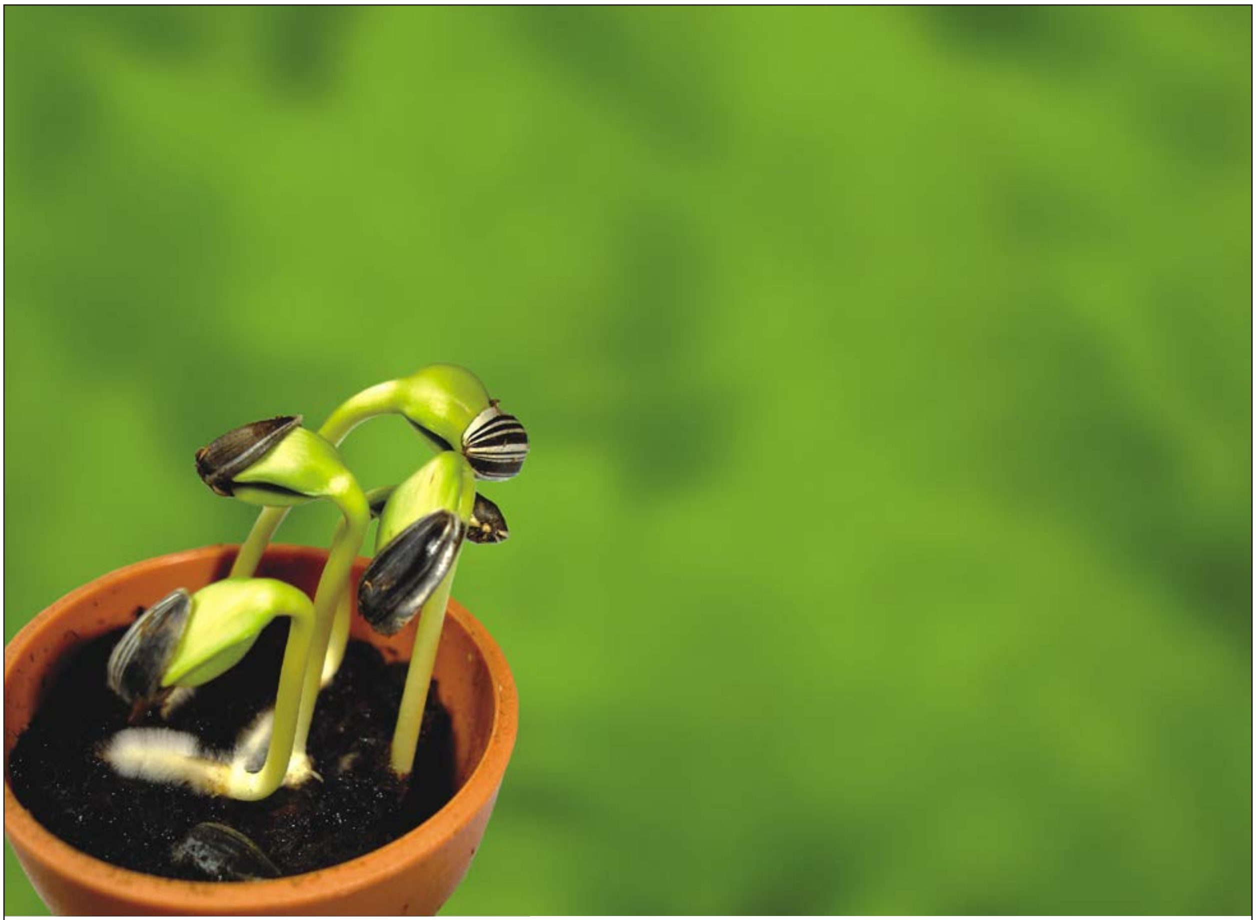

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Genetic Diversity of the Seed Physical Dimensions in Cultivated and Wild Relatives of Sesame (Genera *Sesamum* and *Ceratotheca*)

