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Image and statistical analyses of early sorghum remains (8000 B.P.) from the Nabta Playa archaeological site in the Western Desert, southern Egypt

J.A. Dahlberg[1] **and K. Wasylikowa**[2]

[1] USDA-ARS-TARS, Box 70, Mayagüez, Puerto Rico
[2] W. Szafer Institute of Botany, Polish Academy of Sciences, Lubicz 46, 31-512 Kraków, Poland

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Abstract. Carbonized grains of sorghum, with consistent radiocarbon dates of ca. 8000 B.P., have been excavated at an early Holocene archaeological site (E-75-6) in Nabta Playa near the Egyptian-Sudanese border. The objective of the investigations reported here was to classify these early sorghum grains within the known wild or domesticated races or working groups of sorghum through the use of image-analysis procedures. Image-analysis is a non-destructive analytical method that can provide rapid, repeatable, and accurate measurements of ancient cereal grains. Measurements were taken on samples representing the five major domesticated sorghum races, eight wild relatives, and samples from the Nabta Playa and Jebel et Tomat excavation sites. Statistical and clustering techniques indicated significant differences existed among the sorghums with respect to the various measurements made. Sorghum from Nabta Playa was significantly smaller, with respect to most measurements, than either the wild relatives or the five cultivated sorghums. Smaller grain size and the lack of any spikelets containing attached branchlets of the inflorescence or rachis fragments suggest that the material harvested and eaten at the Nabta Playa site were of a wild type.

Key words: Sorghum – Image analysis – Early agriculture – Egypt – Sudan

Introduction

It has been hypothesized that the first truly domestic sorghums came from the Durras of India. According to this theory, the early Bicolors were transported from Africa along the Sind-Punjab trade routes to India around 3000 B.P., and the Durras later came in from India through the Middle East and down the Nile (Harlan and Stemler 1976; Mann et al. 1983). Mann et al. (1983) indicated that the origin and early domestication of sorghum took place in north-eastern Africa, north of the Equator and east of 10°E latitude, approximately 5000 years ago. Wendorf et al. (1992) have reported that car-

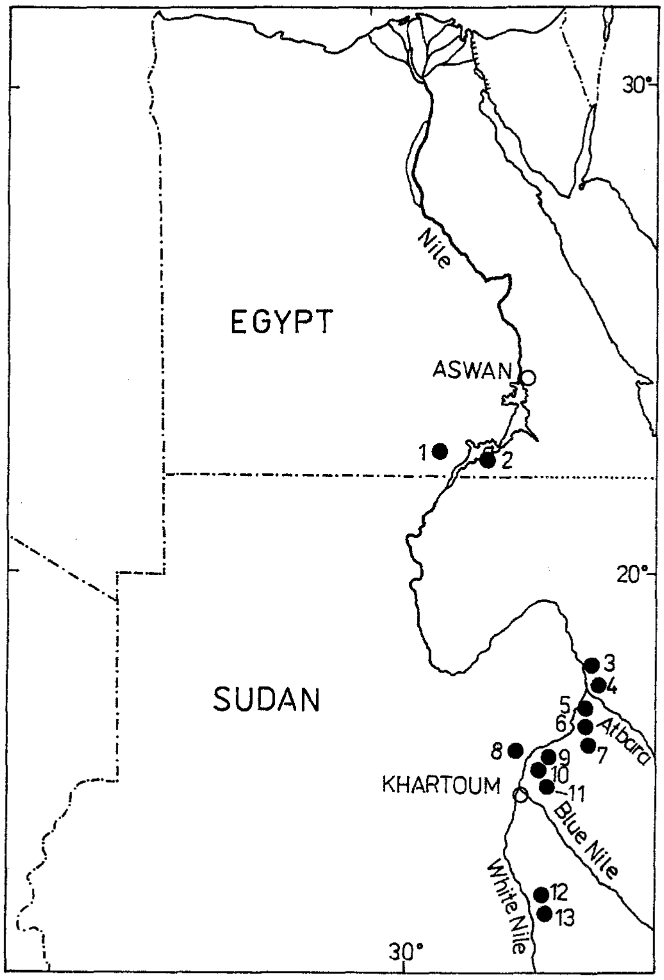

Fig. 1. Location of Nabta Playa (*1*) and other archaeological sites with early records of wild (site *3-13*) and cultivated (sites *2, 12*) sorghum in Egypt and Sudan. Quasr Ibrim (*2*), Aneibis (*3*), Abu Darbein (*4*), El Damer (*5*), El Kadada (*6*), Shaquadud (*7*), Shaheinab (*8*), Zakiab (*9*), Kadero (*10*), Um Direiwa (*11*), Jebel et Tomat (*12*), Rabak (*13*)

