

Evidence for Sorghum Domestication in Fourth Millennium BC Eastern Sudan

Spikelet Morphology from Ceramic Impressions of the Butana Group

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Online enhancements: supplemental appendix

Since the 1970s, the quest for finding the origins of domesticated sorghum in Africa has remained elusive despite the fact that sorghum (*Sorghum bicolor* (L.) Moench. sensu stricto) is one of the world's most important cereals. Recognized as originating from wild populations in Africa (*Sorghum arundinaceum* (Desv.) Stapf), however, the date and cultural context of its domestication has been controversial, with many scholars inferring an early Holocene origin in parallel with better-known cereal domestications. This paper presents firm evidence that the process of domesticating sorghum was present in the far eastern Sahel in the southern Atbai at an archaeological site associated with the Butana Group. Ceramic sherds recovered from excavations undertaken by the Southern Methodist University Butana Project during the 1980s from the largest Butana Group site, KG23, near Kassala, eastern Sudan, were analyzed, and examination of the plant impressions in the pottery revealed diagnostic chaff in which both domesticated and wild sorghum types were identified, thus providing archaeobotanical evidence for the beginnings of cultivation and emergence of domesticated characteristics within sorghum during the fourth millennium BC in eastern Sudan.

Sorghum (*Sorghum bicolor* (L.) Moench. sensu stricto) is one of the world's five most important cereals, but its origins are less well understood than the others (i.e., rice, wheat, barley, maize; Fuller et al. 2014). It is especially important in the semiarid tropics of Africa and South Asia, with significant production also in China, Southeast Asia, and the Americas (Doggett 1970; Hulse, Laing, and Pearson 1980; Snowden 1936). While sorghum has long been recognized as originating from wild pop-

ulations in Africa (*Sorghum arundinaceum* L. (Desv.) Stapf, syn. *S. bicolor* subsp. *arundinaceum* De Wet and Harlan; De Wet and Huckabay 1967; Harlan and Stemler 1976), the date and cultural context of domestication have been controversial. Harlan, Stemler, Clark, Wendorf, and others had inferred an early Holocene origin in parallel with better-known cereal domestications. They hypothesized that origins should be sought in the early ceramic-making and pastoralist cultures of the northern Sudan or the eastern Sahara (Clark 1984; Harlan and Stemler 1976; Wendorf and Schild 1998; Wetterstrom 1998). Historical linguistic inferences point to reconstructed word roots for sorghum dating to an early phase of the Nilo-Saharan subfamily, inferred to date to the early Holocene (9700–6200 BC) in the eastern Sahara (Blench 2006; Ehret 1993, 2014). However, knowledge of a plant need not imply cultivation, as utilization from the wild could also produce such linguistic markers (Blench 2006; Ehret 2014). Archaeobotanical evidence recovered from Nabta Playa, dating to ca. 7500 BC, was composed entirely of morphologically wild sorghum, although some patterning in the samples was taken to suggest that sorghum had a special status relative to other plants, perhaps even as a cultivar (Wasylikowa 2001; Wasylikowa and Dahlberg 1999). Along with reports of wild-type sorghum from pottery impressions in Neolithic central Sudan (6000–3000 BC; e.g., Stemler 1990), these data led to the hypothesis that sorghum might have had a long history of predomestication cultivation, in which cross-pollination with wild populations prevented the kind of rapid domestication that was then expected in self-pollinating cereals such as wheat or barley (Haaland 1995, 1999; Magid 1989).

However, recent advances in the archaeobotanical study of cereal domestication calls into question the inference that sorghum was somehow uniquely difficult to domesticate. Instead, evidence from the Near East and East Asia have similarly indicated that domestication was a protracted process (Fuller et al. 2009; Tanno and Willcox 2006). The period during which domesticated morphotypes evolved, predomestication cultivation, may have been as much as 2,500–3,500 years (Fuller 2007; Fuller et al. 2014), and there is no reason to regard cross-pollinating species as much harder or slower to domesticate than selfing species (Allaby, Brown, and Fuller 2010; Fuller 2007). Therefore, if sorghum had arrived as a domesticated crop in India by 2000–1700 BC, the domestication process in Africa should be sought at least during the two or three millennia prior to this (Fuller and Hildebrand 2013). Recent evidence from western Africa has pushed back the date for domesticated pearl millet (*Pennisetum glaucum*) in Africa to ca. 2500 cal. BC, around a millennium prior to its arrival in India (Manning et al. 2011), and a similar scenario seems plausible for sorghum.

The example of pearl millet in western Africa also illustrates the utility of studying the impressions of crop chaff used as ceramic temper to distinguish the wild from cultivated forms (Amblard and Pernès 1989; Fuller, Macdonald, and Vernet

2007; Manning et al. 2011). Such impressions may be studied even from ephemeral or highly deflated Saharan and Sahelian sites that offer little or no opportunity for the recovery of conventional charred plant macroremains (Manning et al. 2011). Ceramic impressions are not guaranteed to reflect food plant use, as these ultimately reflect choices of potters, but if they do use plant processing debris, this can provide important insights into recurrently processed plants (usually grasses or cereals; Fuller 2013; McClatchie and Fuller 2014; Nixon, Murray, and Fuller 2011). In central Sudan, previous analyses of plant impressions in ceramics have provided evidence for the use of wild sorghum alongside various other savannah grasses in the tempering of Neolithic ceramics from 5000–3000 BC (Magid 1989, 2003; Stemler 1990). This offers a data set not just for documenting wild sorghum use but also as evidence for morphological change indicative of selection under cultivation.

This paper reports the study of plant impressions in pottery sherds from site KG23 located in the southern Atbai near

Kassala in eastern Sudan (fig. 1; Manzo 2012), investigated at University College London (by L. Champion, C. Murphy, C. J. Stevens, and D. Q. Fuller). These sherds were originally recovered from excavations undertaken by the Southern Methodist University Butana Archaeological Project (SMU) during the 1980s under the direction of Anthony Marks (Fattovich, Marks, and Mohammed-Ali 1984) and were studied and classified by Winchell (2013). All of the analyzed sherds with plant impressions are associated with the ceramic type, Khordhag Plain, part of the Butana Group ceramic tradition (see Winchell 2013:189–192), and came from multiple levels within KG23 (located at approximately 15°04'38.0"N, 36°06'06.8"E). Although no flotation or sieving had been carried out for archaeobotanical recovery at KG23 in the 1980s, it was subsequently recognized that impressions of vegetable material preserved in ceramics provided a potential data set for the recovery of some information about past plant use and potentially ancient crops (see, e.g., McClatchie and Fuller 2014).

