International Scholars Journals

African Journal of Wood Science and Forestry ISSN 2375-0979 Vol. 3 (8), pp. 178-190, August, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

A study of variation in *F. albida* seeds morphological characteristics, germination and early seedling growth

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Accepted 22 May, 2015

Faidherbia albida **is an important agroforestry tree species widely distributed across parklands and agricultural systems in Africa. The demand to scale it up in similar agroecologies outside their natural distribution range in agricultural systems in Eastern Africa is increasing. The demand is caused by the observed enhancement of crop yields under mature** ***F. albida*** **trees canopies. There are around 132 provenances of** ***F. albida*** **in Africa all displaying differences in seed, germination and seedling growth characters and therefore recommending which provenance (s) for where is a big challenge. Therefore understanding seed morphology, germination and seedling growth of some provenances is an important step in helping identify which provenances could be proposed for establishment in Eastern Africa. The purpose of the study was to determine provenance variation in** ***F. albida*** **seeds morphological characteristics, germination and early seedling growth. Six provenances namely Chinzombo, Wagingombe, Taveta, Maseno, Lake Koka and Awassa were used in the study. The study revealed highly significant differences among provenances in all studied parameters except for seedling height at month 2 to 5. Highest variation among provenances in seed traits was observed in seed weight while seed thickness had the lowest variation. Overall mean germination among provenances was 70.2% varying from 32.7 to 93.3%. Significant correlation was found between seed length and collar diameter and between temperature and collar diameter. The observed variation will enable selection of provenances with desired traits for tree improvement and recommendation of specific provenances for different sites. It can be concluded that since the period of this study was short (5 months), further progeny tests should be undertaken on these provenances in the field over a longer period so as to obtain more information on the identified traits before a general conclusion is made.**

Key words: Agroforestry systems, germination capacity, germination energy, growth performances, integration, provenance variation, seed characters, seedling traits, selection.

INTRODUCTION

A major decision in forest management is the selection of seed sources for reforestation to ensure a successful crop (Shu et al., 2012). This decision could be assisted by seed zone and seed transfer rules, by determining the size of seed zones thereby reducing the risk of planting poorly adapted trees (Hamann et al., 2000) and ensuring the use of well-adapted planting stock (Ibrahim et al., 1997).

Variations in seed morphological characteristics, germination and seedling growth among provenances of the same species have been reported for many forest trees including *Faidherbia albida* (Dangasuk et al., 1997). Variation among the provenances might be attributed to genetic differences caused by the adaptation of different provenances to diverse environmental conditions (Ginwal et al., 2005) and soil types (Elmagboul et al., 2014).

F. albida (Del.) A. Chev. (Synonym: *Acacia albida* Del.), commonly known as; Apple-Ring Acacia, Ana tree, and Winter Thorn (Barnes and Fagg 2003), is a multipurpose leguminous tree species belonging to the mimosoideae subfamily (Dangasuk et al., 2011). It is widespread and commonly found throughout tropical Africa from Senegal to Sudan and as far as Natal and Angola (Danthu et al., 2002). It is very important for soil conservation and soil fertility improvement throughout the arid and semi-arid areas (Dangasuk et al., 2011). The fallen leaves serve as mulch that protects the soil from erosion thereby improving soil organic matter and nutrient contents, which reduce evapotranspiration and increases infiltration (Gassama-Dia et al., 2003). *F. albida* provides food, fuel, timber and medicine for man; it also provides shade and fodder to the livestock (Kiros et al., 2009). Its flowers provide bee forage (Barnes and Fagg, 2003).

Despite its numerous benefits, breeding and conservation of the species still remain a challenge (Koech et al., 2014). All of the existing *F. albida* trees growing today are believed to have originated by natural regeneration (Weber and Hoskins, 1983). An attempt to domesticate it in Chad and Niger failed (Dangasuk et al., 2006); this could be due to paucity of adequate information and lack of understanding of its genetic diversity and breeding biology (Dangasuk et al., 2006). Although seed traits play an important role in seed germination and seedling growth, there is insufficient information on variation in seed morphological characters of *F. albida* and its effect on germination and seedling growth especially on the selected provenances and its suitability to Eastern African regions. Dangasuk et al. (1997) and Ibrahim (1996) studied the extent of genetic variation in seed and seedling traits of *F. albida* from different provenances but there is insufficient information on the variability of *F. albida* among the provenances selected for this study. Variability studies are needed for higher productivity and future breeding work. Information on morphological variation in seed characteristics amongst the provenances of a species has been reported to be useful for tree improvement programs (Singh et al., 2010). A study on seed morphological, germination and early seedling traits of the different provenances of *F. albida* at nursery stage will help evaluate the suitability of certain provenances of *F. albida* in the area of study and also in Rwanda, Tanzania, Ethiopia and Zambia. It will also help in providing planting materials for agroforestry and to encourage increased cultivation and domestication of the species and its integration into agrarian system.

Domestication of indigenous trees species through agroforestry is one of the major ways of land use transformation in Africa by establishing a better balance between food security and natural resource utilization (Fandohan et al., 2010). Takuathung et al. (2012) also noted that selection of the best provenance of a species for a given site or region is necessary to achieve maximum productivity in agroforestry. Thus the objective of this study was to evaluate the variation existing in different provenances of *F. albida* based on seed morphological characteristics, germination and early seedling growth so as to obtain the most suitable provenances for the production of quality seedlings (planting materials) for mass afforestation in agroforestry systems.

MATERIALS AND METHODS

Study sites

This study was carried out between June and December 2014 at the World Agroforestry Centre in Nairobi, latitude 1°33'S, longitude 37°14'E and altitude of 1580 m above sea level. ICRAF is located about 20 km north-east of Nairobi, Kenya with a mean annual rainfall of between 500 mm and 1370 mm and the mean temperature of 21°C.

Seed materials

The seeds of *F. albida* provenances, namely, Awassa, Chinzombo, Lake Koka, Maseno, Taveta, and Wagingombe used in this study (Table 1) were obtained from the ICRAF germplasm laboratory. The seeds were collected by Oxford Forest institute (OFI) for international provenance trials in 1990. After collection, seeds were cleaned and dried immediately before storage. Seeds were placed in cotton bag and stored in a cool, dry, and dark place with good air circulation at -20°C (WAC, 2013). During collection, 25 mother trees spaced 100m apart to avoid collection from related individuals were selected to represent a provenance (Koech et al., 2014). The samples were representative of the entire natural distribution range of the species in East and Southern Africa (EA and SA respectively). In this study, the term provenance denotes the original geographic zone from which seeds were collected (Loha et al., 2006). The location and geographical descriptions of the different provenances are given in Figure 1 and Table 1. The geographical description of the different provenances was sourced from Barnes and Fagg (2013) and Kithure (2013).

