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Quantitative variation in seeds, seedling growth and biomass among *Acacia senegal* (L) Willd. provenances in Kenya

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Abstract

Conventionally, local seed sources are normally believed to perform better than introduced materials. However, studies show possibility of contrary results with many species such as *Acacia senegal*. The species is an economically and ecologically important tree of arid and semi-arid lands of sub-Saharan Africa. It produces gum arabic, used in land reclamation and agroforestry production. The species is however underutilized in Kenya due to lack of information on growth performance of different seed sources. Glasshouse provenance trial using seeds and soils from seven provenances in Kenya were used to evaluate interactions between seed sources and soils on growth and biomass. Seedling growth was assessed for 12 weeks in a randomized complete block design. Seed length, width, thickness and weight were measured. Seedlings height, root collar diameter, root dry weight, shoot dry weight and biomass were assessed and data subjected to univariate and multivariate analyses. No significant interaction between seed provenance and soils were evident; however, some provenances performed better across all the soils. Significant heritability and relationship between growth and environmental factors are reported. Overall, Ntumburi and Ngarendare provenances showed superior growth and plasticity. These provenances can be used tentatively as seed sources; however, field trials are recommended.

Key words: Acacia senegal, genetic diversity, glasshouse, heritability, provenance trial, seed sources

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Résumé

Par convention, on estime généralement que les semences de sources locales obtiennent de meilleurs résultats que les semences introduites. Cependant, des études montrent que cela peut être le contraire pour de nombreuses espèces, tel l'*Acacia senegal.* Cet arbre est une espèce économiquement et écologiquement importante des terres arides et semi-arides d'Afrique subsaharienne. Il produit la gomme arabique et est utilisé dans la bonification des terres et la production agroforestière. Cette espèce est pourtant sous-utilisée au Kenya en raison du manque d'informations sur les performances des différentes sources de semences en matière de croissance. Des tests de provenance effectués en serre ont utilisé des semences et des sols venus de sept endroits différents du Kenya afin d'évaluer les interactions des différentes sources de semences et de sols sur la croissance et la biomasse. La croissance des jeunes pousses a été évaluée pendant 12 semaines dans un plan en blocs aléatoires complets. La longueur, la largeur, l'épaisseur et le poids des semences ont été mesurés. La hauteur des jeunes plants, le diamètre du col des racines, le poids sec des racines, celui des pousses et la biomasse furent évalués, et les données furent soumises à des analyses univariées et multivariées. Aucune interaction significative ne fut observée entre la provenance des semences et les sols, mais certaines provenances donnaient de meilleurs résultats dans tous les sols. Une héritabilité et une relation significatives entre croissance et facteurs environnementaux sont rapportées. En général, les provenances Ntumburi et Ngarendare présentaient une croissance et une plasticité supérieures. Ces provenances pourraient être choisies comme sources de semences potentielles mais des essais de terrain sont recommandés.

Introduction

Tropical and subtropical regions are endowed with high value indigenous trees and shrubs. Among them is *Acacia senegal* (L) Willd. a multipurpose agroforestry tree species in the Leguminosae family (Raddad & Luukkanen, 2007). Globally, the species is ranked as the most commercially exploited among the Acacias (Fagg & Allison, 2004). The species has appreciable ecological and economic implications to households in ASALs of Africa by diversifying or supplementing their economy and minimizing risks that are brought about by crop and fodder scarcities (Fagg & Allison, 2004). It is also regarded as important because of little input demands and the extensive production cycle (Raddad *et al.*, 2006). *Acacia senegal* was put on the world map because of gum arabic production. This is an internationally traded commodity that has high commercial value but the species is gaining attention due to its roles in the farming systems of ASALs restoring and improving soil fertility in addition to provision of fuelwood and fodder (Ballal *et al.*, 2005). The practice in such systems is that the tree is used in gum production and fodder during the dry seasons but is used in restoring soil fertility during the wet seasons (Eisa, Roth & Sama, 2008).