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ABSTRACT

Physical dimensions of nine morphologically distinct sesame seeds were determined in order to access the extent of variability for size. Length, width and thickness of nine accessions of sesame comprising six cultivated and three wild relatives were measured using micrometer. Other parameters were calculated using standard mathematical procedures. Mean seed length ranged from 2.65 to 3.77 mm, mean seed width from 1.49 to 2.84 mm and mean seed thickness from 0.61 to 1.28 mm. Seed geometric diameter varied from 0.81 to 3.91 mm^3 while surface area varied from 2.43 to 48.66 mm^2. Principal component analysis divided the 11 variables determined into two components which explained 88.96% of the total variation. First component (56.23%) strongly influenced seed geometric diameter, sphericity, thickness, surface area, length-thickness ratio and length. Second component (32.73%) was affected strongly by width-thickness ratio, 1000-seed weight, length-width ratio, seed oil content and width. The dendrogram generated by the un-weighted pair group method using arithmetic averages (UPGMA) cluster analysis grouped the nine accessions into five distinct clusters indicating genetic diversity. This information can be used to design processing and handling machine for sesame seeds and also to plan crosses in order to maximize the expression of heterosis for large seed size.

Key words: Correlation, dendrogram, principal components, sesame, seed sphericity

INTRODUCTION

Sesame (*Sesamum indicum* L.) is often described as the oldest oil seed plant used by humans for its edible seeds which serve as raw food as well as in confectionery; for its oil used in various industrial preparations and for vegetable oil (Khan *et al*., 2001; Yol *et al*., 2010). Sesame fruit is a capsule containing a number of oleaginous seeds which are small, ovate, slightly flattened and somewhat thinner at the hilum than at the opposite end. The testa of the seeds may be smooth or ribbed and the colour may be black, white, yellow, reddish-brown, or grey (Weiss, 1983).

In Nigeria, sesame is now ranked as the second best to cocoa in terms of export volume and value (Anonymous, 2004) and being the primary supplier of sesame seeds to the world's largest importer, Japan, its current annual export is valued at about $20 million US (Anonymous, 2002). Sesame production areas in Nigeria are located between latitudes 7-14°N, characterized by a dry season which lasts about 4-5 months and the crop is widely used and very popular in parts of the Central, North Western and North Eastern Zones where it is usually grown

(Falusi and Salako, 2001). According to Okpara *et al.* (2007), there was low yield of 300 kg ha^{-1} obtained by poor resource farmers as against 1295 kg ha^{-1} obtained under experimental station. This is an indication that there is a need to breed for high seed yielding varieties of sesame in order to meet both local and international demands.

Bedigian (2003) reported that the seed size of sesame has remained virtually unchanged. However in the latter part of the same work, it was cited that the Nuba peoples of Sudan had intentionally selected larger-seeded bitter types which is high in oil content, as well as smaller-seeded "sweet" landraces. This therefore suggested the existence of considerable variation in sesame seed size. Kumar *et al.* (2001) observed that larger seeds may result in a greater seedling reserve, better seedling vigour, a better stand establishment and ultimately more stable yield on farmers' field. Thus, breeding for large seed size is very important. However, information in this area of study is currently very scanty in sesame.

Sesame can be processed to several different stages, such as simply cleaning, or cleaning and dehulling, or cleaning, dehulling and drying, or cleaning, dehulling, drying and crushing for oil. In Nigeria, the primary processing facilities were reportedly focused almost exclusively on cleaning. However, there are no commercial crushing plants for sesame seeds (Anonymous, 2002). Physical and engineering properties of seeds are important in many problems associated with the design of machines and the analysis of the behavior of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. Studies on physical properties were reported for various crops such as hemp seed (Sacilik *et al.*, 2003); lentil seeds (Amin *et al.*, 2004); fenugreek seeds (Altuntas *et al.*, 2005); sunflower seeds (Baumler *et al.*, 2006); and linseed (Selvi *et al.*, 2006). Very few studies have been published on the physical properties of the seeds of sesame and such studies in most cases have been limited to one or few varieties which make it difficult for wide application of such findings to most varieties in cultivation.