Seed morphological characters

To determine the variability in seed morphological characters, seed

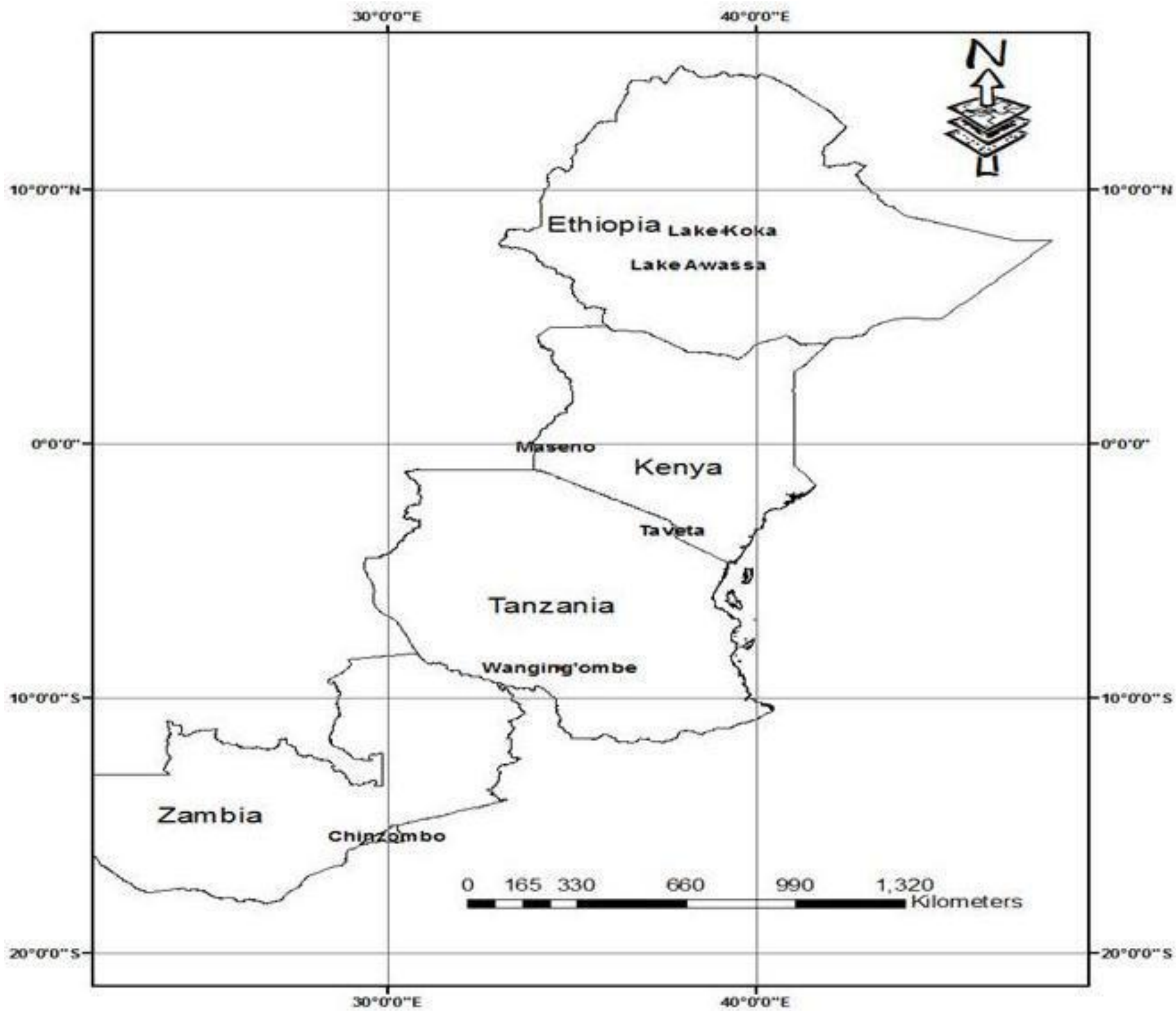

Figure 1. Origin of the different provenances of *F. albida* used in this study.

Table 1. Geographic locations and climatic conditions of the six provenances used in this study.

Provenance	Country	Zone	Geographical location Lat. - Long.	Altitude (m)	Rainfall (mm)	Temperature (°C)
Chinzombo	Zambia	SA	13°08'S, 32°45'E	550	958	24.0
Wangingombe	Tanzania	EA	08°51'S, 34°38'E	1450	819	20.6
Taveta	Kenya	EA	03°24'S, 37°42'E	760	545	23.5
Maseno	Kenya	EA	00°01'S, 34°60'E	1503	119	21.1
Lake Koka	Ethiopia	EA	08°20'N, 38°59'E	1600	742	10.0
Lake Awassa	Ethiopia	EA	07°03'N-38°28'E	1650	961	19.6

EA= East Africa; SA = Southern Africa.

length, seed width, seed thickness and seed weight were measured for each provenance. A total of 150 seeds per provenance were randomly selected (3 replicates of 50 seeds) and organized in a completely randomized design (CRD) for measuring each morphological character (that is, 50 x 3 x 6 = 900 experimental units). Measurement was made on individual seed using a vernier

Table 2. Variation in seeds morphology of *F. albida* from different provenances (Mean±Standard error).

Provenances	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Seed weight (g)
Chinzombo	9.29 ± 0.05^{e}	5.58 ± 0.04^{e}	2.98 ± 0.03^{c}	0.126 ± 0.0021^{e}
Wagingombe	8.82 ± 0.06^{d}	6.06 ± 0.04^{f}	3.18 ± 0.03^{e}	0.132 ± 0.0023^{e}
Taveta	7.15 ± 0.07^{a}	4.75 ± 0.04^{b}	2.86 ± 0.03^{b}	0.075 ± 0.0018^{b}
Maseno	7.44 ± 0.09^{b}	5.09 ± 0.05^{c}	2.93 ± 0.03^{bc}	0.086 ± 0.0025^{c}
Lake Koka	7.79 ± 0.06^{c}	5.22 ± 0.04^{d}	3.07 ± 0.03^{d}	0.102 ± 0.0019^{d}
Awassa	7.03 ± 0.08^{a}	4.59 ± 0.05^{a}	2.68 ± 0.04^{a}	0.067 ± 0.0020^{a}
CV (%)	15.2	14.0	13.7	36.0

Values in the same column with the same letter do not differ significantly ($p \leq 0.05$).

caliper for seed length, seed width and seed thickness and an electronic weighing balance (Mettler Toledo, ML204, Switzerland) for seed weight. Seed length was measured over the seed coat along the longest axis of the seed; seed width measurement was taken on one of the widest faces at the middle of the seed while seed coat thickness was measured on one of the smallest faces at the middle of the seed.