Agroforestry systems based on *A. senegal* can therefore promote higher combined yield if compared to growing trees or cultivation of agricultural crops alone. Such attributes make the species suitable for agroforestry (Ballal *et al.*, 2005) and are promoted by improved use of water and ability to accumulate large biomass (Gaafar *et al.*, 2006). Additionally, the tree has shown significant role in sand dune fixation. Such traits have made the species to be preferred in traditional bush-fallow/shifting cultivation and dry lands agroforestry (Anderson & Weiping, 1992; Ballal *et al.*, 2005; Elmqvist *et al.*, 2005; Gaafar *et al.*, 2006). This system ensures optimum and sustainable utilization of the natural resources. Despite all these valuable genetic resources, *A. senegal* remains underutilized in Kenyan drylands due to insufficient knowledge on the species production systems and seed sources information (Omondi *et al.*, 2010). However, the species is successfully grown and utilized in agroforestry systems in Sudan and in West African countries (Anderson, 1988).

Acacia senegal has a wide range of distribution in Kenya and shows considerable variation in tree form, growth and gum production (Fagg & Allison, 2004). These variations commensurate well with population differences reported on the species genetic diversity studies (Chiveu *et al.*, 2009; Omondi *et al.*, 2010). For improved use in agroforestry production systems, such variations must be taken into account during seed collections. This means that selection of provenances to source planting materials is necessary. It is conventionally supposed that local seed sources are more superior to those from other sources; however, there are contrary evidences. This therefore calls for careful determination of seed sources before use as planting materials. Reports of many provenance trials have contributed to significant breakthrough in selection of seed sources (Madsen, 1995). No such trial has been performed for *A. senegal* in Kenya despite the growing interests and need for seeds by farmers (Chiveu *et al.*, 2009).

Field provenance trials for perennial species such as *A. senegal* require longer time and may not answer the immediate needs of the farmer. However, rapid and reliable results have been produced through glasshouse surrogate provenance experiments. Furthermore, glasshouse experiments in which a range of seed sources from natural populations are grown under common environmental conditions has been used successfully in forestry to assess intraspecific variation (Madsen, 1995). The success of such method however depends upon species. This includes the age at which differences appear and the ease with which they can be measured. In this study, intraspecific variation in seed and seedling morphology was examined using seed and soils collected from the seven major distribution regions of the species in Kenya.

The objectives were to evaluate the relative magnitude of variation in seeds, seedling growth and biomass traits within and among provenances of *A. senegal* in Kenya. The results will have a practical implication in future trials for raising and managing *A. senegal* agroforestry systems with the aim of determining the best adapted provenance for seed collections and raising of planting materials for improved productivity.

Materials and methods

The study was conducted in a common glasshouse condition at Kenya Forestry Research Institute (KEFRI) headquarters, Muguga. The institute is located at

01°12′55.3″ S and 36°37′45.7″ E at an altitude of 2036 masl. The mean annual temperature at Muguga is 21.4°C. Soils used in this experiment were collected from Kimalel, Ntumburi, Ngarendare, Daaba, Kitui, Turkana and Kulamawe sites where *A. senegal* naturally occurs. Four temporary plots of 100 × 100 m was established in each site and several soil samples collected all over the plots and then homogenized into one bag to represent the site. Open pollinated seeds were collected from the seven provenances and kept separately for laboratory and glasshouse experiments. The details of seed sources and their geographical locations are given in Table 1. In every provenance, fifteen individual trees were selected at a distance of 100–200 m apart depending on the distribution of trees and pod availability. The pods were collected and taken to the laboratory where seed extractions were carried out. Seeds from the fifteen trees were then bulked together to form a single seed source. In total, seven soils and seed batches were collected for this study.

Random samples of seeds were picked from each batch and used in seed characterization. Fifty seeds per provenance were used for seed length, width and thickness measurements using dial caliper, while 100 seeds per provenance were used for seed weight determination using weighing balance. A 20 × 10 × 5 m (length, width and height respectively) glasshouse with multiple ventilations was used for this study. In the glasshouse, soils were parked in clean disinfected ½ kg pots and watered to field capacity and allowed to equilibrate. Healthy seeds from each provenance were selected for germination and use in the trial. The seeds were soaked in warm water for ten seconds, surface sterilized for 3 min in 3% sodium hypochlorite, rinsed with distilled sterile water and nipped to break seed dormancy. Nipped seeds were germinated using 0.75% water agar incubated for 48 h at 28°C. Well-germinated seeds were picked with sterile forceps and planted in potted soils. Watering was done to field capacity twice a week till end of the experiment. The glasshouse temperatures ranged between 20 and 30°C during the trial period. Randomized complete block design was used whereby the soils were treated as the blocks. The experimental units were five trees plot, and each provenance was replicated five times. Regular cultural practices such as weeding and pest control were applied. The experiment ran for 12 weeks with growth assessments performed after every 4 weeks, and a final destructive sampling performed at the end of the 12th week.