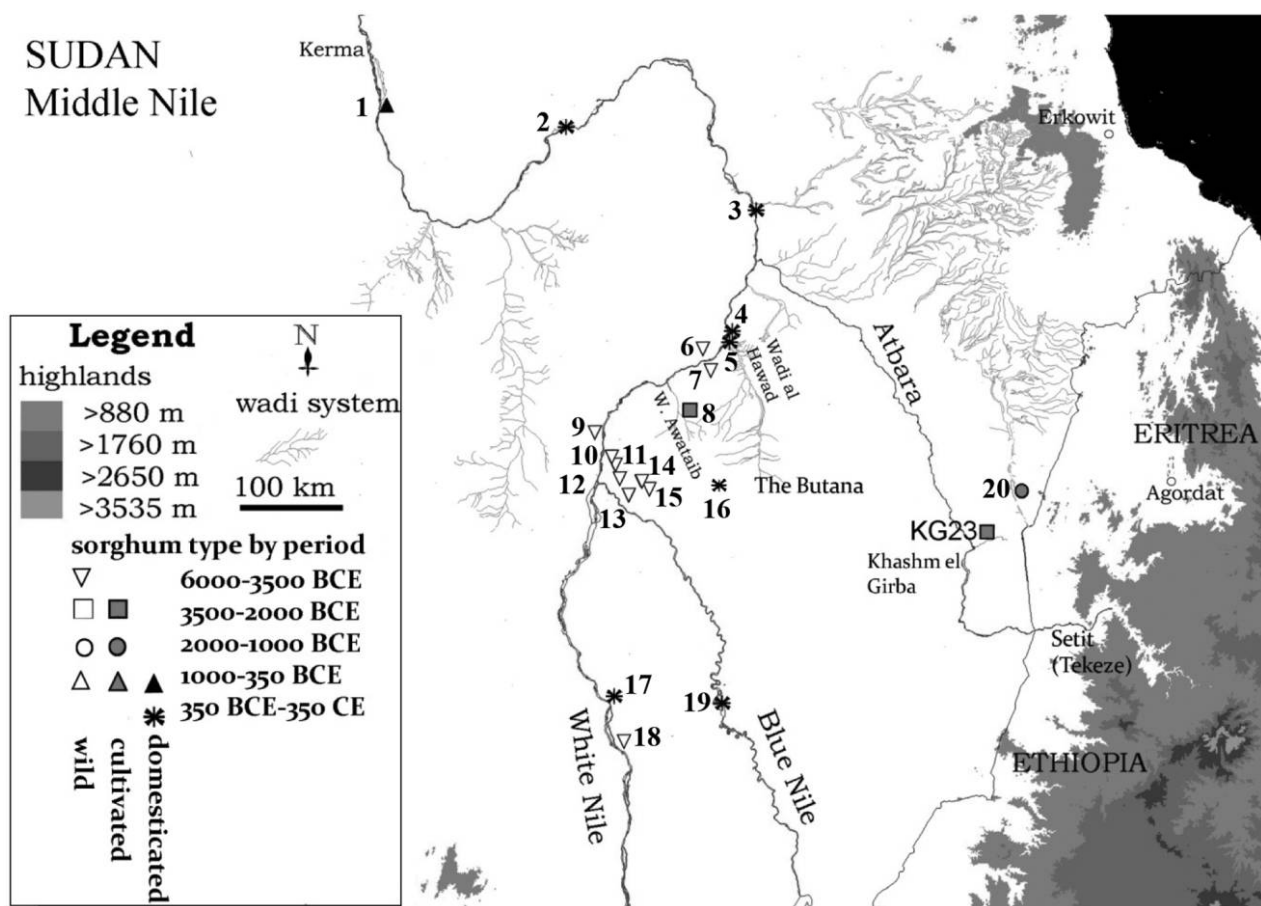


Figure 1. Map of northern Sudan, indicating KG23 in relation to sites with archaeological evidence of sorghum (wild, cultivated, and fully domesticated). 1 = Kawa; 2 = Umm-Muri; 3 = Dangeil; 4 = Meroe City; 5 = Hamadab; 6 = El Kadada; 7 = Naqa (art); 8 = Shaqadud; 9 = Shaheinab; 10 = El Zakiab; 11 = Kadero; 12 = Umm Direiwa; 13 = Sheikh Mustafa; 14 = El Mahalab; 15 = Sheikh el Amin; 16 = Jebel Qeili (art); 17 = Jebel Tomat; 18 = Rabak; 19 = Abu Geili; 20 = Kasala K1 (Magid 1989, 2003; Beldados and Costantini 2011; Fuller 2014; Stemler 1990). A color version of this figure is available online.

KG23 and the Butana Group of the Southern Atbai

KG23 represents the largest of seven Butana Group sites excavated by SMU in the 1980s. All sites are located in the southern Atbai, a featureless semiarid steppe in the easternmost portion of the Sahel, bordered by the Atbara River to the west and the inland Gash River delta to the east (fig. 1). The site of KG23 lies in the Khashm el Girba locality and is composed of a large, undulating midden deposit about 2 m in depth and approximately 120,000 m² in size (fig. 2). Three locations (KG23a, KG23b, and KG23c) were systematically excavated in 1983. Each area was divided into 1 × 1-m² units and dug down in 5-cm levels. The Khordhag Plain sherds studied in this analysis, as with the original ceramic report (Winchell 2013), came from those recovered from stratified deposits excavated in KG23c, with a single exception from KG23b.

Occupation at KG23 is predominately associated with the Butana Group, an archaeological phase dating from the fourth to the late third or early second millennium BC, and part of the larger Atbai ceramic tradition. This ceramic tradition developed uninterrupted in the southern Atbai from the sixth millennium BC into the first millennium AD (Fattovich, Marks, and Mohammed-Ali 1984; Marks and Fattovich 1989; Marks,

Mohammed-Ali, and Fattovich 1986; M'Butu 1991; Sadr 1991; Winchell 2013).

What makes the Butana Group stand out archaeologically are the large occupation sites that range in size from 25,000 to 120,000 m², with cultural deposits ranging from one-half to more than 2 m in depth. The relatively deep midden deposits, along with the density and variety of artifacts found on Butana Group sites, suggest that these settlements represent a movement toward increased sedentism with centuries-long occupation; however, animal remains suggest that the hunting of wild animals was more important than domesticated cattle and ovicaprines, which only appear in the later deposits (Fattovich, Marks, and Mohammed-Ali 1984; Marks and Fattovich 1989; Marks, Mohammed-Ali, and Fattovich 1986; M'Butu 1991; Peters 1992; Sadr 1991; Winchell 2013). KG23 was the largest and perhaps longest occupied of the Butana Group sites (Winchell 2013).

Three radiocarbon dates on wood charcoal from stratified deposits, two from KG23c and one from KG23a, place occupation of the site between 3600 and 3100 cal. BC (fig. 3), although given that these are on wood charcoal, they could be one to a few centuries older due to the old wood effect. The dates are consistent with dates from other Butana Ceramic