Correspondence to: J. A. Dahlberg

bonized seeds of sorghum with consistent radiocarbon dates of 8000 B.P. have been excavated at an early Holocene archaeological site (E-75-6) at Nabta Playa near the Egyptian-Sudanese border (Fig. 1). This material is 3000 years older and 10-15° latitude further north than had been previously reported. This new evidence may change our concepts of the origins of not only sorghum but of the agricultural process in Africa. Because of its significance, sorghum from Nabta Playa has been studied by various methods (Dahlberg et al. 1995).

The objective of this research effort was to classify, if possible, the sorghums dating to 8000 B.P. within the known wild or domesticated races or working groups of sorghum through the use of image-analysis procedures. Image analysis is a non-destructive method of obtaining quantitative measurements of a sample. Components that make up an image analysis system are a microscope, camera (video or digital), frame grabber, computer, and a viewing monitor (Whitaker 1993). The system provides a tool by which one can acquire and examine images, process and enhance those images, and record a series of various image measurements. Traditionally, quantitative measurements of archaeobotanical specimens have relied upon human interpretation; however, human estimates can be greatly influenced by level of experience, expected results, fatigue and attitude. Automation of these routine measurements can provide consistent and reproducible numbers for more detailed statistical analysis and interpretation (cf. Whitaker, 1993).

Van Zeist (1968) has outlined key terminology for use in the description of ancient cereal grains. These measurements include: (1) length (defined as the length of the grain as viewed from the ventral side from the lower to the upper end), (2) breadth, and (3) thickness. Two types of index are also presented: (1) L:B index, which is a "measure of the degree of slenderness (high L:B indices) or plumpness of the grains" and (2) T:B index expressing relative height, with flat grains showing low values for this index. Image analysis can provide more accurate measurements of traditional data, such as length and breadth, along with additional new measurements such as ArCircularity and ArRectangularity, and a series of measurements on points, lines and areas.

Materials

Materials used for this study included charred sorghum grains from the two archaeological sites, Nabta Playa in Egypt and Jebel et Tomat in Sudan, along with modern kernels from the five major races of cultivated sorghums, as described by Harlan and de Wet (1972), and their eight wild relatives (see Table 1). Modern and wild material came from the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) Sorghum National Collection.

Sorghum from Nabta Playa, site E-75-6, was described on the basis of 816 kernels, 15 spikelet fragments and a few detached glume pieces found in several huts and pits (Wendorf et al. 1992; Wasylikowa et al. 1993; Wasylikowa and Kubiak-Martens 1995). Dorsally flattened grains have long and broad embryos and small obovate hilums (Fig. 2). Dorsal grain outlines vary from obovate (most common), through broad oval to narrow oval; lateral outlines are narrow obovate to narrow oval. Embryos are longer than or equal to half of the grain length. No typical 'popped' grains are present so it is assumed that the original shapes have not changed much due to charring.

Spikelet remains include seven more or less complete specimens and eight basal portions of fertile spikelets (Fig. 2). Dorsally flattened spikelets are obovate or elliptic in dorsal outline, their thick, coriaceous glumes are longer than the grain. All spikelets have broad and smooth articulation scars and none are attached to a pedicel. Five grains from three huts have yielded AMS radiocarbon dates of 8020±120 (OxA-3217), 7980±110 (OxA-3221), 8060±120 (OxA-3222), 7950±160 (OxA-3219), and 7960±100 (OxA-3216) B.P. (non-calibrated).