This investigation was therefore designed to provide information on the important physical attributes in order to aid breeding activities for seed size improvement and also, to aid the design of processing and handling machines for sesame seeds.

MATERIALS AND METHODS

Twenty seeds were randomly selected from the harvested seeds of each of the eight tagged plants of nine sesame accessions studied in potted field experiment in 2005 and 2006 (Table 1). The seeds of the nine accessions are as shown in Fig. 1. This investigation was carried out at the Department of Pure and Applied Biology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. The three linear dimensions of each seed namely, length (SLT), width (SWD) and

Table 1: Name of sesame accessions studied, place of collection and germplasm type

Code/Accession No./Local name	Collection locality	Botanical name	Germplasm type
AYK (Ayigba)	Kabah	*Sesamum radiatum*	Black seeds
IBS (Eku Ile)	Bode saadu	*Ceratotheca sesamoides*	Black seeds
ALO (Eku gogoro)	Ogbomoso	*Sesamum radiatum*	Black seeds
EVA	NCRI Badeggi/FAO, Italy	*Sesamum indicum*	White seeds
S530	NCRI Badeggi	*Sesamum indicum*	Dirty white seeds
65-8B	IAR and T Ibadan	*Sesamum indicum*	Mixture of seeds
C-K2	NCRI Badeggi	*Sesamum indicum*	Brown seeds
PACH	NCRI Badeggi/FAO, Italy	*Sesamum indicum*	White seeds
69B-882	NCRI Badeggi	*Sesamum indicum*	Mixture of seeds

Fig. 1: Appearances of the seeds of the nine sesame accessions employed in the study

thickness (STH) were measured using a micrometer screw gauge with a reading accuracy within 0.01 mm. From these three linear dimensions, SLT-SWD ratio, SLT-STH ratio and SWD-STH ratio were determined. The 1000-Seed weight was measured while seed oil content (%) was determined as described by Azeez and Morakinyo (2011).

The geometric mean diameter of seed (De) which is the overall average of the three measured dimensions (i.e., Length, Width and Thickness) was determined using the equation given by Mohsenin, 1986). The seed sphericity 'Φ' (i.e., the extent to which the seed is spherical) was determined by the relation $\Phi = WT/L^2$ while the surface area 'S' was determined by the relationship given by McCabe *et al.* (2005).

Statistical analyses: Data collected were subjected to analysis of variance, Duncan's multiple range tests and correlation analysis on the SPSS software version 10. Principal component analysis was conducted on Statistical Analysis System Software (SAS, 2000) and a cluster analysis was performed based on unweighted pair group method using arithmetic averages (UPMGA) of Sokal and Michener (1958). The significant levels of the statistical analyses were described at the probability of 0.05 and 0.01.

RESULTS

The mean values of the physical seed dimensions and percentage oil content of the nine accessions of sesame are shown in Table 2. The seeds of the nine accessions varied significantly ($p<0.05$) for all the physical dimensions. Accession means showed that seed length varied between 2.65 and 3.77 mm with IBS having the highest value while C-K2 had the least value. Accession IBS had the highest seed width of 2.84 mm and this was about double the value recorded in accession C-K2 (1.49). Seed thickness also varied between 0.61 and 1.28 mm with ALO having the highest value while C-K2 had the lowest value.

Table 2: Means and standard errors for seed physical dimensions and oil content in nine accessions of sesame