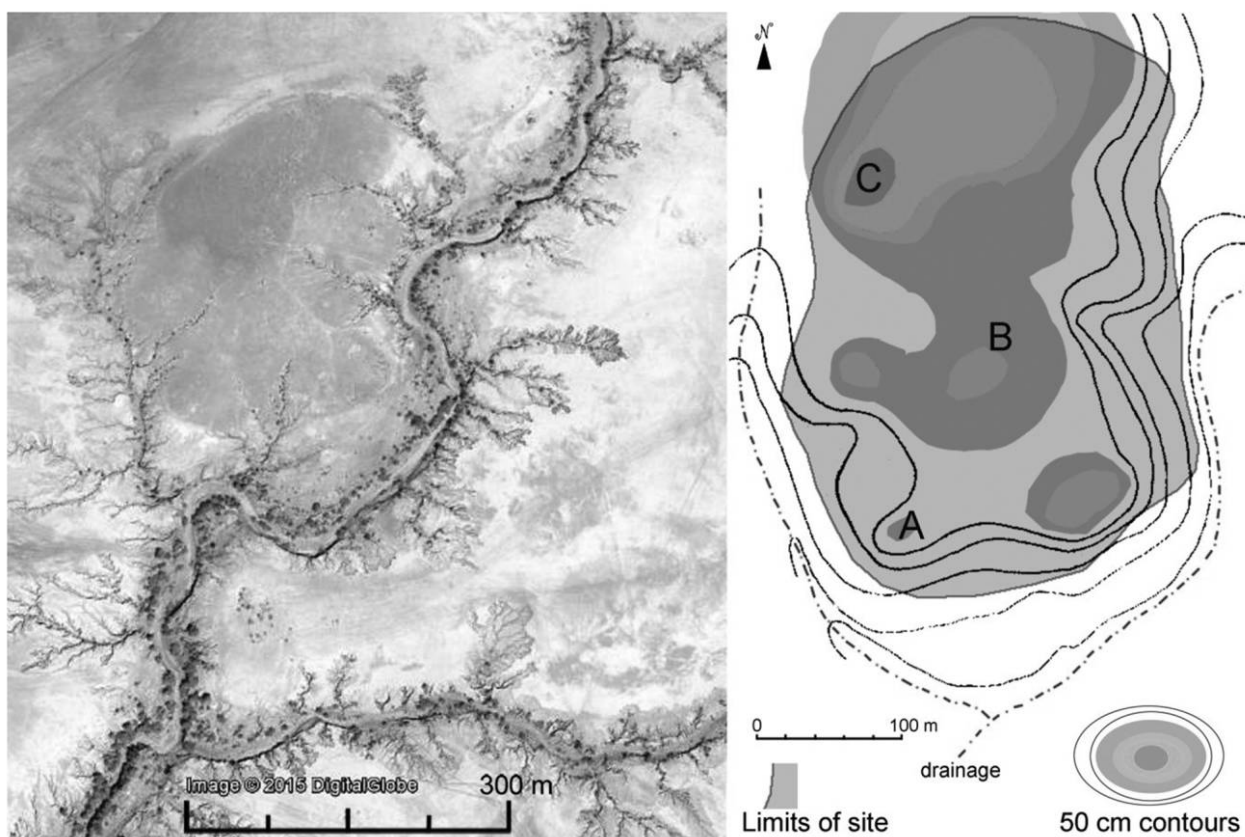


Figure 2. Satellite image (source: Google Earth, 2009) and plan of site KG23 (after Winchell 2013). A color version of this figure is available online.

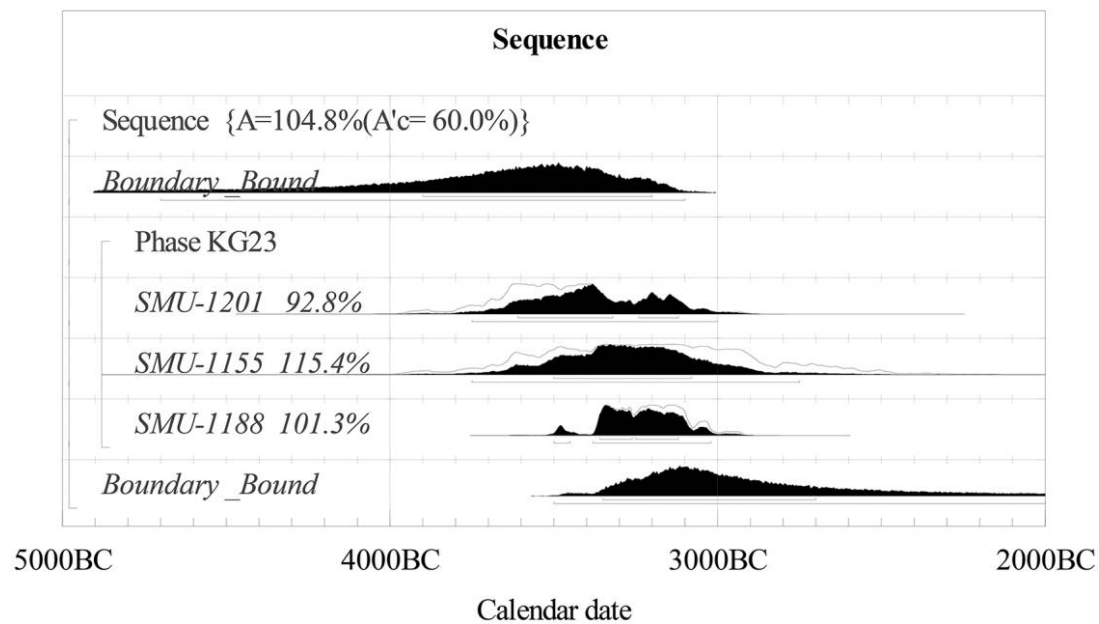


Figure 3. Calibrated radiocarbon dates from KG23 (data after Winchell 2013) in a Bayesian model of start and end dates: SMU-1201, 4727 ± 154 BP (KG23c level 27); SMU-1155, 4542 ± 253 BP (KG23a level 18); SMU-1188, 4519 ± 67 BP (KG23c level 23). A color version of this figure is available online.

Group sites and are consistent with the chronology of the ceramic types (Manzo 2012; Sadr 1991; Winchell 2013).

Examination of the Impressions

The initial examination of ceramic material was conducted for the largest collection of sherds ($n = 7,473$) from area K23c, which had already been comprehensively studied using typological and technological analysis (Winchell 2013). Only sherds of Khordhag Plain ware ($n = 147$) included vegetable tempering, which had left impressions of plant material, seen as dark stains due to combustion of the organic temper when the pots were fired (Winchell 2013:190). Such tempering was visibly present on the outer and inner surfaces, as well as within the fabric, in over 50% ($n = 88$ from K23c, as well as three from layer 28 K23b) of the sherds of this type. Khordhag Plain ware occurred in all levels at KG23 and thus characterize the Butana Group period.

All body sherds (typologically nondiagnostic) with visible vegetable tempering were brought to the University College London (UCL) Institute of Archaeology for archaeobotanical study, and each of the 91 sherds was initially examined using low-power binocular microscopes at $\times 10$ – $\times 40$. The presence of sorghum grains was then noted for each sherd, along with whole spikelets where present. The latter were further classified where possible as to whether they were of domesticated, wild, or immature type (see below for further explanation). Other plant remains where present were also identified if possible and recorded. The sherds used in this analysis are labeled with a provenience—for example, “KG23c-C3–24” indicates

that this sherd was located at KG23, in area c, within the 1-m² excavation unit C3, at level 24 (120–125 cm below the surface). As such, the presence or absence of sorghum types could be recorded throughout the whole 1.4-m sequence (table 1).

Material was photographed and a selection of impressions cast for further examination using scanning electron microscopy (SEM). Casts of grains, spikelet, chaff, and seed impressions were made using a vinyl polysiloxane dental molding agent, which was applied to the surface of the pot sherd and left to dry for approximately 10 min (method follows Fuller, Macdonald, and Vernet 2007; Manning et al. 2011). Multiple casts were taken from each sherd to acquire a clean and anatomically detailed cast. These were then reexamined under a stereomicroscope at $\times 6$ – $\times 40$ magnification, and the most promising in terms of anatomical details were selected for SEM examination and imaging. These casts were cut to suitable size, mounted on metal stubs, and sputter-coated with gold and then studied with a Hitachi S-3400 SEM.

Results and Discussion

Of the 91 sherds examined from KG23, 65 produced a total of 279 identifiable plant impressions, while the remaining sherds produced undiagnostic fragments of grass straw (leaf or culm). Of these 65 sherds, a total of 249 impressions of sorghum were recorded from 63 sherds (table 1). It was notable that almost no sorghum impressions were recovered from pottery in the uppermost layers. However, the percentage of sherds of tempered or Khordhag Organic Plain pottery was noted to generally decline in both this and another site, K7a,

Table 1. Number of sherds with impressions of wild, domesticated, and immature spikelets, along with unidentifiable (as wild or domesticated) sorghum spikelets, grains, and glumes for layers and 10-cm spits