Table 1 Details of geographic locations of the seven *A. senegal* provenances in Kenya (MAR, mean annual rainfall; MAT, mean annual temperature; E, east of the prime meridian; N, north of the equator; S, south of the equator)

Provenances	Latitude	Longitude	Altitude (m)	MAR (mm)	MAT (°C)
Daaba	0.535 N	37.735 E	988	325	29
Ngarendare	0.481 N	37.392 E	996	380	30
Turkana	3.755 N	34.657 E	702	225	35
Kimalel	0.469 N	35.906 E	1318	700	32
Kitui	1.358 S	37.833 E	780	800	28
Kulamawe	0.559 N	38.027 E	933	380	32
Ntumburi	0.198 N	37.517 E	1748	580	28

During the 4 weeks' seedling assessments, root collar diameter (RCD) and height were measured. At the end of the 12th week, destructive sampling was performed and RCD, height, root dry weight (RDW), shoot dry weight (SDW) and total biomass measured. The RCD was measured at 0.5 cm above the soil level using vernier caliper. For RDW and SDW, the seedlings were uprooted from the pots and roots washed thoroughly using running water. The seedlings were then cut into two at root collar separating roots from shoots and oven-dried at 78°C for 24 h then weighed using precision weighing balance. Total biomass was calculated as the sum of RDW and SDW.

Statistical analysis

Seed length, width, thickness, weight, seedling height, RCD, RDW, SDW and total biomass was subjected to statistical analysis. Summery statistics including means and standard error of means for each trait was performed. Analysis of variance (ANOVA) was performed to test the effects of provenance on the measured variables and how provenances performance differed in different soils. By treating provenances as random effects, variance components and narrow sense heritability were estimated following Williams, Matheson & Harwood (2002). Least significance difference (LSD), coefficients of variation and Shannon's diversity indices were calculated. Regression analysis was used to determine the relationship between the environmental and growth factors. Correlation analysis was also performed to determine the relationships between the different seed and seedling traits. Hierarchical cluster analysis was performed to reveal how the provenances have differentiated. Analysis was performed using GenStat 13th Edition (Payne *et al.*, 2010).

Results

The summery statistics for all traits are as shown in Table 2. At the end of 3 months, 99% seedling survival was recorded. The Shannon–Wiener diversity indices of both seed and seedling traits are as shown in Table 3. The highly variable trait among the seed sources was seed length and width (both at $H = 4.791$) followed by seed thickness ($H = 4.785$). The least variable trait was seed weight ($H = 2.675$). Seed width recorded the highest diversity in Kitui provenance ($H = 5.009$), while higher variability of seed length was observed in Daaba ($H = 5.01$). Lowest variation was recorded in Kulamawe for all seed characteristics (Table 3). For other growth parameters such as biomass, height and RDW, highest diversity was recorded in Ntumburi provenance (Table 3). The provenance that showed higher mean intrapopulation genetic diversity based on all the morphometric traits was Turkana ($H = 3.949$) followed by Daaba ($H = 3.945$), while the least diverse provenance was Kulamawe ($H = 3.401$).

Among the provenances, Ntumburi generally showed superior growth performance against other provenances in almost all seedling traits except height, which Kulamawe recorded the highest score (Table 3). Ngarendare provenance also showed superior performance in most traits. Turkana provenance showed least value in height growth, RDW, SDW and biomass. The least RCD was recorded in Kimalel provenance. Ntumburi provenance proved to be superior in all the soils used in this study and Ngarendare came in second (Data not shown).

Higher values of coefficient of variation (CV %) were observed in almost all growth traits except seed weight (1.6%) revealing higher level of genetic diversity among the provenances. The CV% ranged from 1.6 to 47.2% for seed weight and RDW, respectively (Table 2). In comparing seedling growth rates between the first and third measurements, Kimalel provenance recorded the highest height growth (4.74 cm) followed by Kulamawe (3.72 cm) and Daaba (2.89 cm). However, Ntumburi showed superior RCD growth of 0.134 cm followed by Ngarendare (0.12 cm) and Kitui (0.11 cm) provenances. Higher growths were recorded in provenances from semi-arid ecological zones compared with those from arid zones. The ratio of RDWs to SDW s were larger in Ntumburi (0.52) followed by Ngarendare (0.48) and Kitui (0.46). Narrow sense heritability was high with height recording the highest value (0.869) followed by seed weight (0.857) as shown in Table 2.