	Sesame accessions								
Seed characters	AYK	IBS	ALO	EVA	S530	65-8B	C-K2	PACH	69B-882
Seed length (mm)	†3.07±0.01^{b}	3.77±0.02^{h}	3.58±0.01^{f}	3.66±0.02^{g}	3.41±0.03^{e}	3.24±0.02^{d}	2.65±0.02^{a}	3.15±0.02^{c}	3.39±0.04^{e}
	(2.75-3.50)*	(3.44-4.60)	(3.10-3.90)	(3.40-6.79)	(3.00-4.00)	(2.75-4.00)	(2.00-3.00)	(2.00-4.00)	(2.00-4.06)
Seed width (mm)	1.95±0.01c	2.84±0.01^{f}	2.55±0.02^{e}	2.57±0.02^{e}	1.95±0.01c	2.09±0.02^{d}	1.49±0.02^{a}	1.94±0.01c	1.77±0.02^{b}
	(1.43-2.20)	(2.45-2.99)	(2.10-3.31)	(2.00-2.91)	(1.00-2.50)	(1.12-2.51)	(1.00-2.00)	(1.00-2.50)	(1.00-2.36)
Seed thickness (mm)	0.78±0.02^{b}	0.95±0.01^{d}	1.28±0.01^{g}	1.20±0.01^{f}	1.15±0.02^{e}	0.86±0.01c	0.61±0.01^{a}	1.15±0.01^{e}	1.21±0.02^{f}
	(0.34-1.60)	(0.79-1.03)	(0.77-1.40)	(1.11-1.33)	(0.40-1.69)	(0.73-1.24)	(0.11-1.00)	(0.51-1.60)	(0.50-1.69)
1000-Seed weight (g)	4.30±0.01^{d}	2.00±0.02^{b}	3.59±0.02c	5.51±0.02^{e}	8.39±0.03^{b}	6.06±0.02^{f}	1.52±0.02^{a}	6.99±0.02^{g}	8.42±0.02^{b}
	(4.00-4.50)	(1.60-2.50)	(3.10-4.10)	(4.90-6.00)	(7.80-9.00)	(5.60-6.60)	(1.00-2.00)	(6.50-7.50)	(8.00-8.90)
Length-width ratio	1.59±0.01c	1.33±0.01^{a}	1.42±0.01^{b}	1.44±0.01^{b}	1.77±0.02^{d}	1.58±0.02c	1.83±0.03^{d}	1.64±0.02c	2.03±0.05^{e}
	(1.36-2.20)	(1.18-1.63)	(0.99-1.81)	(1.18-2.36)	(1.40-3.50)	(1.16-2.50)	(1.11-3.00)	(1.00-3.00)	(0.85-3.69)
Length-thickness ratio	4.37±0.10c	3.96±0.02^{b}	2.80±0.02^{a}	3.05±0.02^{a}	3.20±0.08^{a}	3.83±0.04^{b}	5.11±0.21^{d}	2.82±0.04^{a}	3.04±0.09^{a}
	(1.88-9.12)	(3.44-5.22)	(2.28-4.44)	(2.64-5.39)	(1.79-8.75)	(2.31-5.48)	(2.20-25.73)	(1.88-5.88)	(1.43-8.00)
Width-thickness ratio	2.78±0.06^{f}	2.98±0.01^{g}	2.00±0.02c	2.15±0.02^{d}	1.84±0.05^{b}	2.47±0.03^{e}	2.82±0.10^{f}	1.75±0.03^{b}	1.57±0.04^{a}
	(1.13-5.88)	(2.47-3.75)	(1.57-2.87)	(1.59-2.59)	(0.89-5.00)	(1.49-3.35)	(1.11-11.00)	(0.72-3.92)	(0.59-3.64)
Seed geometric diameter	1.55±0.04^{b}	3.40±0.02^{f}	3.91±0.03^{b}	3.78±0.03^{g}	2.55±0.05^{e}	1.94±0.03c	0.81±0.02^{a}	2.32±0.03^{d}	2.37±0.05^{d}
	(0.70-3.20)	(2.66-4.34)	(1.94-4.93)	(2.82-8.21)	(0.92-4.33)	(0.77-3.68)	(0.11-1.85)	(1.02-3.79)	(0.79-4.16)
Seed sphericity	0.16±0.01^{b}	0.19±0.01^{d}	0.26±0.01^{f}	0.23±0.01^{e}	0.20±0.01^{d}	0.18±0.01c	0.13±0.01^{a}	0.23±0.01^{e}	0.22±0.01^{e}
	(0.06-0.36)	(0.13-0.24)	(0.15-0.40)	(0.08-0.31)	(0.06-0.35)	(0.08-0.32)	(0.02-0.30)	(0.11-0.50)	(0.04-0.82)
Seed surface area (mm^2)	8.56±0.46^{b}	36.65±0.42c	48.66±0.83^{d}	45.64±1.04^{d}	22.30±0.86^{b}	12.44±0.41^{b}	2.43±0.14^{a}	17.51±0.46^{b}	19.44±0.86^{b}
	(1.55-32.18)	(22.22-59.18)	(11.83-76.28)	(25.04-212.0)	(2.66-59.02)	(1.88-42.67)	(0.04-10.73)	(3.27-45.18)	(1.98-54.39)
Percentage oil content	54.19±0.05^{b}	58.56±0.06^{e}	53.35±0.08^{a}	54.10±0.05^{b}	53.23±0.03^{a}	55.08±0.05^{d}	54.83±0.02c	55.12±0.01^{d}	54.17±0.03^{b}
	(54.01-54.32)	(58.35-58.75)	(53.02-53.58)	(53.97-54.28)	(53.12-53.30)	(54.96-55.23)	(54.77-54.90)	(55.07-55.15)	(54.08-54.26)