The material from Jebel et Tomat, kindly provided to the authors by J. Desmond Clark, was described by Clark and Stemler (1975) as fully domesticated *S. bicolor* (L.) Moench, race bicolor (Fig. 3). Spikelets are attached to

Table 1. Details of sorghum samples used in image analysis. The race or species, identification tag or number, a local common name, and the site of origin are presented for each sample

Race or species	Identification	Local Name	Origin
Bicolor	IS 664	Saccaline	USA
Guinea	IS 3817	Bank Oumano Ziamri Fing	Mali
Caudatum	IS 930	Feterita Fulli Dueim	Sudan
Kafir	IS 10514	Tx 2508	USA
Durra	IS 1510	Vellai Cholan	India
S. hybrid	PI 219759	none	Zimbabwe
S. almum	IS 2241	none	Mexico
S. plumosum	IS 3107	none	USA
S. arundinaceum	PI 199869	none	South Africa
S. purpureserieum	PI 536008	none	Cameroon
S. versicolor	PI 439204	MN 1573	Unknown
S. virgatum	Kansas State	none	Unknown
S. halapense	IS 2695	none	Uganda
Jebel Tomat	Clark and Stemler	none	Sudan
Nabta Playa	Wendorf et al.	none	Egypt

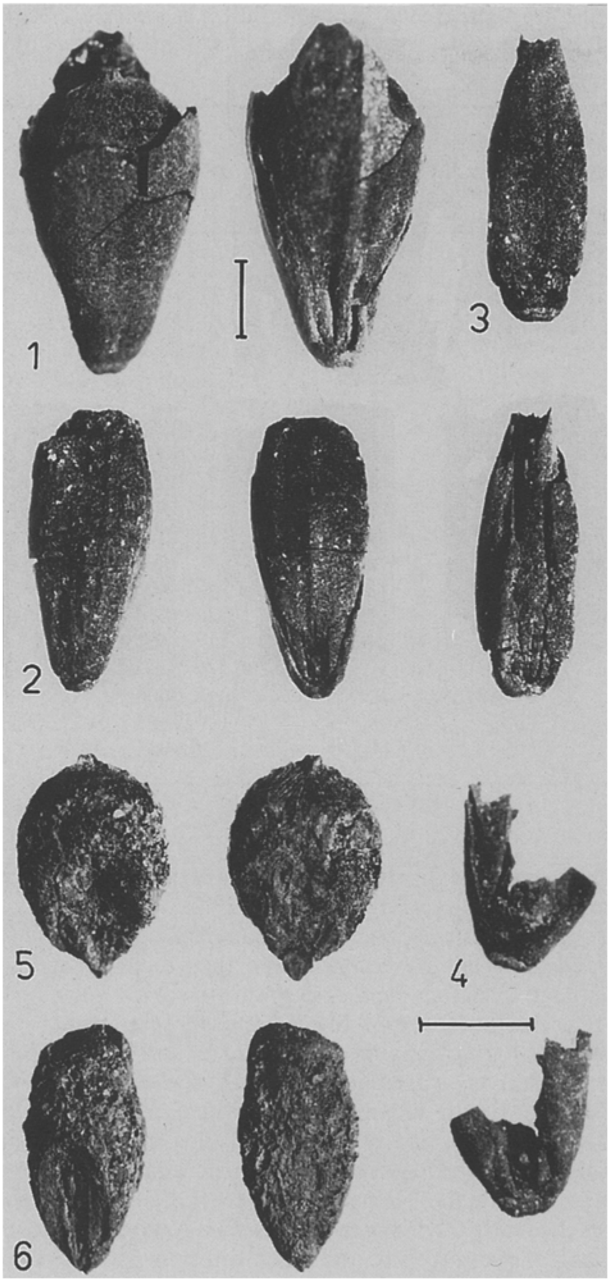

Fig. 2. Sorghum remains from Nabta Playa, site E-75-6. *1-4*, three complete spikelts and one basal fragment seen from the side of lower and upper glumes; *5-6*, two grains from dorsal and ventral sides. Magnification: 1-3, 5, 6 x10; 4 x15. Photo: A. Pacho ski

the pedicels and grains are enclosed by the glumes. Shapes of most kernels are distorted by carbonization ('popped' grains) and only better preserved grains were used in the measurements. This material has been radiocarbon dated to A.D. 245±60 (UCLA 1874M, Clark and Stemler 1975).

Methods

Present-day sorghum kernels were viewed with a Fisher Stereomaster zoom microscope and photographed with a Microage CA2063 auto shutter camera. The image was captured on Imaging Technology's CFG frame grabber board and projected onto two monitors, a Sony Trinitron PVM1343MD and a Sunshine VGA monitor. Samples from the Nabta Playa and Jebel et Tomat sites were photographed using a low-power microscope and black and white images were scanned into a computer using a Hewlett Packard ScanJet IIc. Using an IBM-compatible PC and the Optimas Boiscan software package, images were analyzed and data exported to Microsoft EXCEL for storage. The software was calibrated by capturing an image of a ruler. Employing a drawing tool, the ruler was measured and calibration data stored within the software for each level of magnification.