Seed germination

Seeds were nicked and directly sown in a germination tray measuring 21 cm x 15 cm x 8 cm (length, width and depth respectively) and filled with sharp sand. Watering was done as necessary to maintain ideal soil moisture. Seeds were germinated under a 50% light shade net, no fertilizers or bacterial and/or mycorrhizal inoculation was used. Germination was monitored every day from the date of sowing for 30 days or until there was no further germination for a few days. Germinated seeds were counted when the hypocotyl hook was evident above the soil surface following Fandohan et al. (2010). Percentage germination (germination capacity), germination energy and mean germination time for each provenance was calculated using the equation below.

Germination Capacity (GC) = $\frac{Total\ germinated\ seeds}{Total\ seeds\ sown} * \frac{100}{1}$

Germination Energy (GE) =

$$\frac{Germinated\ seeds\ after\ 9days\ and\ 14days}{Total\ germinated\ seeds\ after\ 30days} * \frac{100}{1}$$

Mean Germination Time (MGT) = $\frac{\sum(t_i\ X\ n_i)}{\sum n_i}$

Where t_i is the number of days starting from the date of sowing and n_i is the number of seeds germinated at each day (Bewley and Black, 1994).

Early seedling growth performances

Following the germination test, a nursery experiment was performed to examine seedling growth parameter variability. 30 seedlings per provenance (germinated in the germination trial) were selected (3 replicates of 10 seeds) and organized in a completely randomized design (CRD) for seedling growth performance (that is, 10 x 3 x 6 = 180 experimental units). Each seedling was transplanted into a polybag measuring 15.5 cm x 40 cm and filled with forest soil (Ngong forest soil). Seedlings were grown under 50% light shade net. Watering was done daily at the beginning, and as often as needed thereafter. Weeding was carried out regularly and when required. No fertilizer or mycorrhizal inoculation was used. The seedling height was measured from the substrate level to the tip of the youngest leaf; stem collar diameter was measured using a vernier caliper at 1 cm above the soil surface; while leaf production was determined by directly counting the number of leaves. Height, collar diameter and seedling leaf number was determined monthly for five months.

Data analysis

Data collected on seed morphology, germination and early seedling growth parameters were subjected to Analysis of Variance (ANOVA) using the SPSS statistical software (SPSS version 16.0. (SPSS Inc. Chicago, USA). This was done to determine the variation among provenances at a 0.05 significant level. The Duncan multiple range test was used to compare means among provenances. Pearson correlations were performed among seed traits, between seed traits and geo-climatic data, seed traits and germination parameters, seed and seedling traits and between seedling traits and geo-climatic data while coefficient of variation (%) was performed to determine the amount of variability in seed traits among provenances.

RESULTS

Seed morphological characters

The average seed length, seed width, seed thickness and seed weight are shown in Table 2. There were significant differences ($p \leq 0.05$) among provenances with regards to mean seed length, width, thickness and weight. The mean seed length varied from 7.03 to 9.29 mm. Seeds collected from Chizombo (9.29 mm) had the highest value for seed length followed by seeds collected from Wagingombe (8.82 mm) while the lowest value was for seeds collected from Awassa (7.03 mm) which is not significantly different from seeds collected from Taveta (7.15 mm). Mean seed diameter varied from 4.59 to 6.06 mm. Seeds collected from Wagingombe had highest values (6.06 mm) compared to the other provenances with the lowest being for seed collected from Awassa (4.59 mm) which was also not significantly different from seeds collected from Taveta (4.75 mm). Mean seed thickness varied from 2.68 to 3.18 mm. Seeds collected

Table 3. Mean correlation coefficients (*r*) among seed characters of six *F. albida* provenances.

Seed traits	Length	Width	Thickness	Weight
Length	1	0.89*	0.69	0.96**
Width		1	0.89*	0.97**
Thickness			1	0.85*
Weight				1

* = Significant and ** = highly significant at 5 and 1% probability level respectively.

Table 4. Pearson correlation coefficient (r) between seed morphological traits and geo-climatic variables (mean altitude, mean annual rainfall and mean annual temperature) of seed origin of six *F. albida* provenances.

Variable	Length	Width	Thickness	Weight	Altitude	Rainfall	Temperature
Length	1	0.737**	0.405**	0.833**	-0.297**	0.295**	0.132**
Width		1	0.471**	0.841**	-0.073*	0.140**	0.019
Thickness			1	0.639**	-0.004	-0.011	-0.101**
Weight				1	-0.169**	0.226**	0.013
Altitude					1	-0.144**	-0.646**
Rainfall						1	-0.075*
Temperature							1

* = Significant and ** = highly significant at the 0.05 and 0.01 levels respectively.

from Wagingombe recorded highest (3.18 mm) while seeds collected from Awassa recorded lowest (2.68 mm) for mean seed thickness as compared to other provenances. Mean seed weight varied from 0.067 to 0.132 g. The highest mean seed weight (0.132 g) was observed for seeds from Wagingombe and was almost twice the mean seed weight of Awassa (0.067 g). The coefficient of variation shows that seed weight exhibited highest (36.0) variability, followed by seed length (15.2), seed width (14.0) while seed thickness was lowest (13.7) (Table 2).

Correlation analysis for seed traits

Inter-trait correlations of seed parameters of *F. albida* provenances, which are shown in Table 3, showed a significant positive inter-character correlation among seed traits except between seed length and seed thickness which did not have a significant correlation (r = 0.69, n = 900 $p \leq 0.05$). Seed weight was highly significantly correlated with seed length (r = 0.96, n = 900 $p \leq 0.05$), and seed width (r = 0. 97, n = 900, $p \leq 0.05$). There was a significant positive correlation between seed length and seed width (r = 0.89, n = 900, $p \leq 0.05$), seed width and seed thickness (r = 0.89, n = 900, $p \leq 0.05$), and between seed thickness and seed weight (r = 0.85, n = 900, $p \leq 0.05$).

Correlation between seed morphological traits and geo-climatic variables

Correlation analysis between seed morphological traits and geo-climatic variables showed that seed length, seed width and seed weight were significantly negatively correlated with altitude and significantly positively correlated with rainfall but the correlations are quite weak. Seed thickness had an inverse non significant correlation with altitude and rainfall. Also seed length, seed width and seed weight had a positive correlation with temperature, while seed thickness had an inverse significant correlation with temperature. Summary of this result is presented in Table 4.

Seed germination

Data on seed germination capacity (GC), germination energy (GE) and mean germination time (MGT) are presented in Figure 3a, b and c respectively. There was significant variation among provenances in seed germination capacity (GC) and germination energy (GE) at day 14 (Figure 3a and b). Germination energy at day 9 and mean germination time were not significant at p ≤ 0.05. The mean germination capacity varied from 32.7 to 93.3% (Figure 3a). Seed germination capacity was highest for Awassa (93.3%) and was lowest for Taveta

Table 5. Pearson correlation coefficient (r) of seed and germination parameters of six *F. albida* provenances.