†Means followed by the same alphabets in the same row are not significantly different at $p = 0.05$level using Duncan multiple range test; *Ranges of values are shown in parenthesis

The 1000 seed weight ranged from 1.52 to 8.42 g with 69B-882 and S530 being the heaviest while C-K2 was the lightest. Length-width ratio ranged from 1.33 in accession IBS to 2.03 in 69B-882 while other accessions were intermediate between the two. Accession C-K2 had the highest length-thickness ratio (5.11) almost twice that recorded for ALO which had the lowest value (2.80). High variation among the accessions was observed for width-thickness ratio with accession IBS having the highest value of 2.98 while the lowest value was recorded for 69B-882 (1.57). Accession ALO had the highest seed geometric diameter (3.91) which was more than quadruple the value recorded for C-K2 (0.81). Seed sphericity ranged from 0.13 in C-K2 to 0.26 in ALO. The greatest variation was observed in seed surface area which ranged from 2.43 in C-K2 to 48.66 mm^2 in ALO. Seed oil content varied from 53.23 in S530 to 58.56 in IBS. Each accession significantly differed from every other accession.

Seed oil content (SOC) in Table 3 showed positive correlation with seed length, seed width, length-thickness ratio, width-thickness ratio but not significant ($p>0.01$). In addition, seed oil content recorded negative but non-significant correlation with seed thickness, 1000-seed weight, length-width ratio and seed sphericity. Seed length had positive and significant correlation with seed width (r = 0.874), seed thickness (r = 0.705), seed geometric diameter (r = 0.931), seed sphericity (r = 0.692) and surface area (r = 0.875). Seed width showed positive and significant correlation with seed geometric diameter (r = 0.872) and seed surface area (r = 0.862) however, its correlation with length-width ratio (r = -0.873) was negative and significant. Positive and significant correlation was recorded between seed geometric diameter and characters such as seed sphericity (r = 0.826) and seed surface area (r = 0.984) while the correlation between seed geometric diameter and 1000-seed weight (r = 0.060) was also positive but not significant.

The principal component analysis for seed physical dimensions (Table 4) revealed that the first two principal components accounted for approximately 88.96% of the total variation among the accessions. Most of the genetic variation was explained by the first principal component (56.23%), followed by the second (32.73%). The first component had high positive loadings from seed geometric diameter (0.382), seed sphericity (0.380), seed thickness (0.374), seed surface area (0.362) and seed length (0.354) and high negative loading from the length-thickness ratio (-0.361). The second component had high positive loadings from width-thickness ratio (0.429), seed oil content

Table 3: Correlation coefficients of seeds physical dimensions in nine accessions of sesame studied