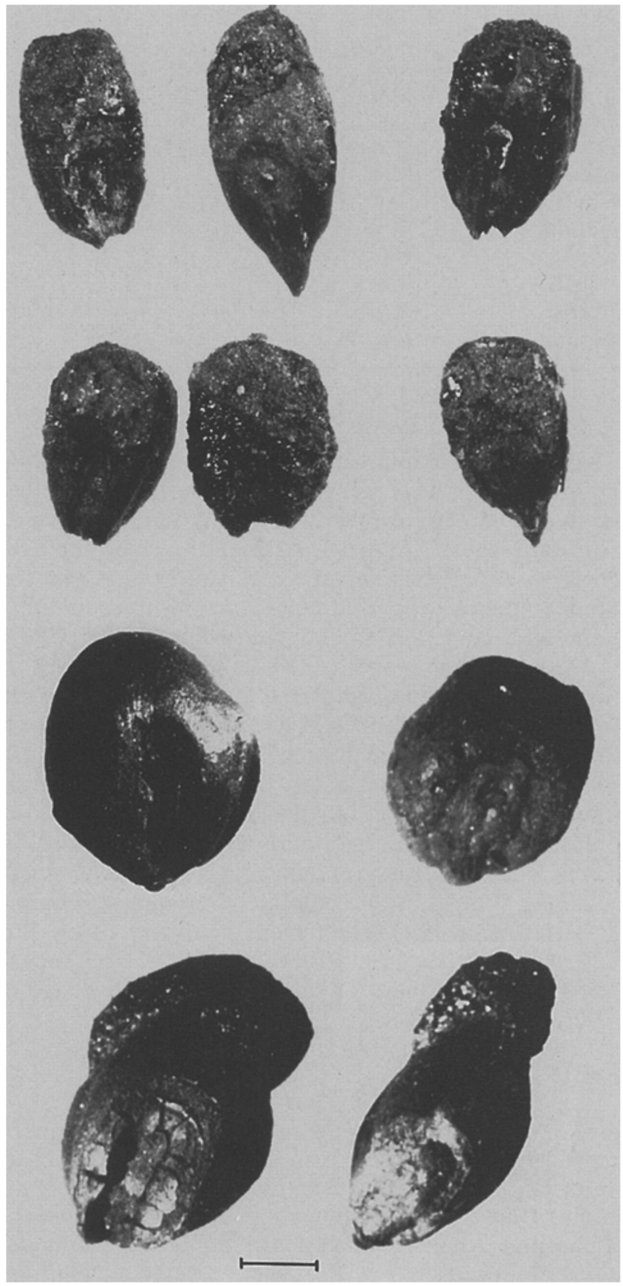

Fig. 3. Comparison of sorghum grains from Nabta Playa (two upper rows) and Jebel et Tomat (two lower rows). Magnification: x10. Photo: K. Wasylikowa

Table 2. Means for measurements taken on sorghum samples representing the five major races, eight wild relatives and samples from the Nabta Playa and Jebel et Tomat excavation sites. Means followed by different letters with regard to each particular measurement (each column), indicate significant differences using LSD (P = 0.05)