Depth (cm)	Layers	No. sherds	Wild	Domesticated	Immature	Gain/spikelet	Glume	Total	Stems	Other ^a
0–10	1 and 2	11	...	...	...	1 (4)	...	1 (4)	4	...
10–20	3 and 4	11	1 (2)	1 (3)	3 (5)	6 (12)	...	7 (22)	5	2 (2)
20–30	5 and 6	6	2 (4)	...	...	5 (13)	2 (4)	5 (21)	1	1 (1)
30–40	7 and 8	5	...	1 (1)	...	...	...	1 (1)	2	...
40–50	9 and 10	5	2 (3)	2 (2)	1 (1)	4 (11)	...	5 (17)	1	...
50–60	11 and 12	7	1 (1)	...	1 (5)	3 (17)	1 (3)	4 (23)	3	2 (2) ^b
60–70	13 and 14	5	1 (1)	1 (1)	2 (2)	5 (16)	2 (2)	5 (22)	3	1 (1) ^c
70–80	15 and 16	1	...	...	...	...	...	...	...	...
80–90	17 and 18	8	1 (1)	...	1 (1)	7 (21)	...	7 (23)	1	2 (5)
90–100	19 and 20	8	2 (2)	...	1 (2)	8 (21)	...	8 (25)	2	3 (18) ^d
100–110	21 and 22	1	...	1 (5)	...	1 (4)	...	1 (9)	...	...
110–120	23 and 24	7	1 (2)	1 (1)	1 (1)	6 (16)	1 (3)	7 (23)	1	2 (3)
120–130	25 and 26	8	...	...	...	5 (18)	1 (2)	5 (20)	1	3 (22) ^e
130–140	27 and 28	8	2 (2)	2 (3)	...	6 (33)	1 (1)	7 (22)	2	1 (2)
Total	Sherds impressions	91	13 (18)	9 (16)	10 (17)	57 (186)	8 (12)	63 (249)	26	17 (30)

Note. The total number of impressions within each 10-cm spit is shown in parentheses. Also shown are the total number of sherds (and impressions) with sorghum, as well as the total number of sherds with stems and other impressions.

^a All other identifications are of grass seeds (Poaceae) unless otherwise noted.

^b Poaceae × 1, *Brachiaria* × 1.

^c *Carex* sp. × 1.

^d Poaceae × 5, *Brachiaria* × 10, *Fimbristylis* × 2, *Carex* sp. × 1.

^e Poaceae × 21, *Brachiaria* × 1.

some 15 km to the southwest (Winchell 2013:42), but decline in sorghum-tempered pottery is most likely to be explored in terms of ceramic change and not change in plant use (McClatchie and Fuller 2014). As a basis for determining the status of sorghum represented by impressions, we have examined a wide range of modern reference material from wild and domesticated sorghum, held in the UCL archaeobotanical reference collection, as well as published illustrations and descriptions (e.g., Harlan and Stemler 1976; Snowden 1936). Figure 4 illustrates key differences between wild and domesticated sorghum, which are used to interpret the archaeological remains. A full table summarizing our reference collection and photographs of representative reference material (tables S1, S2; figs. S1–S48; tables S1, S2 and figs. S1–S90 are available online) are provided in a supplemental appendix.

In wild cereals, the spikelets containing the grain naturally shatter or disperse on ripening from the ear or panicle, whereas domesticated cereal crops are entirely comprised of nonshattering plants. Unlike fully domesticated cereal fields, where ripening is simultaneous, within wild stands nonsynchronous ripening of panicles occurs between plants as well as between spikelets within individual panicles. As such, in assemblages resulting from the collection of wild sorghum using baskets or through ground collection, with no cultivation, we would expect predominately wild-type shattering spikelets with only a small number of immature types that are broken due to paddling. Hunter-gatherers also green harvest wild grasses by pulling or occasionally cutting them. This has been observed ethnographically among the Bagundji wild millet collectors of Australia, with plants left to afterripen by drying

them in heaps (Allen 1974). In sorghum, the abscission layer, as in many cereals, is formed before flowering. As such, drying results in natural shattering—for example, within the Bagundji, plants were simply trampled after drying rather than being threshed, causing the spikelets to naturally shatter and leaving a smooth wild-type abscission scar (Fuller, Allaby, and Stevens 2010:16). These practices may produce some grains with attached rachises; however, such spikelets would likely be accompanied by immature grains. We therefore expect assemblages resulting from early stages of predomestication cultivation to have mixtures of nonshattering domesticated-type spikelets with rounded, fully mature grain, with some immature spikelets and many wild shattering types, as early cultivators green harvested, seeking to minimize grain losses from natural shattering. Such transitions have been recorded in archaeobotanical assemblages for rice (Fuller, Harvey, and Qin 2007; Fuller et al. 2009).

The presence or absence of the rachis has been used previously within studies of ancient sorghum to distinguish between wild and domesticated forms. Dahlberg and Wasylkova (1996) state for the sorghum from Nabta Playa that the smaller grain size and lack of spikelets with rachis fragments suggest that the harvested grains were of the wild type. Conversely, the presence of attached rachis and absence of the smooth abscission layer were the criteria used to identify domesticated sorghum from charred material within a storage context from central Sudan (Clark and Stemler 1976).

To access the frequency and nature of nonshattering types within wild populations, a collection of 50 sorghum accessions acquired within the last 100 years and held in the collections at

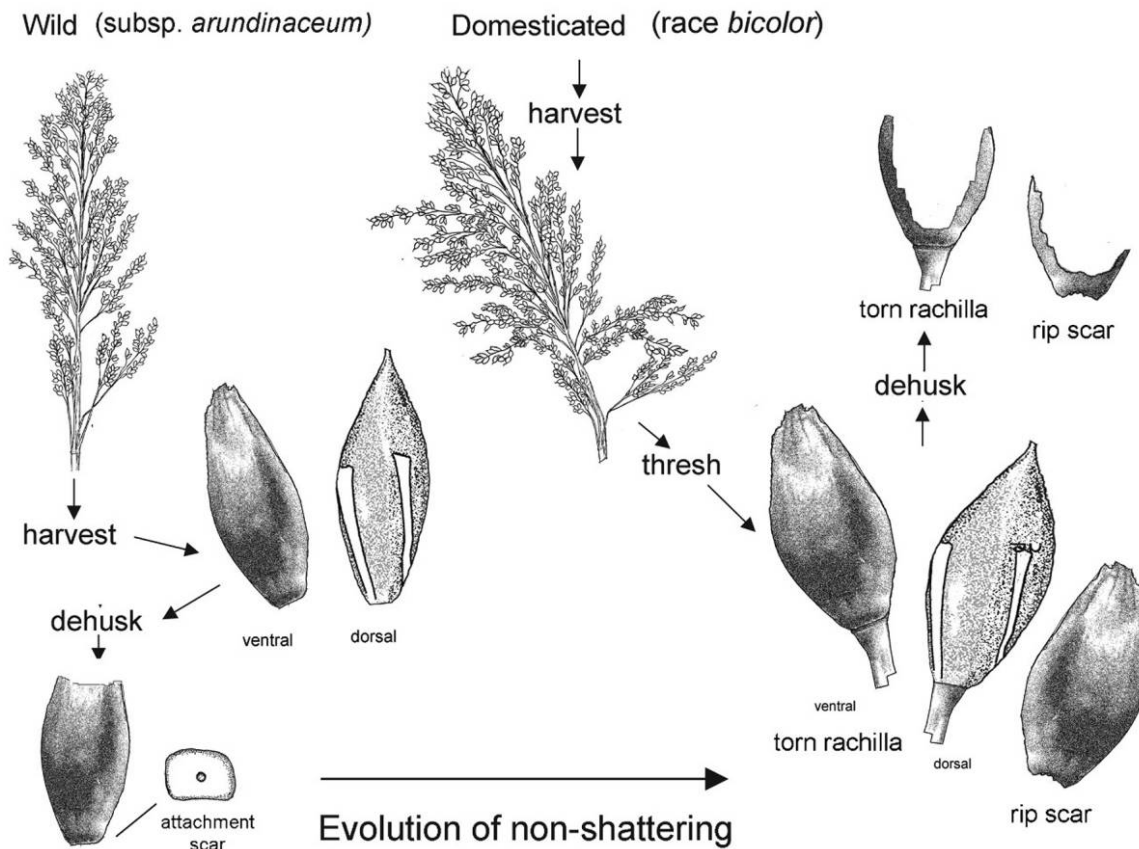


Figure 4. Diagrammatic comparison of wild and domesticated sorghum (drawing by D. Q. Fuller).

the UCL Institute of Archaeology were examined (tables S1, S2; figs. S1–S48). The percentage of spikelets with smooth, broken, and torn rachilla along with the presence of awns, hairs, and sterile spikelets within these accessions of wild sorghum were examined, as well as some accessions of hybrid and domesticated sorghum. The difference between domesticated and wild populations is clear (fig. 5), while weedy and introgressed populations present a spectrum as might be expected. The average percentage of specimens with attached and torn rachises throughout the 28 assigned wild populations (table S1) was generally low (7.4%). However, 4.8% of these occurred within three accessions in which other obvious characteristics suggesting introgression with domestic populations was present (e.g., open glumes, rounder grains, or a lack of pigmentation). It is notable that in several cases (figs. S31–S40) material from the USDA has been reclassified from wild *Sorghum arundinaceum* types to domesticated *bicolor* types (table S2). In two further cases where the accessions have not been reclassified from wild (figs. S41, S42), the gene for nonenclosing glumes that characterizes domesticated varieties is clearly present along with larger rounded grains. *Sorghum* × *drummondii* (Nees ex Steud.) Millsp. & Chase, a cultivated fodder variety of sorghum, is often deciduous to semideciduous and easily confused with true wild sorghums.