Seed traits	SLT	SWD	STH	SWG	LWR	LTR	WTR	SGD	SSP	SSA	SOC
SLT (mm)	1.000										
SWD (mm)	0.874**	1.000									
STH (mm)	0.705*	0.416^{ns}	1.000								
SWG (g)	0.154^{ns}	-0.271^{ns}	0.577^{ns}	1.000							
LWR	-0.549^{ns}	-0.873**	-0.089^{ns}	0.498^{ns}	1.000						
LTR	-0.638^{ns}	-0.366^{ns}	-0.974**	-0.652^{ns}	0.096^{ns}	1.000					
WTR	-0.213^{ns}	0.174^{ns}	-0.815**	-0.831**	-0.435^{ns}	0.842**	1.000				
SGD	0.931**	0.872**	0.787*	0.060^{ns}	-0.614^{ns}	-0.717*	-0.294^{ns}	1.000			
SSP	0.692*	0.511^{ns}	0.960**	0.417^{ns}	-0.259^{ns}	-0.957**	-0.722*	0.826**	1.000		
SSA (mm^2)	0.875**	0.862**	0.725*	-0.066^{ns}	-0.632^{ns}	-0.633^{ns}	-0.222^{ns}	0.984**	0.779*	1.000	
SOC	0.218^{ns}	0.413^{ns}	-0.327^{ns}	-0.487^{ns}	-0.407^{ns}	0.322^{ns}	0.587^{ns}	0.059^{ns}	-0.260^{ns}	0.027^{ns}	1.000

**Correlation is significant at $p<0.01$ level. *Correlation is significant at $p<0.05$ level. ^{ns}: Not significant, SLT: Seed length, SWD: Seed width, STH: Seed thickness, SWG: Seed weight, LWR: Length-width ratio, LTR: Length-thichness ratio, WTR: Width-thickness ratio, SGD: Seed geometric diameter, SSP: Seed sphericity, SSA: Seed surface area, SOC: Seed oil content

Table 4: Eigenvectors and percentage explained variation by the first five principal components of seed physical dimensions of nine accessions of sesame studied

	Eigenvectors				
Seed traits	Prin 1	Prin 2	Prin 3	Prin 4	Prin 5
Seed length	0.354	0.167	0.272	0.309	0.438
Seed width	0.287	0.363	0.040	0.209	-0.001
Seed thickness	0.374	-0.183	0.029	-0.161	0.057
1000-Seed weight	0.137	-0.430	0.397	0.624	-0.099
Length-width ratio	-0.172	-0.425	0.225	-0.321	0.646
Length-thickness ratio	-0.361	0.210	-0.094	0.062	0.341
Width-thickness ratio	-0.225	0.429	-0.065	0.243	0.086
Seed geometric diameter	0.382	0.152	-0.072	-0.033	0.204
Seed sphericity	0.380	-0.111	-0.087	-0.327	-0.291
Seed surface area	0.362	0.180	-0.236	-0.149	0.320
Seed oil content	-0.046	0.381	0.796	-0.387	-0.157
Eigenvalue	6.190	3.600	0.650	0.290	0.240
Individual percentage	56.230	32.730	5.950	2.620	2.220
Cumulative percentage	56.230	88.960	94.910	97.530	99.750