Race, species or location	No. seeds examined	ArArea (mm^2)	ArBreadth (mm)	ArCircularity	ArMajor Axis Length (mm)	ArPerimeter (mm)	ArRectangularity
Nabta Playa	169	3.254 l	1.6902 m	15.216 f	2.4790 l	6.997 m	0.77027 a
S. almum	126	3.614 k	1.6309 n	18.678 b	3.1150 j	8.168 k	0.71282 hi
Jebel et Tomat	100	3.912 j	1.8115 l	15.340 f	2.8639 k	7.728 l	0.75113 b
S. plumosum	200	4.961 i	1.9563 k	16.351 e	3.5515 h	8.990 j	0.71517 gh
S. arundinaceum	200	5.247 h	2.1601 i	16.671 e	3.3837 i	9.307 i	0.71648 gh
S. purpureserieum	200	5.401 h	2.1079 j	17.976 c	3.5683 h	9.810 h	0.71860 g
S. versicolor	125	6.126 g	2.0744 j	21.043 a	4.1721 c	11.283 e	0.70891 i
S. halapense	200	6.174 g	2.2492 h	17.469 d	3.9524 e	10.347 g	0.69435 j
S. virgatum	209	6.938 f	2.5026 g	16.252 e	3.8230 f	10.573 f	0.72553 f
Durra	200	8.187 e	2.9725 e	13.977 h	3.7036 g	10.656 f	0.73938 d
S. hybrid	200	9.199 d	2.8464 f	15.153 f	4.4017 b	11.784 d	0.73379 e
Bicolor	200	9.347 d	3.1715 d	14.691 g	4.1032 d	11.689 d	0.71580 gh
Guinea	200	10.302 c	3.3904 c	14.086 h	4.1463 cd	12.015 c	0.73106 e
Kafir	144	11.841 b	3.6218 b	14.128 h	4.4323 b	12.902 b	0.73454 ed
Caudatum	200	14.591 a	4.2298 a	13.700 h	4.6175 a	14.103 a	0.74453 c
Mean		7.482	2.6161	15.913	3.7943	10.551	0.72688
CV (%)		13.933	7.5924	13.231	8.0435	8.811	3.29827
LSD (P = 0.05)		0.222	0.0423	0.449	0.0650	0.198	0.0051

Six measurements, ArArea, ArBreadth, ArCircularity, ArMajor Axis Length, ArPerimeter and ArRectangularity (BioScan, Inc. 1992), were taken and stored on a data sheet. ArArea, ArBreadth, ArMajor Axis Length and ArPerimeter are real values that give the bounded area in calibrated units squared, the sum of the maximum distance of the boundary from either side of the major axis, the length of the major axis, and the total boundary length all in calibrated units. ArRectangularity is a dimensionless number in which the values for a circular boundary approaches 0.79 ($\pi/4$), 0.5 for square boundaries, and approximately 1.0 for long and narrow rectangular boundaries. ArCircularity is also a dimensionless number with a minimum value of 12.57 (4π) for objects with a circular boundary, 16.0 for a square boundary, and 20.78 for equilateral triangular boundaries (BioScan 1992). Data were analyzed using Proc GLM, Proc Means, Proc Prin, and Proc Cluster in SAS (1985) and clustering programs using NTSYS-pc (Rohlf 1994).

Results

Employing image analysis techniques, measurements were taken on 2673 sorghum samples representing the five major domesticated races, eight wild relatives, and samples from the Nabta Playa and Jebel et Tomat excavation sites. Analysis of variance for all measurements indicated significant differences existed among the sorghums for each measurement taken. Means, ceofficients of variation (CV), and least-significant-difference (LSD) values are presented in Table 2. In general, the specimens from Nabta Playa and Jebel et Tomat were significantly smaller with respect to most measurements than either the wild relatives or the five cultivated sorghums (Table 2), and the specimens from Nabta Playa tended to be significantly smaller than those from Jebel et Tomat. Charring can cause grains to shrink during carbonization and four of the six measurements were reanalysed using enhanced data (25% and 50% greater than actual measurement). Though some shifts in the placement of the means of the Nabta Playa sample did take place, the interpretations of the results did not change significantly (results of these analyses not presented). Both the Nabta Playa and the Jebel et Tomat sites had slightly larger means for ArRectangularity, though the significance of these differences is difficult to interpret. This was also true for ArCircularity.

Data were standardized using Z-scores and a principal components analysis was run. The first three principal components explain 99.1 of the variability within the dataset. From each of the three principal components retained, the response with the largest loads, ArArea, ArRectangularity and ArCircularity, was selected and used in another cluster analysis. The results are presented in Table 3. Three distinct clusters can be seen. The first cluster contains the wild sorghums, the second cluster contains the major cultivated races along with the sorghum hybrid, and the last cluster contains the two samples from Nabta Playa and Jebel et Tomat. Clustering was also performed using NTSYS-pc (Rohlf 1994). Using a full set of data, a phenogram was developed (Fig. 4). This phenogram clustered the samples into essentially the same groups as did the principal components analysis coupled with cluster analysis.