Parameters	Seed length	Seed width	Seed thickness	Seed weight
GC	0.21	0.08	-0.12	0.15
GE (day 9)	-0.26	-0.23	-0.43	-0.33
GE (day 14)	-0.67	-0.43	-0.21	-0.51
MGT	0.45	0.40	0.56	0.51

GC = germination capacity; GE = germination energy and MGT = mean germination time. * = significant and ** = highly significances at the 0.05 and 0.01 levels respectively.

Table 6. Mean seedling height (cm) of different provenances of *F. albida* from first to fifth month after sowing (H = height at month 1 to 5).

Provenances	Seedling Height (cm)				
	H1	H2	H3	H4	H5
Chinzombo	10.11[a]	15.91[a]	23.45[a]	41.44[a]	52.47[ab]
Wagingombe	12.34[c]	17.30[a]	25.70[a]	43.32[a]	51.59[ab]
Taveta	11.98[bc]	17.21[a]	23.67[a]	43.50[a]	49.97[ab]
Maseno	10.67[a]	15.67[a]	23.77[a]	42.33[a]	51.43[ab]
Lake Koka	13.06[c]	17.26[a]	25.73[a]	41.04[a]	48.05[a]
Awassa	10.80[ab]	15.83[a]	25.45[a]	42.55[a]	53.67[b]
Mean	11.49	16.53	24.63	42.36	51.20
CV (%)	22.8	21.3	20.7	16.8	14.8
P	<0.001	0.168	0.222	0.772	0.100

Values in the same column with the same letter do not differ significantly ($p \leq 0.05$).

(32.7%) provenances. Germination energy which is used to determine the speed of germination showed no variation among provenances (32.2 to 62.5%) at day 9. GE (day 9) was highest (62.5%) for Maseno provenance and lowest (32.2%) for Lake Koka after 9 days of germination (Figure 3b). After 14 days of germination, there was significant variation in germination energy which varied between 90.1% (Chinzombo) and 97.5% (Lake Koka). There was no significant variation among provenances in seed Mean germination time which ranged between (9.6 days to 10.7 days) that is, 10 to 11 days. Seeds collected from Maseno had the lowest MGT (9.6 days) while seeds collected from Lake Koka exhibited highest MGT (10.7 days) (Figure 3c).

Correlation between seed characters and germination parameters

No significant correlation was recorded between seed traits and germination parameters. Seed length, seed width and seed weight were positively correlated with GC while seed thickness had an inverse correlation with GC. Germination energy at day 9 and 14 showed a negative correlation with all seed traits while mean germination time was positively correlated with all seed traits. This information is given in Table 5.

Early seedling growth performances

Provenances of *F. albida* displayed significant differences ($p \leq 0.05$) in seedling height after 1 month and non significant differences ($p \leq 0.05$) after 2 to 5 months of growth in the nursery. Overall mean seedling height after 1 to 5 months varied from 11.49 cm at month 1 to 51.20 cm at month 5 (Table 6). Lake Koka exhibited highest height at 1 and 3 months while lowest height was observed in Chinzombo. After 2 months, seedling height was highest in Wagingombe and lowest in Maseno. Lowest height at 4 and 5 months was observed in Lake Koka while highest height was observed in Taveta and Awassa respectively (Table 6). The coefficient of variation (%) shows that seeding height in the first month exhibited highest (22.8) variability, followed by the second month (21.3), third month (20.7), fourth month (16.8) and lowest in the fifth month (14.8) (Table 6). This indicated that CV reduced as seedling height increased with time. Figure 4 shows the time courses of height of the tested provenances. There was no consistent trend for the best provenance in terms of seedling height from the first month to the fifth month. Although Lake Koka started off as the highest in height after 1 month, it had the lowest value in height after 4 and 5 months while Chinzombo which started off as the lowest in height after 1 month exhibited second highest in height after 5 months

Table 7. Mean seedling collar diameter (mm) of different provenances of *F. albida* from first to fifth month after sowing (CD = collar diameter at month 1 to 5).

Provenance	Seedling Collar Diameter (mm)				
	CD1	CD 2	CD 3	CD 4	CD 5
Chinzombo	1.34^{d}	1.59^{c}	1.85^{d}	2.34^{b}	2.83^{c}
Wagingombe	1.22^{c}	1.48^{b}	1.73^{c}	2.31^{b}	2.62^{b}
Taveta	1.06^{b}	1.21^{a}	1.52^{b}	2.01^{a}	2.46^{ab}
Maseno	1.06^{b}	1.18^{a}	1.48^{b}	1.98^{a}	2.50^{ab}
Lake Koka	0.97^{a}	1.11^{a}	1.34^{a}	1.92^{a}	2.31^{a}
Awassa	0.98^{ab}	1.11^{a}	1.29^{a}	1.89^{a}	2.32^{a}
Mean	1.10	1.28	1.54	2.08	2.51
CV (%)	18.4	21.1	20.1	17.1	16.4
P	<0.001	<0.001	<0.001	<0.001	<0.001

Values in the same column with the same letter do not differ significantly ($p \leq 0.05$)

Table 8. Mean seedling leaf number (mm) of different provenances of *F. albida* from first to fifth month after sowing (LF= number of leaves at month 1 to 5).

Provenances	Seedling Leaf Number (mm)				
	LF1	LF 2	LF 3	LF 4	LF 5
Chinzombo	6.33^{a}	10.30^{ab}	17.90^{a}	37.78^{a}	49.85^{a}
Wagingombe	7.87^{b}	11.97^{c}	23.17^{d}	52.04^{b}	46.00^{a}
Taveta	7.93^{b}	11.43^{bc}	20.83^{cd}	39.00^{a}	63.37^{b}
Maseno	7.50^{b}	10.97^{bc}	20.53^{bc}	44.30^{a}	67.74^{b}
Lake Koka	8.17^{b}	10.73^{abc}	18.00^{ab}	39.63^{a}	61.22^{b}
Awassa	6.67^{a}	9.63^{a}	18.37^{abc}	43.15^{a}	63.74^{b}
Mean	7.41	10.84	19.80	42.65	58.65
CV (%)	19.5	22.3	25.4	29.2	32.4
P	<0.001	<0.003	<0.001	<0.001	<0.001

Values in the same column with the same letter do not differ significantly ($p \leq 0.05$)

(Figure 4).

Provenances displayed significant differences ($p \leq 0.05$) in seedling collar diameter from the first to the fifth month. Overall mean collar diameter after 1 to 5 months varied from 1.10 at month 1 to 2.51 at month 5 (Table 7). Seedling height was considerable highest in Chinzombo after 1 to 5 month and lowest in Lake Koka after 1, 2 and 5 months and in Awassa after 2, 3 and 4 months when compared to the other provenances. Coefficient of variation (%) for seedling collar diameter showed highest variability (21.1) in the second month, followed by the (20.1) in the third month and lowest in the fifth month (16.4) (Table 7). There was a consistent growth trend for the best provenance in terms of seedling collar diameter as shown in Figure 5. Chinzombo and Wagingombe exhibited higher collar diameter followed by Taveta and Maseno and lower in Awassa and Lake Koka from the first month to the fifth month (Figure 5).