Further, both wild and domesticated sorghums are cross-pollinating, and some introgression of wild and domesticated forms has likely taken place within the millennia since sorghums spread through Africa. Snowden (1936:236) notes some 80 years ago that intermediate forms between wild and domesticated sorghums are commonly found close to or within cultivated fields. If these three accessions are omitted, then the figure with nonshattering-type rachilla falls to 2.7%. Indeed, one of the challenges confronting any modern study of wild sorghum is that the widespread cultivation of this species for millennia means that the weight of introgression is likely to be from domesticated crops into the wild, thus contaminating wild sorghum with the presence of domestication traits.

In the KG23 sherds, all three types were distinguished: clear shattering wild sorghum types, immature spikelets (green harvested before shattering), and domesticated types (nonshattering and harvested mature). Wild-type spikelets are the most clear, as they are distinguished through possessing a smooth spikelet base (fig. 6A–6C). Both immature and domesticated types potentially have a rachilla broken below the spikelet. Domesticated types were therefore taken as those with either clearly filled grains with such rachilla (fig. 6D, 6E) or as empty glumes and spikelet forks with the rachis still attached (fig. 6F–

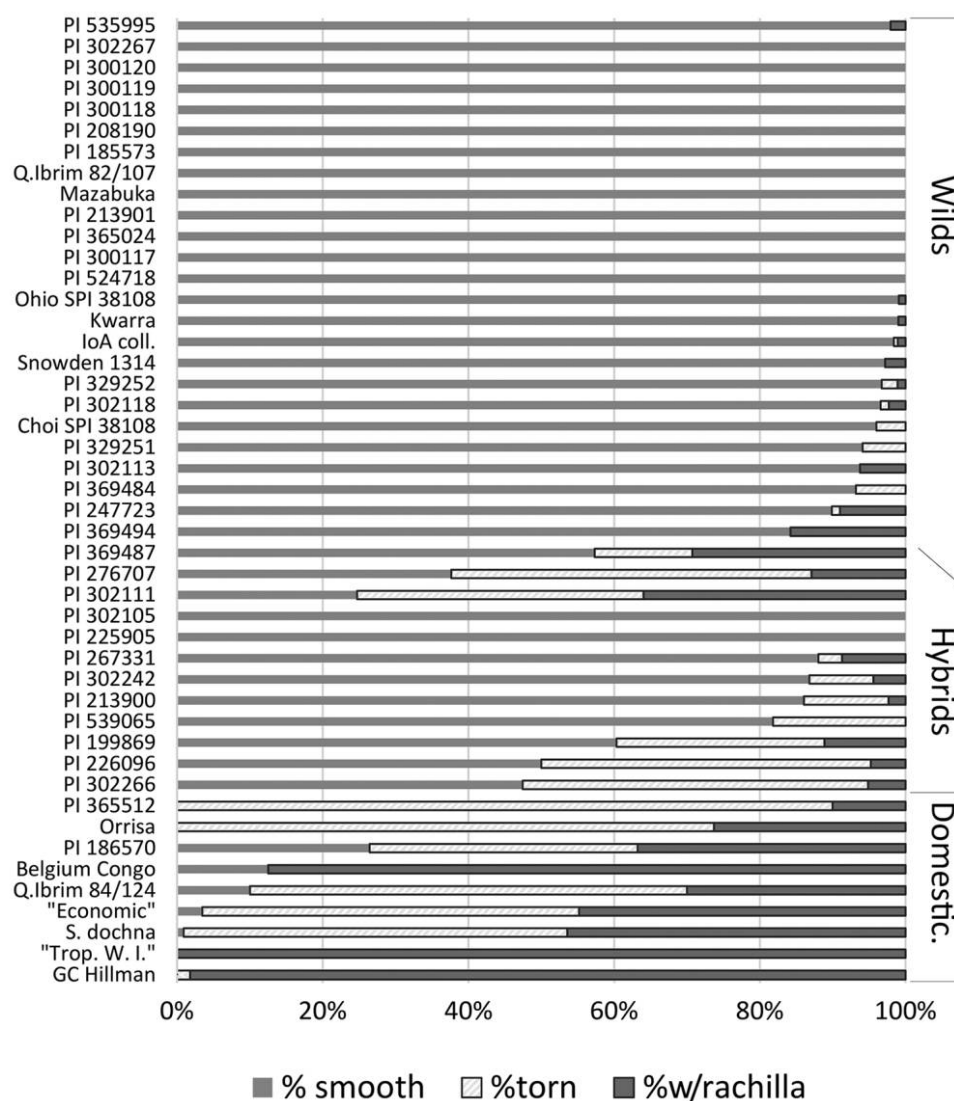


Figure 5. Bar charts comparing the proportion of wild-type (smooth) spikelet bases versus nonshattering types (torn or with attached rachilla) in modern reference materials, including those classified as wild, obvious hybrids or feral, and domesticated crops. Details of these accessions are provided in tables S1, S2, available online. A color version of this figure is also available online.

6H). Immature spikelets, where the rachilla is still attached to the panicle, were categorized as those in which the chaff was clearly narrow, suggesting that the grain had not fully filled.

Taking into account the composition of the assemblage as a whole, it appears closer to the mix we expect to see during cultivation and the domestication process than that produced by basket harvesting, ground collection, or green harvesting. A number of spikelets with rachillae (around 16) clearly contained fully mature or near-mature grains, increasing the likelihood that they were of a nonshattering type. The results suggest the harvesting of a sorghum population that had begun to include plants possessing nondehiscent, domesticated-type spikelet bases. However, it likely includes the harvesting of slightly green to near-mature spikelets within cultivated stands to avoid yield losses due to shattering of mature wild-type

spikelets, accounting for the recorded immature spikelets as well as the high number of stems and leaves.

Interestingly, no rip scars were seen, an alternative breakage pattern to the tearing of the rachilla (see fig. 4). This might be because such characteristics perhaps reflect more fully domesticated populations, but alternatively, they might arise only with changes in threshing techniques.

In the majority of cases, the grains still appeared to be hulled, in that they were contained within an intact palea and lemma and as such had been incorporated into the clay fabric without being dehusked (fig. 6B, 6C, 6E). In these examples, it is worth noting that the spikelets appear plump, suggesting that we are dealing with changes in grain morphology in which the grain width increases relative to its length, as commonly seen as part of the domestication process for other cereals (Fuller et al.