Table 3. Ward's minimum variance cluster analysis using three responses chosen from the retained principal components. The data have been standardized to mean 0 and variance 1. The root-mean-square total-standard deviation equals 0. The root-mean-square distance between observations equals 2.44949 [from SAS (1988) output]

	Eigenvalue	Difference	Proportion	Cumulative
1	1.9625	1.13176	0.654167	0.65417
2	0.83074	0.62397	0.276912	0.93108
3	0.20676	–	0.068921	1.00000

Cluster No.	Clusters	Joined	Freq. New Clus	Semipartial *R*-squared	*R*-squared	Pseudo *F*	Pseudo *t***2
14	Arund	Plumosum	400	0.000543	0.999457	376763.10	.
13	Guinea	Kafir	344	0.002968	0.996489	62914.57	.
12	Almum	Purpur	326	0.005588	0.990901	26343.22	.
11	Durra	Hybrid	400	0.007574	0.983327	15699.54	.
10	Jebel	Nabta	269	0.009342	0.973985	11077.89	.
9	CL14	Virgatum	609	0.011333	0.962652	8583.16	12678.26
8	CL11	CL13	744	0.014769	0.947883	6924.26	1039.52
7	Bicolor	CL8	944	0.022899	0.924984	5478.82	852.23
6	CL12	CL9	935	0.029287	0.895697	4580.55	1564.62
5	CL6	Hala	1135	0.038778	0.856919	3994.68	939.79
4	CL5	Versi	1260	0.064451	0.792468	3397.22	947.97
3	CL7	Caud	1144	0.067488	0.72498	3519.19	1598.65
2	CL3	CL10	1413	0.222575	0.502405	2696.82	2511.61
1	CL4	CL2	2673	0.502405	0.000000	.	2696.82

Race or species	ArArea	ArCircularity	ArRectangularity
		Cluster 1	
S. arundinaceum	0.62122	0.57852	0.30318
S. plumosum	0.70883	0.64692	0.14757
S. almum	1.12204	0.77069	1.28216
S. purpureserieum	0.57407	0.46696	0.93957
S. virgatum	0.10275	0.10307	0.09915
S. halapense	0.33707	1.74076	0.6925
S. versicolor	0.35183	0.97611	2.43518
		Cluster 2	
Guinea	0.92876	0.95715	0.18731
Kafir	1.40093	0.93673	0.37038
Durra	0.28044	1.01014	0.62463
S. hybrid	0.59077	0.43693	0.33117
Bicolor	0.63602	0.66182	0.61423
Caudatum	2.24416	1.14498	0.89518
		Cluster 3	
Jebel et Tomat	1.03069	0.34563	1.24163
Nabta Playa	1.23258	0.40593	2.24695

Discussion

Image analysis provides a new tool for archaeobotanists for classifying samples in a more quantitative manner. The repeatability, accuracy, and speed of measuring specimens enable a sound statistical basis to be speedily obtained of size and shape of seed from archaeological sites and this, in turn, facilitates investigation of variation within and between samples and hence interpretation.

Several early finds of sorghum have been reported in the literature. Impressions, in pottery, of wild sorghum grains and spikelets were recovered from ten sites, and charred grains, also of a wild form, are available from one site in the Central Sudan (Fig. 1) (Magid 1989, 1995; Stemler 1990). These records have been placed within the age range ca. 8500-4000 B.P. Only two impressions of a possibly stalked spikelet from Um Direiwa (ca. 5000 B.P.), were described by Stemler as slightly resembling a domesticated form but, in her opinion, this "does not