Analysis of variance (ANOVA) showed significant differences among the provenances for all growth parameters (Table 4). Regression analysis of growth and environmental factors showed significant positive linear relationship implying that favourable climatic conditions of the provenances were reflected in seed sizes and promoted seedling growth ($R^2 = 0.332$; $P = 0.012$).

Correlation coefficients (r) between the traits are as presented in Table 5. There were significant positive relationships between most of the growth and seed parameters. However, RDW/SDW did not show significant relationship with most of the traits except that of RDW at $P < 0.05$. Comparing seed traits against seedling growth, there were significant positive correlations except for RDW with seed characteristics. Hierarchical cluster analysis revealed three major groups separating eastern and western Rift Valley *A. senegal* populations. Isolated group of only Kitui provenance was observed (Fig. 1).

Discussion

Acacia senegal has a wide distribution in Kenya with significant on-farm potential for environmental conservation and sustainable livelihoods (Fagg & Allison, 2004). Despite slow pace in on-farm use in east Africa, the species has been successfully adopted into farms for crops and gum arabic production in West Africa and Sudan (Ballal *et al.*, 2005). However, establishment of agroforestry systems with high-quality planting materials that are adapted to local conditions is paramount (Barnes *et al.*, 1999). Furthermore, for successful establishment of managed plantations, less variability of seedling growth parameters is desirable (Wanyancha, Mills & Gwaze, 1994). However, trees used in agroforestry systems are semi-domesticated and normally show great variability in growth traits which should be used in selection for superior materials (Wolde-Meskel & Sinclair, 2000). The present study shows that the provenances are significantly different in both seed and growth variables, and exhibits considerable amount of genetic variability. Seed length and width, seedling height, biomass, RDW, SDW and the ratio of RDW to SDW emerged as the traits that contributed significantly to the provenance variation. These findings are similar to those reported for *Acacia senegal* (Chiveu *et al.*, 2009), *Cordia africana* (Loha, Tigabu & Fries, 2009), broad leaved species (Cundall, Cahalan & Connolly, 2003) and *Magnolia officinalis* (Shu, Young & Yang, 2012). These could be attributed to the genetic characteristics of the

Table 2 Overall means and standard errors for seed and growth traits of the seven *A. senegal* provenances at 12 weeks in the glasshouse (The experiment was replicated five times; seed weight represents the weight of 100 seeds)