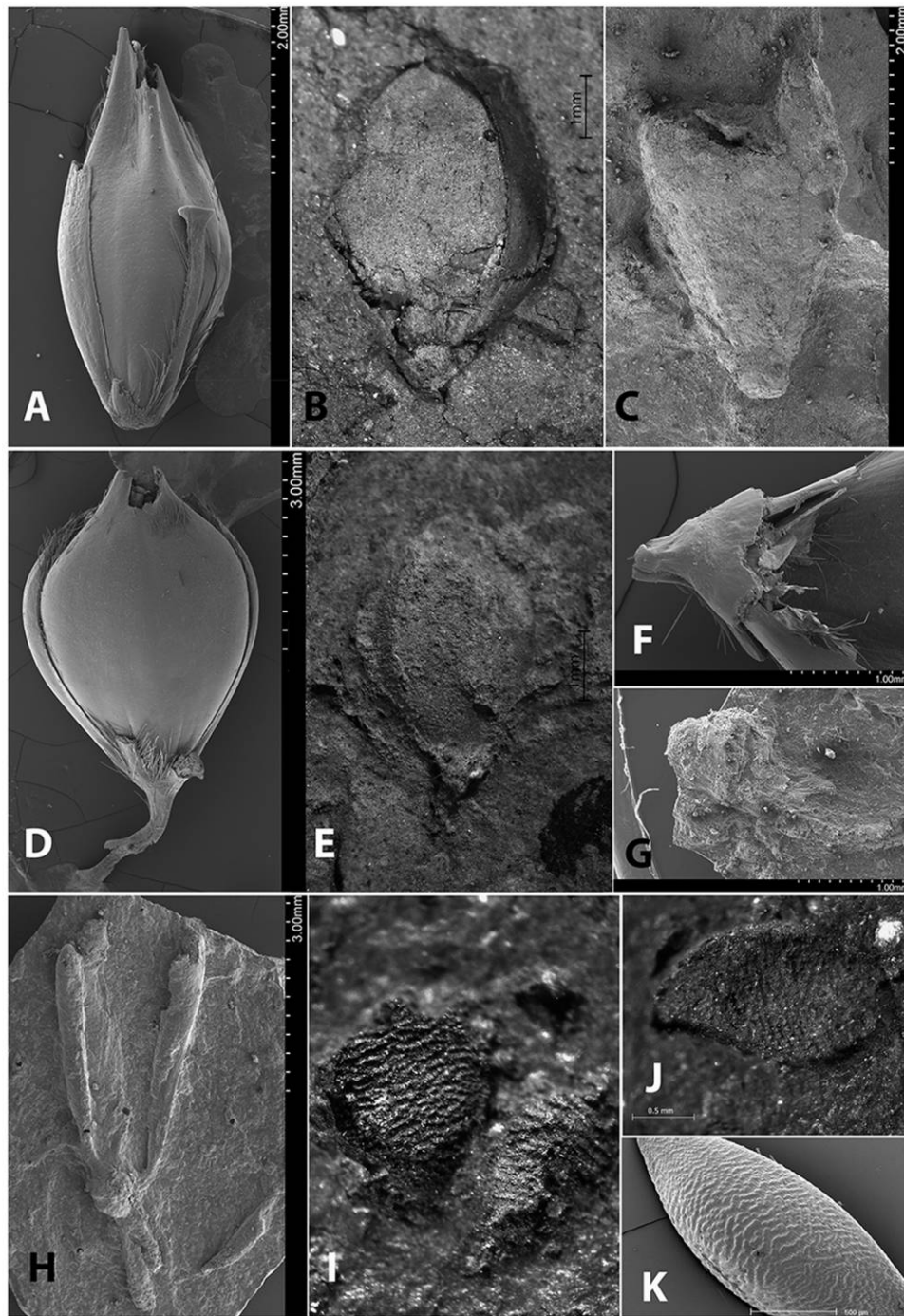


Figure 6. Example of chaff and spikelet impressions from KG23 sherds, together with modern comparisons (University College London archaeobotany reference collections). A, Modern wild sorghum spikelet (*Sorghum arundinaceum*). B, Wild-type shattering spikelet impression from sherd no. 114: KG23b-C2-28. C, Wild-type shattering spikelet impression from sherd no. 82: KG23c-D3-18. D, Modern sorghum domesticated (*Sorghum bicolor*). E, Domesticated-type nonshattering impression from sherd no. 83: KG23c-C3-3. F, Modern sorghum nonshattering spikelet base showing breakage. G, Sorghum impression from sherd no. 11: KG23c-C3-24. H, Impression of empty spikelet fork from nonshattering spikelet with attached rachis clearly visible from sherd no. 9: KG23c-D3-7. I, Chaff impressions of *Bracharia* sp. from sherd no. 126: KG23c-C3-19. J, Impression of *Urochloa* sp. from sherd no. 126: KG23c-C3-19. K, Modern chaff (lemma) husks of *Bracharia ramosa* showing distinctive texture of lemma surface.

2014). However, in a few instances, the presence of empty spikelets and broken glumes (fig. 6G, 6H) might indicate the incorporation of some waste from dehusking. It is of course possible that threshing methods led to some accidental dehusking or that waste from both crop-processing stages was used as temper.

The use of threshing waste as temper also explains the presence of fine straw and leaf impressions in many sherds. Routine threshing, however, is expected only after nonshattering forms have begun to form a more substantial part of the harvest (Fuller, Allaby, and Stevens 2010). In addition, as stated, many spikelets and grains appear somewhat plump (wide), characteristic of plants undergoing grain size increase during domestication. Taken together, the evidence suggests the appearance of at least some domesticated-type plants, consistent with the assemblage falling within the predomestication cultivation stage. However, narrow spikelets and grains that characterize wild sorghum (e.g., Wasylukowa 2001) also persist into some later fully domesticated populations (e.g., Fuller 2004).

Grains of probable *Brachiaria* sp. were noted in three sherds (fig. 6I). *Brachiaria* has a distinctive texture to the lemma and palea. The distinguishing feature is the tip of the spikelet, which has a distinctive beak, and the seeds compare to *Brachiaria deflexa* or *Brachiaria ramosa* (fig. 6K) due to a somewhat thicker rugae on the rugose lemma surface. *Brachiaria* has previously been recorded in archaeobotanical assemblages, including from Nabta Playa (Wasylukowa 2001). In Sudan, both *B. deflexa* and *B. ramosa* have edible seeds, the former a cultivar today in parts of West Africa (Harlan 1992), the latter a relict cultivar in southern India, significant in prehistory (Kingwell-Banham and Fuller 2014). While *Brachiaria* occurs as weeds within cultivated sorghum fields today (see Burkill 1997:191–194), only a few spikelets of wild or immature sorghum were seen in a sherd with numerous *Brachiaria* seeds, along with occasional seeds of *Urochloa* sp. (fig. 6J), suggesting that these species may have also been targeted for harvest from the wild as a food grain.

Conclusion

The ceramic temper in the Kasala region from the second half of the fourth millennium BC provides evidence for threshing waste, including spikelets from nonshattering, domesticated-type sorghum plants. The sherds appear to contain a mixture of green-harvested panicles, mature wild-type spikelets, and nonshattering spikelets, providing evidence for the beginnings of the appearance of domesticated morphotypes, together with harvesting slightly green to maximize yields of wild morphotypes. The implication is that sorghum was being cultivated around Khashm el Girba between 3500 and 3000 BC. While further investigation is needed, it should also be noted that stone picks recovered from Butana sites have potentially been associated with cultivation (Sadr 1991:41). We therefore place the assemblage in the predomestication stage of the domestication process (as defined by Harris and Fuller 2014) and

conclude that domesticated morphotypes first evolved in Africa, not India (contra Haaland 1999); but domestication was not yet fixed in evolutionary terms.

Previously, the earliest unambiguously cultivated and domesticated sorghum was reported from Late Harappan India, ca. 2000–1700 BC (Boivin and Fuller 2009; Fuller 2003). A few earlier, less well-documented reports could even put sorghum in South Asia in the later third millennium BC during the Mature Harappan period (e.g., at Kunal and Banawali; Saraswat 2002; Saraswat and Pokharia 2003). These new data confirm that sorghum cultivation had begun at least a millennium earlier and that the sorghum translocated to India was a well-established cultivar that had already acquired domestication traits (at least in part). However, the extent to which the very first sorghum in India might have been semidomesticated (e.g., with some proportion of shattering genotypes) remains unclear, as South Asian archaeobotanical sorghum has not been subjected to the same degree of study in terms of domestication characters.