Significant variations ($p \leq 0.05$) were also observed for the number of leaves per seedling within and among provenances throughout the stages of growth. Overall mean leaf number after 1 to 5 months ranged from 7.41 at month 1 to 58.65 at month 5 (Table 8). Highest leaf number after 1 and 5 months was observed in Lake Koka and Maseno respectively while Wagingombe exhibited highest leaf number after 2, 3 and 4 months. Chinzombo exhibited lowest leaf number after 1, 3 and 4 months, Awassa after 2 months and Wagingombe after 5 months. Seedling leaf number exhibited a coefficient of variation ranging from 19.5 to 32.4%. Leaf number in the fifth month showed the highest Coefficient of variation while Leaf number in the first month had the lowest Coefficient of variation. Coefficient of variation (%) was noted to have increased with time accordingly from the first month to the fifth month (Table 8). There was also no consistent trend for the best provenance in terms of seedling leaf number from the first month to the fifth month. But during the fifth month, the southern Africa provenances (Wagingombe and Chinzombo) exhibited considerable lower values in leaf number when compared to the East

Table 9. Correlations between seedling growth traits and seed morphological traits and geo-climatic variables (mean altitude, mean annual rainfall and mean annual temperature) of seed origin of six *F. albida* provenances.

Parameters	Seed length	Seed width	Seed thickness	Seed weight	Altitude	Rainfall	Temperature
H1	-0.130	0.181	0.509	0.098	0.142	0.008	-0.233**
H2	0.056	0.293	0.573	0.243	0.002	0.028	0.034
H3	-0.071	0.171	0.236	0.097	0.152*	00.82	0.124
H4	-0.274	-0.046	-0.139	-0.227	-0.006	-0.023	00.13
H5	0.124	-0.047	-0.477	-0.045	-0.013	0.072	-0.083
CD1	0.900*	0.727	0.444	0.793	-0.431**	0.193**	0.393**
CD2	0.927**	0.783	0.504	0.840*	-0.427**	0.253**	0.365**
CD3	0.875*	0.757	0.527	0.798	-0.447**	0.123	0.392**
CD4	0.927**	0.844*	0.589	0.874*	-0.287**	0.176*	0. 259**
CD5	0.849*	0.661	0.394	0.729	-0.305**	0.073	0.280**
LF1	-0.274	0.115	0.490	-0.026	0.155*	-0.206**	-0.233**
LF2	0.221	0.563	0.702	0.404	-0.028	-0.116	0.034
LF3	0.081	0.452	0.432	0.236	0.037	-0.128	0.124
LF4	0.152	0.520	0.404	0.316	0.204**	-0.017	0.13
LF5	-0.903	-0.872	-0.647	-0.900**	0.134	-0.252**	-0.083

* = Significant and ** = highly significant at the 0.05 and 0.01 levels respectively. Where H1-H5 = height at 1 month to 5 month, CD1-CD5 = collar diameter t at 1 month to 5 month and LF1-LF5 = number of leaves at 1 month to 5 months.

Africa provenances (Taveta, Maseno, Lake Koka and Awassa) (Figure 6).

Correlation between seedling traits and seed morphological traits

Correlation analysis revealed that Height at month 1, 3 and 4 negatively correlated with seed length while month 2 and 5 were positively correlated with seed length although correlations were not statistically significant. Collar diameter at month 1 to 5 showed a significant positive correlation with seed length. Leaves number at month 1 and 5 are negatively correlated with seed length while Leaf numbers at month 2 to 4 were positively correlated with seed length. Also correlations between seed length and number of leaves were not significant at all stages. Seed width was not significantly correlated with almost all seedling traits except Collar diameter at month 4 and Leaf number at month 5 (inverse). There were also no significant correlations between seed thickness and all seedling traits at all ages. Seed weight was significantly correlated with only Collar diameter at month 2, 4 and Leaf number at month 5. Note that, height at month 4 and leaf number at month 5 were inversely correlated with all seed traits (Table 9).

Correlation between seedling traits and geo-climatic variables

Correlation analysis between seedling traits and geo-climatic variables showed that Height at month 1, 2 and 3 positively correlated with altitude, while Height at month 4 and 5 negatively correlated with altitude. There was a positive non significant correlation between seedling height and rainfall except for Height at month 4 which was negatively correlated with rainfall. Height at month 1 to 3 had an inverse correlation with temperature while correlation with Height at month 4 and 5 was positive. Collar diameter at month 1 to 5 significantly negatively correlated with altitude and significantly positively correlated with temperature. Also, collar diameter at month 1 to 5 positively correlated with rainfall but correlations were significant at month 1, 2 and 4 and non significant at month 3 and 5. Leaf number at month 1 and 4 significantly positively correlated with altitude while month 2, 3 and 5 were not significantly correlated with altitude. Leaf number at month 1 to 5 had an inverse correlation with rainfall, correlation was significant at month 1 and 5 only. Also, correlation with temperature was negative at month 1 and 5 and positive at month 2, 3 and 4. Summary of these results is presented in Table 9.

DISCUSSION

Seed morphological characters

The provenances of *F. albida* studied showed considerable amount of variation in seed morphological characters (Figure 2 Table 2). This may be due to its occurrence over a wide range of geo-climatic conditions (Friis, 1992). Analysis of variance of seed characters showed significant differences ($p \leq 0.05$) in all seed traits among the six provenances of *F. albida* obtained from

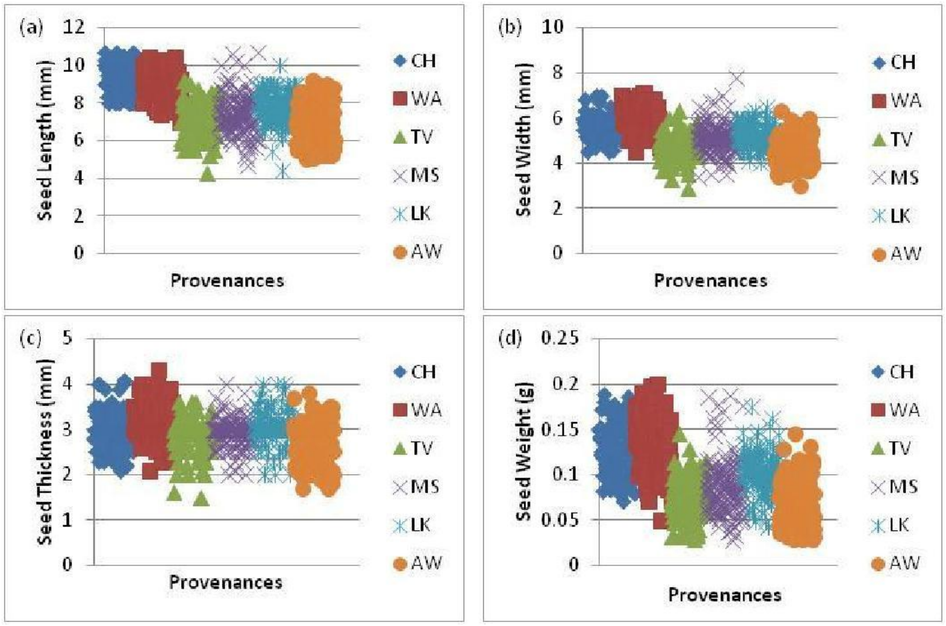

Figure 2. Individual a) seed length, b) seed width, c) seed thickness and d) seed weight of six provenances of *F. albida*. CH – Chinzombo; WG = Wagingombe; TV - Taveta; MS – Maseno; LK - Lake Koka; AW - Awassa.