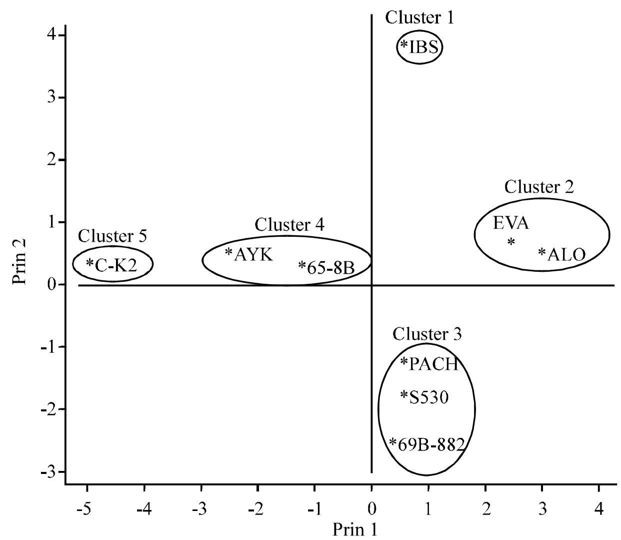

Fig. 2: The ordination of nine accessions of sesame on Principal Component Axes (PCA) 1 and 2 from cluster analysis of seed physical dimensions

(0.381) and seed width (0.362) and high negative loading from 1000-seed weight (-0.430) and length-width ratio (-0.425). However, none of the variables were redundant.

Using the principal components axes 1 and 2, the nine accessions are separated into five groups (Fig. 2). Accession IBS forms the first cluster, EVA and ALO are grouped together in the second cluster, PACH, S530 and 69B-882 form the third cluster, AYK and 65-8B form the fourth cluster while C-K2 forms the fifth cluster. A dendrogram constructed using minimum dissimilarity distance and UPGMA clustering method (Fig. 3) again discriminate among the nine accessions by dividing them into two major genetic groups (Clusters A and B). The genetic dissimilarity coefficients between accessions varied widely, ranging from 0.132 to 0.830. Two major clusters and four subgroups were revealed according to their relationship for seed dimensions and seed oil percentage.

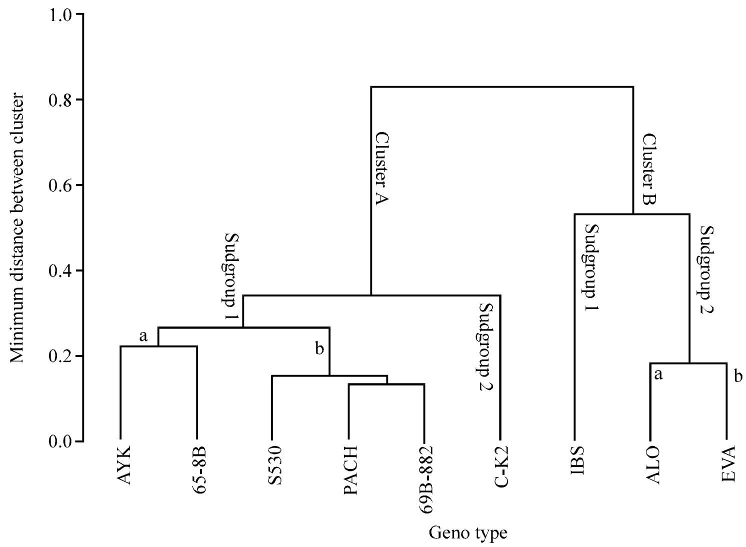

Fig. 3: Dendrogram generated based on UPGMA clustering method depicting genetic relationship among nine accessions of sesame using seed physical dimensions

Cluster A was subdivided into two subgroups such as 1 and 2 and out of these, only subgroup 1 consisted of sub-subgroups 'a' and 'b'. Subgroup 2 contained only one accession C-K2. This accession had the least values for the seed physical dimensions measured except for length-thickness ratio (5.1) which was the highest. Sub-subgroup 1a contained AYK and 65-8B accessions that were 78% similar and were closely related. Sub-subgroup 1b contained PACH and 69B-882 that were 87% similar and were closely related to S530 with a genetic distance of 0.15. These accessions in sub-subgroup 1b had the highest 1000-seed weight (7.9 g).

Cluster B was subdivided into two subgroups 1 and 2. Out of these, only subgroup 2 consisted of sub-subgroups 'a' and 'b' while subgroup 1 contained only accession IBS. Accessions ALO and EVA were 82% similar and were separated from IBS with a genetic distance of 0.53. IBS in subgroup 1 had the highest seed length (3.77 mm), seed width (2.84 mm), width-thickness ratio (2.98) and seed oil percentage (58%). ALO and EVA accessions in subgroup2 had the highest seed surface area (47 mm^2).