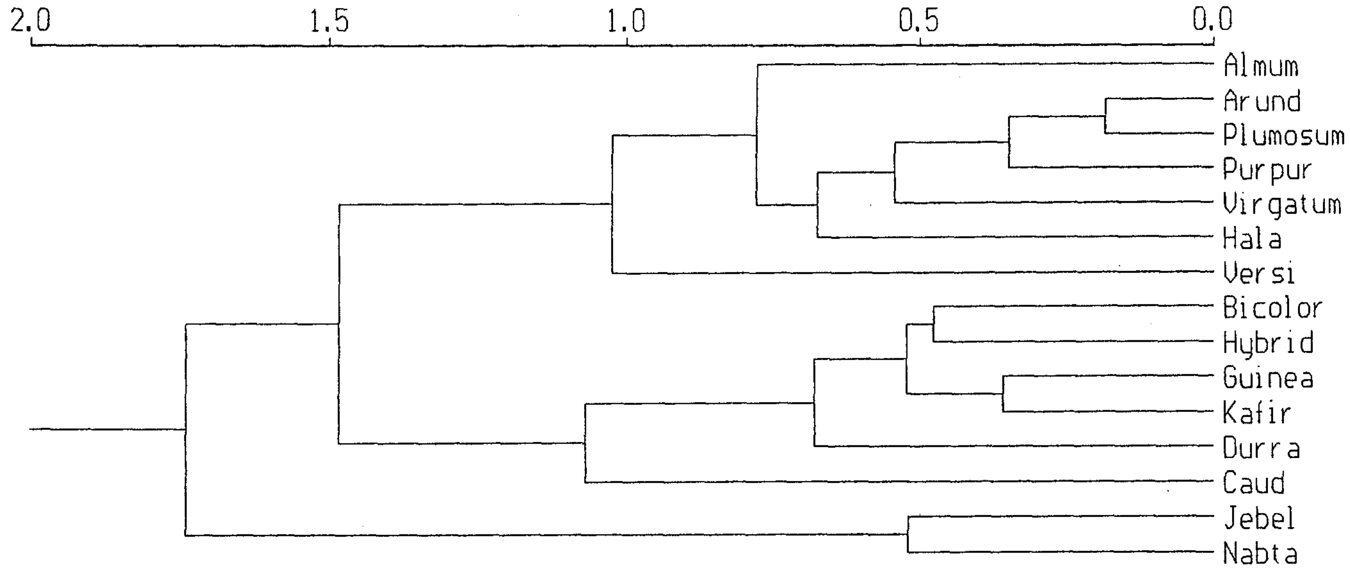

Fig. 4. Phenogram based on full data set of cultivated, wild, and sorghum samples from Nabta Playa and Jebel et Tomat

constitute clear evidence for the presence of domesticated cereals at the site" (Stemler 1990, p 92). The oldest domesticated sorghums, hitherto known from the eastern north Africa, come from Quasr Ibrim, Egypt (A.D. 100) (Rowley-Conwy 1991) and Jebel et Tomat, Sudan (A.D. 245) (Clark and Stemler 1975). However, domestic sorghum occurred in Arabia at around 4800 B.P. and possibly a millennium earlier (Potts 1993; Cleuziou and Costantini 1982). Unless one assumes that wild sorghums were carried to Arabia and domesticated there, cultivated sorghum must have existed in Africa well before that date. In any discussion on the domestication of cereals, it is normally assumed that wild species were cultivated for some time for selection of morphological characteristics of a domesticated taxon to occur. Haaland (1992), in her discussion on cultivation and domestication, concluded that around 6000 B.P., people started cultivating wild sorghum in the Khartoum region and, at that time, food production based on animal husbandry and wild grain cultivation emerged. Recently, new evidence of wild sorghum from the sites in the Atbara region, dated to 7700-8500 B.P. (Aneibis, Abu Darbein, El Damer), allowed Magid (1995) to suggest that cultivation began ca. 2000 years earlier, at a time when there is no evidence for the presence of domesticated animals (Peters 1995).

Site E-75-6 at Nabta Playa is of about the same age as the three last mentioned sites and shows no good evidence of animal husbandry. The oldest remains of sheep/goats are associated with levels dated to ca. 7000 B.P. The presence of cattle in a context dated to 8100 B.P. is possible, but not proven (Wendorf et al. 1991). The samples taken from the Nabta Playa excavation site appear to be more closely related to wild or primitive sorghums based on several grain measurements. Grain morphology alone cannot, however, answer the question as to whether or not the sorghum from Nabta was wild or domesticated. Though the sorghum grain from Jebel et Tomat was smaller and more 'primitive' in morphology than sorghums recently grown in the area, Clark and Stemler (1975) clearly identified the samples as being those of *Sorghum bicolor* spp. *bicolor*. Their conclusions were based on several spikelets that had grain still attached to the branchlets of the inflorescence or rachis fragments. Material from Nabta Playa contains only a few complete spikelets and the seed morphological data indicate that it is significantly smaller than the samples identified from Jebel et Tomat with respect to ArArea, ArBreadth, ArMajor Axis Length, and ArPerimeter. The significantly smaller grain size and the lack of any spikelets containing attached branchlets of the inflorescence or rachis fragments suggest that the material harvested and eaten at the Nabta Playa site was of a wild type.

It is clear that sorghum played an important role in the lives of the inhabitants of Nabta some 8000 years ago. What is not so clear is whether or not this find indicates sorghum cultivation that could have led to domestication. A satisfactory question awaits further evidence which will certainly become available as more sites are uncovered in Africa.

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