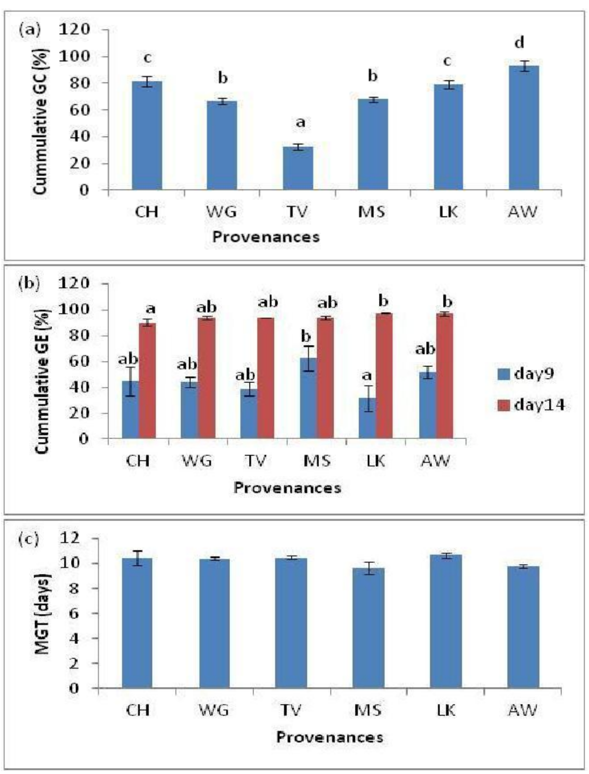

Figure 3. a) Germination capacity (GC), b, germination energy (GE) and c, mean germination time (MGT) of six provenances of *F. albida*. Bars with the same letter (s) are not significantly different at the 0.05 level. Where CH – Chinzombo; MS – Maseno; AW - Awassa; TV - Taveta; LK - Lake Koka; WG = Wagingombe.

eastern and southern African provenances. Seeds from Zambia (Chinzombo) and Tanzania (Wagingombo) the two southern provenances exhibited similarity (that is, larger) in seed size while those from Kenya (Maseno and Taveta) and Ethiopia (Lake Awassa and Lake Koka), the eastern provenances exhibited similarity (that is, smaller) in seed size. This may be due to similarity in ecological zone between Zambia and Tanzania and between Kenya and Ethiopia. There was a higher variability between Eastern African provenances (Maseno, Taveta Lake Awassa and Lake Koka) than Southern African provenances. Koech et al. (2014) also observed a higher variability between Eastern African provenances than Southern African provenances of *F. albida* and attributed it to high variability in environmental conditions within the regions. Although Wagingombe had highest seed width, seed thickness and seed weight, Chinzombo had highest seed length. In general, Wagingombe seeds were largest, followed by Chinzombo seeds then Lake Koka while Awassa seeds were lowest for all seed traits. Variation among the provenances may also be due to genetic differences caused by the adaptation to diverse environmental conditions (Ginwal et al., 2005). Correlation between seed traits and geo-climatic factors indicates that environmental factors also have effect on the expression of the seed traits although some seed traits were not significantly correlated with geo-climatic factors. Elmagboul et al. (2014) hypothesised that variation in seed weight, length, width and thickness between or within plant species are due to evolutionary responses of plants to maximize the potential fitness by

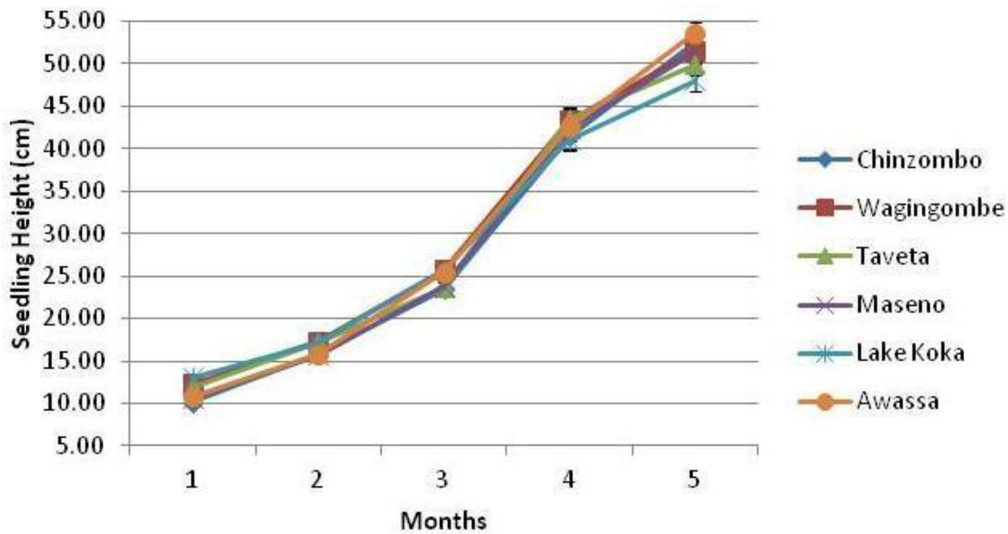

Figure 4. A times series plot showing growth trend in height of *F. albida* provenances from first to fifth month after sowing.