Trait	Daaba	Kimalel	Kitui	Ngarendare	Turkana	Ntumburi	Kulamawe	Mean	CV%	LSD	Heritability
Seed length (mm)	11.16 ± 0.07	8.71 ± 0.12	8.33 ± 0.14	10.20 ± 0.22	9.93 ± 0.09	11.13 ± 0.21	11.54 ± 0.10	10.14 ± 0.14	10.20**	0.041	0.845**
Seed width (mm)	10.52 ± 0.27	9.19 ± 0.12	8.59 ± 0.07	10.22 ± 0.10	9.13 ± 0.11	11.45 ± 0.13	11.01 ± 0.09	10.02 ± 0.13	15.20**	0.010	0.845**
Seed thickness (mm)	1.77 ± 0.03	1.59 ± 0.04	1.22 ± 0.02	1.67 ± 0.04	1.54 ± 0.03	1.99 ± 0.053	2.18 ± 0.03	1.71 ± 0.04	9.90*	0.039	0.842**
Seed weight (g)	15.13 ± 0.02	8.58 ± 0.04	8.11 ± 0.03	12.43 ± 0.04	11.06 ± 0.04	20.24 ± 0.22	20.92 ± 0.06	13.78 ± 0.06	1.60	0.262	0.857**
$Height_1$ (cm)	10.99 ± 0.25	9.27 ± 0.44	10.40 ± 0.35	12.78 ± 0.39	09.26 ± 0.29	14.25 ± 0.28	12.62 ± 0.51	11.37 ± 0.36	19.14	1.031	0.742**
$Height_2$ (cm)	13.12 ± 0.68	12.39 ± 1.25	11.70 ± 0.71	14.03 ± 0.50	10.43 ± 0.69	14.97 ± 0.39	15.15 ± 0.70	13.11 ± 0.70	23.12	1.561	0.855**
$Height_3$ (cm)	13.88 ± 0.51	14.01 ± 0.84	12.60 ± 0.59	14.50 ± 0.46	11.85 ± 0.49	15.60 ± 0.37	16.34 ± 0.55	14.54 ± 0.54	28.55*	2.076	0.869**
Root collar $diameter_1$ (cm)	0.29 ± 0.01	0.26 ± 0.01	0.28 ± 0.01	0.31 ± 0.01	0.27 ± 0.01	0.31 ± 0.01	0.31 ± 0.01	0.29 ± 0.01	12.28	0.017	0.798**
Root collar $diameter_2$ (cm)	0.36 ± 0.01	0.29 ± 0.01	0.34 ± 0.01	0.38 ± 0.01	0.33 ± 0.01	0.37 ± 0.01	0.34 ± 0.01	0.39 ± 0.01	12.59	0.023	0.802**
Root collar $diameter_3$ (cm)	0.39 ± 0.01	0.31 ± 0.01	0.39 ± 0.01	0.43 ± 0.01	0.37 ± 0.01	0.44 ± 0.01	0.40 ± 0.01	0.46 ± 0.01	13.32*	0.029	0.758**
Root dry weight (g)	0.37 ± 0.01	0.31 ± 0.02	0.45 ± 0.07	0.59 ± 0.04	0.31 ± 0.01	0.65 ± 0.02	0.41 ± 0.03	0.45 ± 0.05	47.20**	0.107	0.813**
Shoot dry weight (g)	1.07 ± 0.07	1.05 ± 0.11	0.98 ± 0.08	1.22 ± 0.07	0.85 ± 0.05	1.25 ± 0.05	1.24 ± 0.08	1.07 ± 0.10	40.10**	0.205	0.747**
Biomass (g)	1.43 ± 0.08	1.36 ± 0.13	1.43 ± 0.10	1.81 ± 0.09	1.16 ± 0.05	1.90 ± 0.06	1.43 ± 0.10	1.52 ± 0.13	35.30**	0.252	0.808**

Underscore 1, 2, 3 represents the first, second and third measurements in the glasshouse.
*Significant at $P < 0.05$.
**Significant at $P < 0.001$.

Table 3 Estimates of Shannon's diversity index (*H*) for the seven provenances of *A. senegal* in Kenya using five seedling and four seed morphometric parameters

	Shannon's diversity Index (*H*)							
Trait	Daaba	Kimalel	Kitui	Kulamawe	Ngarendare	Ntumburi	Turkana	Mean
Biomass	3.503	3.409	3.469	3.408	3.509	3.539	3.519	3.479
Height	3.533	3.492	3.519	3.447	3.538	3.546	3.526	3.514
Root collar diameter	3.551	3.542	3.549	3.453	3.550	3.545	3.550	3.534
Root dry weight	3.534	3.458	3.266	3.380	3.486	3.537	3.531	3.456
Shoot dry weight	3.482	3.382	3.448	3.403	3.501	3.532	3.502	3.464
Seed length	5.010	5.006	5.002	3.910	5.001	4.598	5.009	4.791
Seed width	4.998	5.006	5.009	3.910	5.008	4.602	5.007	4.791
Seed thickness	5.004	4.995	5.003	3.907	4.995	4.587	5.003	4.785
Seed weight	2.890	2.890	2.890	1.792	2.890	2.485	2.890	2.675
Mean (*H*)	3.945	3.909	3.906	3.401	3.942	3.775	3.949	3.832

Table 4 Analysis of variance (ANOVA) for five seedling morphological and four seed parameters among seven provenances of *A. senegal* in Kenya

Trait	Mean square	Variance	*P*-value
Seed length	78.056	72.82*	<0.001
Seed thickness	4.899	72.97*	<0.001
Seed width	56.837	57.94*	<0.001
Seed weight (100 seeds)	162.939	3345.77*	<0.001
Height	79.600	7.25*	<0.001
Root collar diameter	0.066	26.27*	<0.001
Shoot dry weight	0.440	2.82**	0.011
Root dry weight	0.615	14.19*	<0.001
Biomass	2.410	8.22*	<0.001