DISCUSSION

Physical seed dimensions such as length, width and thickness are useful in determining aperture size in the design of grain handling machinery. Adebowale *et al.* (2011) reported that the knowledge of the physical seed dimensions can enhance the selection of the size of perforations for optimum performance of the cleaner as too big or too small a hole may either result in unclean seeds or lesser efficiency of the machine. The range of values obtained for these parameters are within the range for black cumin seeds (Al-Mahasneh *et al.*, 2008), millet (Baryeh, 2002) and local variety of sesame seeds (Tunde-Akintunde and Akintunde, 2004). The range of values for seed geometric diameter obtained in this study (0.81-3.91mm) were lower than that of millet (Baryeh, 2002) and sorghum (Simonyan *et al.*, 2007) but wider than those reported by Adebowale *et al.* (2011) for sesame seeds.

The degree of sphericity ranged between 0.13 and 0.26 which is lower than the values obtained by Tunde-Akintunde and Akintunde (2004, 2007) and Adebowale *et al.* (2011) for sesame. The observed differences may be associated with variations in the genotypic background of the sesame seeds employed. However, higher degree of seed sphericity was reported for millet (Baryeh, 2002). The seed surface area in this study ranged from 2.43-48.66 mm^2 which is wider than those reported by Tunde-Akintunde and Akintunde (2004, 2007) and Adebowale *et al.* (2011) for both local and improved varieties of sesame. The forgoing implied that the information on physical seed dimension of sesame here could be used to complement already existing information in designing machine for its processing. Furthermore, accession ALO with the highest seed geometric diameter could be incorporated into breeding programme for introgression of this trait into heavy-seeded accessions like S530 and 69B-882 for sesame grain size improvement.

Positive and significant correlations observed between seed length and seed width, thickness, geometric diameter, sphericity and surface area indicate that improvement in one of these attributes will positively affect others in sesame and will consequently lead to increase in seed size. However, non significant correlation between seed oil content and the physical parameters determined suggest that increase in seed size may not necessarily lead to an increase in seed oil content. In principal component analysis, the sign of the loading indicates the direction of the relationship between the component and the variable. In this study, Seed geometric diameter, seed sphericity, seed thickness, seed surface area, seed length and seed width were loaded with positive signs (0.382, 0.380, 0.374, 0.362, 0.354 and 0.287, respectively) and exhibited high correlations. Selection based on these characters may be more efficient in screening for large seed size in sesame. This finding is in line with that of Biabani and Pakniyat (2008) on sesame who further suggested that traits with positive loading and high correlation might be influenced with the same gene or genes.

The clustering patterns using principal component analysis and dendrogram generated by UPGMA of seed physical dimensions also depict genetic relationship among the nine accessions of sesame and both are essentially similar. Accessions IBS, ALO and EVA that clustered together had large seed size based on their high values for the three physical dimensions (i.e. length, width and thickness), seed geometric diameter and surface area. Accessions S530, PACH and 69B-882 were heavy seeded with high 1000-seed weight. The foregoing demonstrates genetic diversity among the nine accessions for the traits determined. Divergent accessions may have good breeding values and accessions in the same cluster may represent members of one heterotic group. According to Genet *et al.* (2005), the maximum variability for segregation in the segregating population may be achieved by utilizing accessions from different clusters as parents of crosses. Therefore, this information can be used in the selection of parents for crosses in order to maximize expression of heterosis for large seed size in sesame.

CONCLUSION

The results of this investigation has suggested high genetic variability for physical dimensions in sesame. Information from seed size characters could be used to complement already existing data in the development of hopper and dehuller designs for sesame seeds. Selection based on seed geometric dimension, seed sphericity, seed thickness, seed surface area and seed length may be more efficient for suitable sesame genotype screening for large seed size. Furthermore, parents from distinct clusters may be selected in planning crosses for seed size improvement.

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