The evidence reported here points toward the eastern Sudanese savannah, including southern Atbai and the Gash delta/Kassala region, as a center for the origins of *Sorghum bicolor* cultivation. Earlier finds of sorghum in the Butana region to the west, although perhaps morphologically wild, also indicate a long tradition of sorghum exploitation in this region (Magid 1989; Stemler 1990; fig. 1). Later archaeobotanical remains preserved as impressions in clay, dating to the early second millennium BC, indicate that morphologically wild sorghum was still among harvests more than a millennium later than KG23 (Beldados and Costantini 2011; Beldados et al., forthcoming). This might potentially imply that the predomestication cultivation stage and the selection for domestication traits continued into the second millennium BC, congruent with domestication episodes for other cereals of up to 3,000 years (Fuller et al. 2014). It should perhaps be no surprise that the Butana region was likely a key region of sorghum production in the first millennium BC, when this region was incorporated into the economy of the Meroitic kingdom (Fuller 2014).

Acknowledgments

Our current archaeobotanical research (D. Fuller, C. Stevens, C. Murphy) is supported by a European Research Council grant on Comparative Pathways to Agriculture (ComPAG, 323842). Research was facilitated by a research visit to London by F. Winchell supported by the ComPAG project. We are particularly grateful to Michael Brass (University College London), whose own research interests on Sudanese archaeology brought together F. Winchell with the archaeobotanical team, and Andrea Manzo, who facilitated consultation of the ceramic collections in Italy. We also give great credit for the original 1983 excavations at KG23 involving Tony Marks, who directed the excavations, and Karim Sadr and Stephen Mbutu (deceased). We dedicate this paper to the memory of Dr. Stephen Mbutu, col-

league and friend, who one day walked out from his village in Africa and became an archaeologist.

References Cited

- Allaby, Robin G., Terence A. Brown, and Dorian Q. Fuller. 2010. A simulation of the effect of inbreeding on crop domestication genetics with comments on the integration of archaeobotany and genetics: a reply to Honne and Heun. *Vegetation History and Archaeobotany* 19(2):151–158. doi:10.1007/s00334-009-0232-8.
- Allen, Harry. 1974. The Bagundji of the Darling basin: cereal gatherers in an uncertain environment. *World Archaeology* 5:309–322. doi:10.1080/00438243.1974.9979576.
- Amblard, Sylvie, and Jean Pernès. 1989. The identification of cultivated pearl millet (*Pennisetum*) amongst plant impressions on pottery from Oued Chebbi (Dhar Oualata, Mauritania). *African Archaeological Review* 7:117–126. doi:10.1007/BF01116840.
- Beldados, Aleho, and Lorenzo Costantini. 2011. Sorghum exploitation at Kassala and its environs, northeastern Sudan in the second and first millennium BC. *Nyame Akuma* 75:33–39.
- Beldados, Aleho, Andrea Manzo, Charlene Murphy, Chris J. Stevens, and Dorian Q. Fuller. Forthcoming. Evidence of sorghum cultivation and introduced West Africa crops in the second millennium BC at Kasala, eastern Sudan. In *Plants and people in the African past: progress in African archaeobotany*. A.-M. Mecuri, C. D'Andrea, R. Fornaciari, and A. Holn, eds. New York: Springer.
- Blench, Roger. 2006. *Archaeology, language and the African past*. Lanham, MD: Alta Mira.
- Burkill, Humphry M. 1997. *The useful plants of west tropical Africa*, vol. 4. 2nd edition. Kew, UK: Royal Botanic Gardens.
- Clark, J. Desmond. 1984. Prehistoric cultural continuity and economic change in the central Sudan in the Early Holocene. In *From hunters to farmers: the causes and consequences of food production in Africa*. J. Desmond Clark and Steven A. Brandt, eds. Pp. 113–126. Berkeley: University of California Press.
- Clark, J. Desmond, and Ann Stemler. 1976. Early domesticated sorghum from central Sudan. *Nature* 254:588–591. doi:10.1038/254588a0.
- Dahlberg, Jeff A., and Krystyna Wasylkova. 1996. Image and statistical analyses of early sorghum remains (8000 B.P.) from the Nabta Playa archaeological site in the Western Desert, southern Egypt. *Vegetation History and Archaeobotany* 5:293–299. doi:10.1007/bf00195297.
- de Wet, Jan M. J., and J. P. Huckabay. 1967. The origin of *Sorghum bicolor*. 2. Distribution and domestication. *Evolution* 21(4):787–802. doi:10.2307/2406774.
- Doggett, Hugh. 1970. *Sorghum*. Harlow, UK: Longman.
- Ehret, Christopher. 1993. Nilo-Saharan and the Sharao-Sudane Neolithic. In *The archaeology of Africa: food, metals and towns*. Thurstan Shaw, Paul Sinclair, Bassey Andah, and Alex Okpoko, eds. Pp. 104–125. London: Routledge.
- . 2014. Linguistic evidence and the origins of food production in Africa: where are we now? In *Archaeology of African plant use*. Chris J. Stevens, Sam Nixon, Mary Anne Murray, and Dorian Q. Fuller, eds. Pp. 233–242. Walnut Creek, CA: Left Coast.
- Fattovich, Rodolfo, Anthony Marks, and Abbas Mohammed-Ali. 1984. The archaeology of the eastern Sahel, Sudan: preliminary results. *African Archaeological Review* 2(1):173–188. doi:10.1007/bf01117231.
- Fuller, Dorian Q. 2003. African crops in prehistoric South Asia: a critical review. In *Food, fuel and fields: progress in Africa archaeobotany, Africa praeistorica*, vol. 15. Katharina Neumann, Ann Butler, and Stefanie Kahlheber, eds. Pp. 239–271. Cologne: Heinrich-Barth-Institut.
- . 2004. The central Amri to Kirbekan survey: a preliminary report on excavations and survey 2003–04. *Sudan and Nubia Bulletin* 8:4–16.
- . 2007. Contrasting patterns in crop domestication and domestication rates: recent archaeobotanical insights from the Old World. *Annals of Botany* 100(5):903–924. doi:10.1093/aob/mcm048.
- . 2013. Observations on the use of botanical material in ceramic tempering at Gobero. In *Gobero: the no-return frontier: archaeology and landscape at the Saharo-Sahelian borderland*. Elena A. A. Garcea, ed. Pp. 241–248. Journal of African Archaeology Monograph Series. Frankfurt: Africa Magna.
- . 2014. Agricultural innovation and state collapse in Meroitic Nubia: the impact of the savannah package. In *The archaeology of African plant use*. Chris J. Stevens, Sam Nixon, Mary Anne Murray, and Dorian Q. Fuller, eds. Pp. 165–178. Walnut Creek, CA: Left Coast.
- Fuller, Dorian Q., Robin G. Allaby, and Chris Stevens. 2010. Domestication as innovation: the entanglement of techniques, technology and chance in the domestication of cereal crops. *World Archaeology* 42(1):13–28. doi:10.1080/00438240903429680.
- Fuller, Dorian Q., and Nicole Boivin. 2009. Crops, cattle and commensals across the Indian Ocean: current and potential archaeobiological evidence. *Études Océan Indien* 42–43:13–46.
- Fuller, Dorian Q., Tim Denham, Manuel Arroyo-Kalin, Leilani Lucas, Chris J. Stevens, Ling Qin, Robin Allaby, and Michael D. Purugganan. 2014. Convergent evolution and parallelism in plant domestication revealed by an expanding archaeological record. *Proceedings of the National Academy of Sciences* 111(17):6147–6152. doi:10.1073/pnas.1308937110.
- Fuller, Dorian Q., Emma Harvey, and Ling Qin. 2007. Presumed domestication? evidence for wild rice cultivation and domestication in the fifth millennium BC of the Lower Yangtze region. *Antiquity* 81:316–331. doi:10.1017/S0003598X0009520X.
- Fuller, Dorian Q., and Lisa Hildebrand. 2013. Domesticating plants in Africa. In *The Oxford handbook of African archaeology*. Peter Mitchell and Paul Lane, eds. Pp. 507–525. Oxford: Oxford University Press.
- Fuller, Dorian Q., Kevin Macdonald, and R. Vernet. 2007. Early domesticated pearl millet in Dhar Nema (Mauritania): evidence of crop-processing waste as ceramic temper. In *Fields of change: progress in African archaeobotany*. René T. J. Cappers, ed. Pp. 71–76. Groningen Archaeological Studies 5. Groningen: Barkhuis.
- Fuller, Dorian Q., Ling Qin, Yunfei Zheng, Zhijun Zhao, Xugao Chen, Leo Aoi Hosoya, and Guo-Ping Sun. 2009. The domestication process and domestication rate in rice: spikelet bases from the Lower Yangtze. *Science* 323:1607–1610. doi:10.1126/science.1166605.
- Haaland, Randi. 1995. Sedentism, cultivation, and plant domestication in the Holocene Middle Nile region. *Journal of Field Archaeology* 22:157–174. doi:10.1179/009346995791547868.
- . 1999. The puzzle of the late emergence of domesticated sorghum in the Nile Valley. In *The prehistory of food: appetites for change*. Chris Gosden and Jon Hather, eds. Pp. 397–418. London: Routledge.
- Harlan, Jack R. 1992. Indigenous African agriculture. In *The origins of agriculture: an international perspective*. C. Wesley Cowan and Patty Jo Watson, eds. Pp. 59–70. Washington, DC: Smithsonian.
- Harlan, Jack R., and Ann B. L. Stemler. 1976. The races of sorghum in Africa. In *Origins of African plant domestication*. Jack R. Harland, Jan M. de Wet, and Ann B. L. Stemler, eds. Pp. 465–478. The Hague: Mouton.
- Harris, David, and Dorian Q. Fuller. 2014. Agriculture: definition and overview. In *Encyclopedia of global archaeology*. Claire Smith, ed. Pp. 104–113. New York: Springer Reference. doi:10.1007/978-1-4419-0465-2_64.
- Hulse, Joseph H., Evangeline M. Laing, and Odette E. Pearson. 1980. *Sorghum and millets: their composition and nutritive value*. London: Academic Press.
- Kingwell-Banham, Eleanor, and Dorian Q. Fuller. 2014. Brown top millet: origins and development. In *Encyclopedia of global archaeology*. Claire Smith, ed. Pp. 1021–1024. New York: Springer Reference.
- Magid, Abdel Anwar. 1989. *Plant domestication in the Middle Nile basin: an archaeobotanical case study*. British Archaeological Report Supplement 523. Oxford: British Archaeological Reports.
- . 2003. *Exploitation of food-plants in the Early and Middle Holocene Blue Nile area, Sudan and neighbouring areas*. Complutum 14. Universidad Complutense de Madrid. Madrid: Servicio de Publicaciones.
- Manning, Katie, Ruth Pelling, Tom Higham, Jean-Luc Schwenniger, and Dorian Q. Fuller. 2011. 4500-year old domesticated pearl millet (*Pennisetum glaucum*) from the Tilemsi Valley, Mali: new insights into an alternative cereal domestication pathway. *Journal of Archaeological Science* 38(2):312–322. doi:10.1016/j.jas.2010.09.007.
- Manzo, Andrea. 2012. The investigations at site UA 14. In *Italian archaeological expedition to the eastern Sudan of the University of Naples "L'Orientale": report of the 2011 field season*. Andrea Manzo, ed. Pp. 4–6. Naples: Università degli studi di Napoli "L'Orientale."
- Marks, Anthony, and Rodolfo Fattovich. 1989. The later prehistory of the eastern Sudan: a preliminary view. In *Late prehistory of the Nile basin and the Sahara*. Leah Krzyzaniak and Michal Kobusiewicz, eds. Pp. 451–458. Poznań: Archaeological Commission of the Polish Academy of Sciences, Poznań Archaeological Museum.
- Marks, Anthony, Abbas Mohammed-Ali, and Rodolfo Fattovich. 1986. The archaeology of the eastern Sudan: a first look. *Archaeology* 39:44–50.

