these species appear to have been actively trialed for key roles in food production as part of newly emerging sedentary lifeways during the Early Neolithic. We do not imply by the use of this term that people were auditioning species with any long-term view to, or prior knowledge of, farming, but rather that auditioning took place within the broader context of niche construction and in pursuit of short-term advantage(s). Critically however, unlike pre-domestication cultivation, this pre-agricultural plant strategy did not result in the domestication of these species and was eventually supplanted by a strategy of food-production based on the cultivation of domesticated crops.

In contrast to other wild grass species whose pre-domestication cultivation is well documented at a number of archaeological sites, for example wild barley (Kislev 1997; Willcox and Stordeur 2012; White and Makarewicz 2012), the absence of a weed flora associated with this suite of wild grasses at Sheikh-e Abad suggests their grain was harvested from wild populations (e.g. dense, natural stands) as opposed to cultivated plots. Of the four-prominent species recorded at the site, at least two — *P. holciforme* and *Stipa* spp. (potentially also *L. perenne/rigidum*) — are perennials, and thus, while plausibly managed (e.g. weeded, watered, protected etc.) this would not have provided the same degree of control over the timing and abundance of the harvest as sowing the seeds of annual crops allows (Nesbitt 2006: 12; Van Tassel et al. 2010). It is therefore unlikely that it would have created the selection pressures necessary for domestication. These medium-seeded wild grass species therefore occupied a fundamentally different niche to that of annual crop progenitors, one that is identified clearly here for the first time in southwest Asia.

It is also plausible that a dominance of perennial grasses in the local environment, as indicated by the present-day flora, would have made it more difficult for annual crops to become established in the absence of tillage and re-sowing, as these cannot compete with perennial grasses and the dense vegetation that develops. This observation has been documented in modern field experiments on *Triticum boeoticum thaoudar* (Willcox 1999) and lends further support to the theory that domesticated crops arrived at Sheikh-e Abad as part of an integrated farming package that included established methods of cultivation and crop husbandry. Once adopted, this would have opened up a new cultural niche, in which perennials as poor and unreliable seed setters (Harlan 1992: 120; Nesbitt 2006: 13; Van Tassel et al. 2010), would have struggled to compete. It is worth noting that there is no evidence to suggest any attempt was made to integrate these 'auditioned' wild grasses within this farming package and manage them as annuals; though they overlap in the Trench 2 sequence, their distribution and abundances suggest different routes of entry. Indeed, retaining an alternative strategy of plant management may have helped mitigate some of the risks associated with early crop cultivation and food storage, and is consistent with patterns noted across western Asia for the continued use of wild plant foods through the Early Neolithic.

Emergence of farming

Established crops, including domestic-type barley, glume wheat and a range of pulses, first appear in later 8th millennium BC levels of the site. Here, they are associated with a range of wild plant species that are best interpreted as weeds of cultivation, including several taxa that are absent from earlier levels (e.g. *Adonis* sp., *Ajuga* sp.). Also, appearing for the first time alongside crops are charred rodent pellets, indicating that crops/crop products where being stored at the site, although no direct evidence for storage (e.g. storage bins) has been identified to date. From this evidence, we infer that later inhabitants of Sheikh-e Abad were engaged in a strategy of food-production based on the cultivation of a domesticated crop package from at least 7960 cal BC. Significantly, no crop remains (domestic species or their wild progenitors) were recovered from earlier 10th millennium BC levels at the site, suggesting that domesticated crops were introduced to the settlement from an external source, providing a new alternative to existing food-procurement strategies. This is in contrast to contemporary Chogha Golan in the low foothills of the southern Zagros, where wild emmer wheat was apparently domesticated *in situ* and other wild progenitors of domesticated crop species (e.g. wild barley, lentil and grass pea) were also cultivated (Riehl et al. 2013; Weide et al. 2017).

Conclusions

Analysis of the Sheikh-e Abad macrobotanical assemblage has allowed us to trace, for the first time, long-term plant management strategies across the agricultural transition in an upland setting. Significantly, we identify a pre-agricultural strategy of plant-food production centered on locally available wild taxa, including a group of medium-seeded wild grasses. We observe that several of these wild grass species have perennial growth strategies, as opposed to the wild progenitors of cereal crops that are all annuals, and hypothesise that the life history of favoured wild grasses, as well as their distribution, was a key factor in diverging trajectories during the Early Neolithic. It is likely that other factors relating to plant availability, seasonality, local climate, animal husbandry and socio-cultural practices at the site, also played a role in precluding the *in situ* development of farming at Sheikh-e Abad. The appearance of a domesticated crop package in later levels of the site we interpret as the result of a farming package being brought in externally from a lowland source. We suggest that the arrival of this farming package opened up a new cultural niche in this upland zone, as cultivation practices that had evolved alongside domesticated annuals allowed these crops to outcompete the perennial species that previously dominated the local environment. The spread of this new agricultural niche into the central Zagros also corresponds to, and may in part explain, the appearance of other early farming sites here during the later phases of the Early Neolithic (e.g. Ganj Dareh, Abdul Hosein, Asiab).