*Significant at $P < 0.001$.
**Significant at $P < 0.05$).

source populations. Through cluster analysis, the provenances grouped into three clusters separating western and eastern Rift Valley groups as was reported by Omondi *et al.* (2010) and one isolated group of Kitui provenance. These observations are supported by population genetic studies of Kenyan populations of *A. senegal*. Genetic diversity and population structure study of *A. senegal* in Kenya using both ISSR and RAPD markers by Chiveu *et al.* (2008) showed higher genetic diversity and revealed two clusters for the populations. These findings were further corroborated by quantitative study of the same populations by Chiveu *et al.* (2009), which registered significant genetic diversity with specific outstanding diversity observed in seed characteristics. However, Chiveu *et al.* (2009) realized highest diversity index in seed weight contrary to the present study that recorded least diversity. This difference may be attributed to sample size as Chiveu *et al.* (2009) used weight of 1000 seeds, while the present study used weight of 100 seeds. Despite this difference, these studies in their recommendations stressed the need for stratified sampling along the diversity fault lines for improvement programs.

Similar results were reported by Omondi *et al.* (2010) with slight differentiation into regions. These variations offer opportunities for seed source selections and tree improvement programs. Significant provenance diversity have been reported in many other studies involving seedling growth for a number of useful agroforestry tree species, including *Acacia albida* (Sniezko & Stewart, 1989), *A. nilotica* ssp. *indica* of the Indian provenance (Krishan & Toky, 1996), *Gliricidia sepium* (Salazar, 1986), *Brachystegia spiciformis* (Ernst, 1988) and some Central American multipurpose trees (Ngulube, 1989). These variations have been attributed to genetic differences, which are useful in selection for adaptation. In this connection, diversity reported here is an indication of a good scope of genetic improvement because there is a possibility of achieving genetic gains by selecting suitable seed sources (Krishan & Toky, 1996). Such variation would generally be expected from trees species with a wide geographical distribution as *A. senegal*. Furthermore, contrary to the need for uniformity in intensively managed plantations, there may be advantages in maintaining variability in agroforestry, especially in semi-arid areas where large and uncontrollable variation in environmental conditions

Table 5 Correlation coefficient (*r*) among seedling traits and geographical variables of *A. senegal* provenances in Kenya

	Biomass	Height	RCD	RDW/SDW	RDW	SL	ST	SWT	SW	SDW
Height	0.786**									
RCD	0.964*	0.679**								
RDW/SDW	0.214	−0.321	0.286							
RDW	0.893**	0.571**	0.857**	0.571**						
SL	0.571**	0.643**	0.607**	−0.5	0.179					
ST	0.714**	0.857**	0.679**	−0.464	0.357	0.929*				
SWT	0.679**	0.75**	0.714**	−0.393	0.321	0.964*	0.964*			
SW	0.786**	0.821**	0.75**	−0.286	0.464	0.857**	0.964*	0.929*		
SDW	0.929*	0.929*	0.857**	−0.107	0.714**	0.714**	0.893**	0.821**	0.929*	

RCD, root collar diameter; RDW, root dry weight; SDW, shoot dry weight; RDW/SDW, ratio of RDW and SDW; SL, seed length; ST, seed thickness; SW, seed width; and SWT, seed weight.
*Correlation is significant at 0.01 level.
**Correlation is significant at 0.05 level.

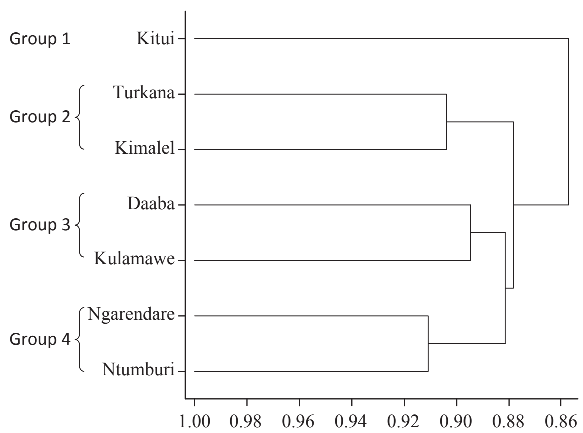

Fig 1 Hierachical cluster analysis dendrogram derived from analysis of nine phenotypic characteristics of seven *Acacia senegal* provenances in Kenya

exists (Wolde-Meskel & Sinclair, 2000). The extant variability provides ample biological resources to improve agroforestry trees with respect to growth and yield, nitrogen fixation, or canopy structure (Wolde-Meskel & Sinclair, 2000).