- M'Butu, S. 1991. The Butana lithic industry: its implication on regionalism during the Neolithic period in northeastern Africa. PhD dissertation, Southern Methodist University, Dallas.
- McClatchie, Meriel, and Dorian Q. Fuller. 2014. Leaving a lasting impression: arable economies and cereal impressions in Africa and Europe. In *The archaeology of African plant use*. Chris J. Stevens, Sam Nixon, Mary Anne Murray, and Dorian Q. Fuller, eds. Pp. 259–266. Walnut Creek, CA: Left Coast.
- Nixon, Sam, Mary Anne Murray, and Dorian Q. Fuller. 2011. Plant use at an early Islamic merchant town in the West African Sahel: the archaeobotany of Essouk-Tadmakka (Mali). *Vegetation History and Archaeobotany* 20 (3):223–239. doi:10.1007/s00334-010-0279-6.
- Peters, Joris. 1992. Late Quaternary mammalian remains from central and eastern Sudan and their palaeoenvironmental significance. In *Palaeoecology of Africa and the surrounding islands*, vol. 23. Klaus Heine, ed. Pp. 91–115. Rotterdam: Balkema.
- Sadr, Karim. 1991. *The development of nomadism in ancient Northeast Africa*. Philadelphia: University of Pennsylvania Press.
- Saraswat, K. S. 2002. Banawali, district Hissar. *Indian Archaeology: A Review* 1996–1997:203.
- Saraswat, K. S., and Anil K. Pokharia. 2003. Palaeoethnobotanical investigations at Early Harappan Kunal. *Pragdhara* 13:105–140.
- Snowden, Joseph D. 1936. *The cultivated races of Sorghum*. London: Adlard & Sons.
- Stemler, Ann B. L. 1990. A scanning electron microscopic analysis of plant impressions in pottery from the sites of Kadero, El Zakiab, Um Direiwa and El Kadada. *Archéologie du Nil Moyen* 4:87–105.
- Tanno, Ken-Ichi, and George Willcox. 2006. How fast was wild wheat domesticated? *Science* 311:1886. doi:10.1126/science.1124635.
- Wasylikowa, Krystyna. 2001. Site-75-6: vegetation and subsistence of the Early Neolithic at Nabta Playa, Egypt, reconstructed from charred plant remains. In *Holocene settlement of the Egyptian Sahara*, vol. 1. Fred Wendorf, Romuald Schild, and Kit Nelson, eds. Pp. 544–591. New York: Kluwer Academic.
- Wasylikowa, Krystyna, and Jeff Dahlberg. 1999. Sorghum in the economy of the Early Neolithic nomadic tribes at Nabta Playa, southern Egypt. In *The exploitation of plant resources in ancient Africa*. Marijke van der Veen, ed. Pp. 11–32. New York: Kluwer.
- Wendorf, Fred, and Romuald Schild. 1998. Nabta Playa and its role in north-eastern African history. *Journal of Archaeological Anthropology* 17(2):97–123. doi:10.1006/jaar.1998.0319.
- Wetterstrom, Wilma. 1998. The origins of agriculture in Africa: with particular reference to sorghum and pearl millet. *Review of Archaeology* 19(2):30–46.
- Winchell, Frank. 2013. *The Butana group ceramics and their place in the Neolithic and post-Neolithic of Northeast Africa*. Cambridge Monographs in African Archaeology 83. British Archaeological Report Series 2459. Oxford: Archaeopress.