Continued sampling and analysis of plant material from the site, including additional radiocarbon dating to refine the chronology of occupation here, will allow us to test these inferences further. It should be stated that the ubiquity values provided in Table 2 have been calculated over a limited number of samples and should be treated with some caution. It should also be noted that while the upper levels of Trench 2 overlap with the lower levels of Trench 3, the top of Trench 1 and base of Trench 2 are separated by a depth of approximately 5m of deposit, corresponding to some 1000 years in time (*ca*. 9000–8000 BC). These deposits remain to be investigated along with other areas of the mound, and are likely to provide additional data on the complexity and diversity in plant management and consumption strategies at the site.

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Figures

Fig. 1 (a) Location of Sheikh-e Abad in the central Zagros of western Iran and other key Early Neolithic sites across the Fertile Crescent; **(b)** elevation profile of straight line between Chogha Golan and Sheikh-e Abad

Fig. 2 (a) Location of Trenches 1, 2 and 3 at Sheikh-e Abad; **(b)** plan of Buildings 1 and 2 in Trench 3; (**c)** wild sheep/goat skulls from Building 2, Trench 3

Fig. 3 The dimensions (mm) and ellipsoid volume (mm^3) of wild grasses identified at Sheikh-e Abad along with other common Poaceae taxa (values shown on y-axis). Measurements calculated using values reported by Nesbitt (2006) as described in text. *denotes taxa identified at Sheikh-e Abad, † indicates taxa identified at Sheikh-e Abad that potentially fall into multiple categories (e.g. *Bromus* and *Stipa*)

Fig. 4 (a) Relative percentages of crops, small-seeded grasses, medium-seeded wild grasses (including small, medium and large sub-divisions) and other potentially edible taxa through time at Sheikh-e Abad based on 24 samples containing 30 or more items. Y-axis gives sample numbers (arranged stratigraphically with lowest/oldest at bottom) and in brackets the total number of items within each sample. Taxa occurring at proportions <5% are indicated by +. Presence of rodent pellets in samples indicated by open circles. Samples 510, 617, 613 and 612 potentially missing fine flot (0.3mm) material and therefore small seeds may be underrepresented; **(b)** Relative percentages of four major medium-seeded grass taxa (*Lolium perenne/rigidum, Piptatherum holciforme, Taeniatherum caput-medusae, Stipa* spp.) within 24 samples, calculated as percentage of total number of all medium-seeded grass taxa. Y-axis presents sample numbers (arranged stratigraphically with lowest/oldest at bottom) and in brackets the total number of medium-seeded grasses within each sample)

Fig. 5 Examples of major wild grass taxa from Sheikh-e Abad as mentioned in text (**a)** *Stipa* awn fragments; **(b)** *Taeniatherum caput-medusae* rachis; **(c)** *Stipa* grains showing morphological evidence consistent with being ground for consumption prior to charring, and **(d)** *Piptatherum holciforme* grains charred in their chaff and demonstrating a distinctive tapering appearance consistent with parching

Fig. 6 Correspondence analysis plot of 44 taxa based on their occurrences in 14 samples, showing axis 1 (horizontal axis) and axis 2 (vertical axis), with taxa coded according to type and labelled as mentioned in text

Fig. 1a, b created in ArcGIS 10.4.1; Fig. 3 and 4a, b created in Microsoft Excel 15.32; Fig. 6 created in Canoco 5.0; All figures formatted in Adobe Illustrator

Tables

Table 1 Radiocarbon determinations from Sheikh-e Abad

Table 2 Records of the frequency and abundance of all recorded taxa across Trenches 1, 2 and 3 at Sheikh-e Abad. ‘cf.’ denotes a lower certainty of identification and brackets the uncertainty of cultivated/domestic status. * indicates taxa interpreted as possible “arable weeds” based on correspondence analysis as discussed in text

Table 3 Classification of major wild plant taxa at Sheikh-e Abad based on their likelihood of surviving in dung (ranked from low to high) as discussed in text