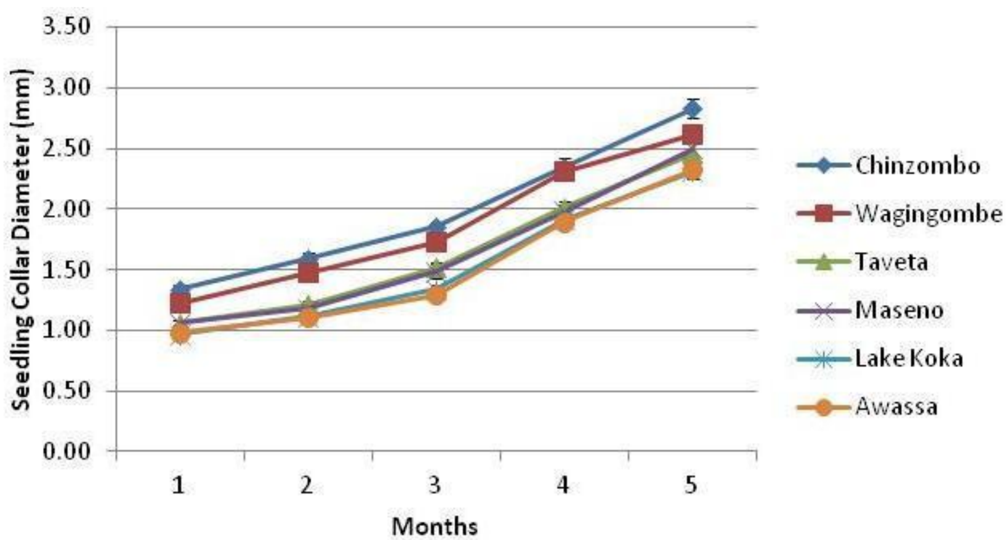

Figure 5. A times series plot showing growth trend in collar diameter of *F. albida* provenances from first to fifth month after sowing.

producing a larger number of seeds and increase the chance of establishment of resulting seedlings through greater allocation of maternal resources to individual seeds. Takuathung et al. (2012) also noted that variability in seed size (width, length and thickness) was probably a consequence of a compromise between the requirements for dispersal (which might favor small seeds) and the requirements for seedling establishment (which would favor large seeds). Also variation in seed weight may partly be due to the different position of seed on mother plants or due to different environmental conditions to which the mother plants were subjected to during the growing season (Singh et al., 2010). Variation among seed provenances with respect to seed traits (length, width, thickness and weight) have earlier been reported in many species including *F. albida* (Dangasuk et al., 1997), *Acacia karroo* (Abdelkhair et al., 2003), *Pinus roxbrughii* (Ghildiyal et al., 2009), *Dalbergia melanoxylon* (Amri et al., 2008), and *Celtis australis* (Singh et al., 2006). The coefficient of variation in seed traits was moderate for seed length, seed width and seed thickness (15.2, 14.1 and 13.6 respectively) and high for seed weight (36.3). High coefficient of variation for seed weight suggest its sensitivity to environmental factors

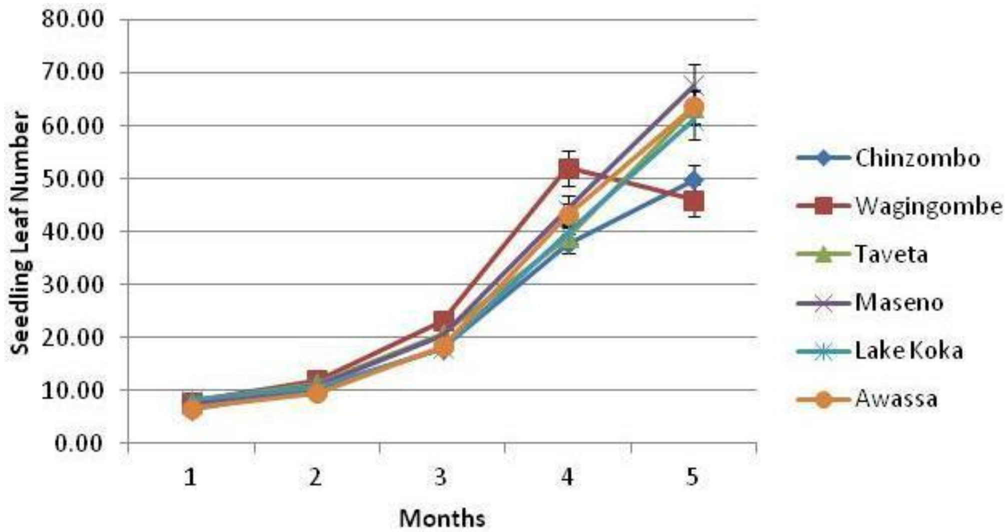

Figure 6. A times series plot showing growth trend in leaf production of *F. albida* provenances from first to fifth month after sowing.

(Dangasuk et al., 1997). There was also a significant positive correlation between seed length and seed width, seed length and seed weight, seed width and seed thickness, seed width and seed weight as well as between seed thickness and seed weight (Table 3). Correlated quantitative characters are of a major interest in an improvement program, as the improvement of one character may cause simultaneous changes in the other character (Loha et al., 2006; Shu et al., 2012). Similar results have been reported for *F. albida* (Ibrahim, 1996), *Tectona grandis* L.f. (Jayasankar et al., 1999), and *Magnolia officinalis* (Shu et al., 2012).

Seed germination

Provenances also displayed highly significant differences in seed germination capacity at $p \leq 0.05$ which varied from 32.7% to 93.3% and germination energy at day 14 (Figure 3a). There were no significant differences in germination energy at day 9 and mean germination time (Figure3c). Germination also was not affected by regional differences. Seeds from Awassa which were physically the smallest on average had the highest germination capacity (93.3%) while seeds from Chinzombo which had larger seeds (second largest in seed size) had the second highest seed germination capacity (Figure 3). Similar results have been reported in germination capacity for *F. albida* (Dangasuk et al., 1997), *Cordia africana* (Loha et al., 2006), Pine species (Lopez-Upton et al., 2005), and *Magnolia officinalis* (Shu et al., 2012). In most plant species, seeds vary in their degree of germination between and within populations and between and within individuals (Mkonda et al., 2003; Loha et al., 2006). Causes of such variability- might be generally attributed either to (a) genetic characters of source population/plant (Shu et al., 2012), or (b) impact of mother plant environment (Singh et al., 2010). Gutterman (2000) stated that germination of seeds can be influenced by maternal factors, such as position of the seed in the fruit/tree, the age of the mother plant during seed maturation, as well as environmental factors such as day length, temperature, light quality, water availability and altitude. None of the seed morphological characters showed strong correlation with germination capacity or germination energy (Table 5) although some seed characters were fairly correlated with mean germination time (Table 5). This indicates that seed morphological characters have little importance in predicting the ability of seeds of *F. albida* to germinate.

Early seedling growth performances

The provenances of *F. albida* studied showed considerable variation in seedling height at 1 month and non-significant variation at 2 to 5 months (Figure 4 and Table 6). Variation in height at 1 month was not regionally structured as mean minimum seedling height values were observed in Chinzombo (southern) and Maseno (eastern) while maximum height values were observed in Wagingombe (southern) and Lake Koka (eastern). Dangasuk et al. (1997) in his provenance trials with *F. albida* reported that there was little variation among and within the Southern African and East African provenances in seedling height. Variation among provenances in seedling height has been reported for most tree species. Coefficient of variation in seedling height was noticed to decrease with time (Table 6), this implies that as the seedlings get older, variation in height among provenances tend to reduce.