Against the expectations of established theories, two provenances, Ntumburi and Ngarendare showed superior performance in most of the soils. This did not support the long-held belief that plant populations are adapted to their local environmental conditions; hence, local provenances would perform better than the others in soils from these populations (Ginwal, 2009). Similar results were reported in Niger where exotic provenances of *A. senegal* performed better than local materials. However, such observation might be temporal and changes may occur at later growth stages where local provenances would outperform nonlocal seed Sources. Provenance trial in Burkina Faso involving fourteen provenances showed no significant growth differences at age 3, but significances were later reported at the age of five where local material became superior (Raebild, Grandal & Ouedrago, 2003).

Generally, *A. senegal* differentiates into four growth forms known as variety *senegal*, *kerensis*, *leiorhachis* and *rostrata* (Brenan, 1983). Three of these growth forms, *kerensis*, *senegal* and *leiorhachis,* are found in Kenya. Variety *kerensis* and *senegal* are known to develop into shrubs, bushes or small trees with moderate height depending on the environmental conditions while *leiorhachis* normally grows into a tall whippy tree (Fagg & Allison, 2004). From the present study and based on this knowledge, Kulamawe provenance which showed superior height growth may actually be *leiorhachis* believed to be found within this area (Omondi *et al.*, 2010). Therefore, the provenance differences reported here might also be attributed to the different growth forms of the species found in the country.

All phenotypic correlations were high and statistically significant indicating the possibility of selection in one trait while obtaining a gain in another. The significant positive correlation between seed and seedling characteristics can be attributed to the ability of seeds to store food needed during the active germination and seedling development of roots and shoots (Chiveu *et al.*, 2009). This translates to the theory of the bigger the seed size, the higher the amount of food reserve and the faster the seedling growth. Furthermore, favourable environmental condition of the provenances may have promoted healthy seed production latter reflected in seedling growth and development. This was exhibited by the significant positive relationship between the overall provenance environmental factors and seedling growth parameters. Similar results were also reported for *Dalbergia sissoo* (Singh & Pokhriyal, 2000), *Celtis australis* (Singh, Bhatt & Prasad, 2006) and *Magnolia officinalis* (Shu, Young & Yang, 2012).

Coefficients of variation percentage for various traits were significantly different. The presence of such difference among populations might have been brought about by different intensities of natural selection acting upon these traits in their natural habitat. Some of the variation may also be associated with the relative small number of trees from which seeds were collected in each provenance (Ginwal *et al.*, 2004). However, high heritability values at 12 weeks indicate that selection would be efficient and effective at this age. This is supported by Dvorak *et al.* (1998) who in his study concluded that heritability of growth traits of some forest tree species do not change significantly between seedling and sapling stages. However, it would be important to do further test beyond 12 weeks. Heritability estimates reported here are quite high in comparison with findings reported for other species such as eucalyptus which are in the range of 0.07–0.19 (Pinopusarerk *et al.*, 1996; Vargese *et al.*, 2008). However, higher heritability for RCD and height has also been reported for other tropical hardwood species (Pinopusarerk *et al.*, 1996; Hodge *et al.*, 2002; Rochon, Margolis & Weber, 2007).

Some local seed source in the present study ranked low in seedling growth parameters (Kitui and Turkana) in comparison with others. This is an indication that there is an ample scope of selection of outstanding genotypes from the materials under study and introduction of superior provenance for agroforestry productivity. Furthermore, large variation among the seven *A. senegal* provenances is statistically significant and is consistent with earlier observations. These variations are quantitatively large enough to warrant selection of best performing provenances in a large number of soils. Results show clearly that Ntumburi provenance is the best performer in growth traits hence can be selected as a source of planting material. Apart from this, Ngarendare provenance has also shown good performance. However, further knowledge of field growth performance is highly recommended. Field trials are also advisable when studying growth in relation to factors, such as drought, nutrition or nitrogen fixation, in unimproved wild agroforestry species such as *A. senegal*. This may improve the quality of information gained from experiments and directs proper decisions on seed sources.

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