Considerable variation was found in seedling collar diameter and number of leaves. Analysis of variance showed significant differences ($p \leq 0.05$) in seedling collar diameter at all ages among the six provenances obtained from eastern and southern African provenances (Table 7).Variation in collar diameter at all ages (that is, 1 to 5 months) was regionally structured since Chinzombo and Wagingombe (Southern) exhibited a higher collar diameter consistently, followed by Maseno and Taveta (South Eastern) and lower in Lake Koka and Awassa (North Eastern) (Figure 5). This indicates that the diameter growth in the early stages could predict the diameter growth at late stages. Dangasuk et al. (2001) and Ibrahim (1996) also observed variation in seedling diameter for *F. albida* Provenance at the nursery stage after 3 months. Ibrahim et al. (1997) reported that the seedlings produced by seeds from southern African provenances had larger collar diameter than those from other regions and this is in conformity with our findings. Stem diameter (in Cordia) has been reported to be more sensitive to environmental effects than height (Loha et al., 2006). Therefore, it is risky to use these criteria (consistency in growth) as the sole indicator for seed selection since collar diameter is very sensitive to environment (Takuathung et al., 2012). Coefficient of variation in collar diameter did not follow a particular trend since coefficient of variation was highest at 2 months and lowest at 5 months.

Highly significant variation in leaf number per provenance was observed at all ages of growth (Figure 6 and Table 8). These present findings are in conformity with the observations of Dangasuk et al. (1997) who reported significant difference in leaf number of *F. albida* provenances thirty days after germination. Singh et al. (2010) also observed significant variation in the number of leaves per plant in *Quercus glauca* and attributed it to wide range of distribution of the species. Seedling variation in relation to habitat has also been reported in *Celtis australis* (Singh et al., 2006) and *Magnolia officinalis* (Shu et al., 2012). Unlike in seedling height, coefficient of variation in leaf number (Table 8) was noticed to increase with time, this implies that as the seedlings get older, variation in leaf number among provenances increases.

Correlation analysis of seedling height with seed traits showed no significant correlations between seed traits and seedling height at all ages (Table 9), this indicates that seed traits do not have much effect on the expression of the seedling height. Loha et al. (2006) reported a poor correlation between seed traits and seedling height in *Cordia Africana.* Takuathung et al. (2012) also reported a very poor correlation between seed traits and seedling height of *Senna siamea* and suggested that seed morphometric traits could not be used as an indicator of tree height. Also non-significant correlation between seedling traits and geo-climatic factors implies that variation in seedling height at that age could have been affected by other factors. Most variation in seedling height of different species in common-garden studies has been attributed to provenance effect (Shu et al., 2012). A significant correlation analysis was observed between seedling collar diameter and seed traits which is why southern African provenances with larger seed sizes exhibited larger seedling collar diameter. Loha et al. (2006) also reported that diameter of *Cordia africana* at the early stage of growth (4 months) had a significant correlation with seed length and weight and stated that these correlations are expected since the emerging seedling depends on the seed reserve for its initial growth until it becomes autotrophic. This implies that seed traits could affect seedling growth at an early stage. Fandohan et al. (2010) noted that larger seeds also showed higher growth speed than smaller ones and that seed traits can be determinants for seedling growth and survival during early life stages of plants. Significant correlations between seedling collar diameter and some geo-climatic factors (Table 9) indicate that environmental factors also have effect on the growth of the seedling. There was a poor correlation between seed traits and number of leaves at all ages and this indicates that seed traits do not have much effect on leaf production. Significant correlations between some geo-climatic factors and number of leaves implies that variation due to seed source origin could also have affected seedling leaf production although variations in this study is supposed to be genetic since all seed sources were raised under the same condition. Correlated quantitative characters are of a major interest in an improvement program, as the improvement of one character may cause simultaneous changes in the other character (Loha et al., 2006; Shu et al., 2012).

Conclusion

F. albida is a multipurpose leguminous tree species growing over wide range of geo-climatic conditions throughout Africa. The tree exhibits considerable phenotypic variability across its diverse natural range which may indicate high genetic variability that might be exploited for genetic improvement. The aim of this investigation was to measure the variability of morphological characteristics and germination in seeds of *F. albida* from throughout the natural range, in order to understand the extent and pattern of variation with respect to seed characters and germination. Such an investigation may help in selection of most suitable provenance(s) for a given site for conservation, breeding and improvement in this species.

The study revealed the existence of considerable variation among provenances with respect to seed morphological characters, germination and seedling growth of *F. albida*. Highly significant variation in seed morphological characteristics among and within the provenances of *F. albida* may be due to both environmental and genetic variation and their interaction. The best three provenances recommended from this study based on germination for integration into agrarian systems within this region are Awassa, Chinzombo and Lake Koka because they had high germination capacity and also exhibited highest germination speed which was determined by germination energy. This will also ensure provision of planting materials for farmers. The low germination percentage observed in Taveta could be attributed to poor handling and processing of the seeds or absence of ripened pods during collection. This calls for recollection of ripened pods for extraction of matured seeds and ensure proper handling for future studies. Variation in seedling traits followed a particular trend in collar diameter with Chinzombo and Wagingombe having a higher value and Lake Koka and Awassa a lower value consistently at all stages of growth while in leaf number and height such trend was not observed. Higher and lower values in height and number of leaves were not specific to any provenance and tend to vary as growth advanced. It should be noted that all seed and seedling characters should be considered during provenance selection because selection done on the basis of one character alone may not give the desired level of superiority (Singh et al., 2010). Since the period of this study was short (5 months), further progeny tests in the field should be undertaken for a longer period so as to obtain definitive recommendations for early selection as

"It is advisable that the age of early selection in any species should be sufficiently long to achieve a reasonable level of accuracy in selection" (Loha et al.,

2006). Finally, selecting and analyzing additional provenances in future studies could be considered in order to get a more suitable provenance(s) for breeding purposes and integration into agrarian systems. Poor correlation between seed characters and germination parameters indicates that seed traits of this species have little importance in predicting germination. Finally, variation in germination capacity at the nursery level calls for a wide-range trial to enhance selection of the most suitable provenances of *F. albida* for breeding and conservation in the area of study.

Conflict of Interest

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

Authors are thankful to the World Agroforestry Centre (ICRAF, Nairobi) for providing the necessary materials for this work. This work was carried out under the 'trees for food security' project led by ICRAF and funded by the Australian Centre for International Agriculture Research – (ACIAR). The project is operating in Ethiopia, Rwanda, Uganda and Burundi and *F. albida* is one of the important tree species being studied under the project. We also want to thank Lucy Mwaura of the ICRAF seed laboratory for availing the seeds and Julius Njoroge, Agnes Gachuiri, Julius Kimani and Valentine Gitonga for their support in setting up the experiment.

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