Adaptation of Sub Saharan African *Faidherbia albida* (Del.) A. Chev. provenances in the Sudano–Sahelian climatic condition of Cameroon

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1 ABSTRACT

To provide a suitable seed source for the reforestation program in Cameroon, a nursery trial was set up in the Diamare Division of the Far North region of Cameroon. The aim was to assess the adaptation of 23 provenances of *Faidherbia albida* to the climatic conditions of Far North Cameroon. A randomized complete block design for single tree plots was used for the nursery trial. Traits of adaptation (survival rate, height of the plant, root collar diameter, number of leaves, number of leaflets, number of bi-pinnate leaves at the last formed leaf and number of branches) were assessed at 30, 60 and 90 days after sowing (DAS). The results obtained showed variations in the expression of performance of provenances with the Rama provenance from Ethiopia among the best for most growth traits. Though Rama had the highest values for growth traits among provenances, seeds sourced from Ethiopia were not among the source countries with the highest growth traits. Because seed sources from most Southern African countries were among the best performing provenances, the Southern African region overall was considered best for growth traits on a regional basis. Furthermore, the South African region was also best in the trend for survival, followed by Central Africa. Although seedlings from the Rama provenance in Ethiopia grew fast, the percentage survival of seedlings from the Rama provenance and from the East Africa region overall was the lowest in terms of survival. It was notable that Rama ranked closely with South Africa provenances for growth traits and while it ranked with Central Africa provenances for percentage survival. Generally, provenances from the South African region performed best in this study in Cameroon. These results will be used in *Faidherbia albida* improvement programs intended to ensure the survival and sustainability of the species in Cameroon as well as for use in reforestation programs.

2 INTRODUCTION

The land area for reforestation in the Sahel zone of Cameroon is enormous and has in recent years witnessed an increase in reforested area in several communities. It is estimated that about 500000 hectares of plantation forest are to be developed (Chemete, 2018) in this zone. Many ongoing restoration projects, such as Operation Green Sahel, Development of the Benue Basin, the African Forest Landscape Restoration Initiative (AFR100, 2015) will need large amounts of high quality and quantity seeds to succeed. Practices in the forestry sector have so far been directed mainly at forest management, agroforestry and the development of private forest plantations. Agroforestry offers an alternative land use practice for reforestation because of its potential for enhancing food production and alleviating economic and environmental problems (Leakey *et al.,* 2005; Dupraz *et al.,* 2008). Among the different agroforestry systems, a common agroforestry practice is parklands which combines trees, livestock and crops (sorghum, cowpea, maize. cotton, millet and groundnut) in one production system (Pelissier, 1980; Breman and Kessler, 1997; Bonkoungou, 2001; Liniger *et al.,* 2011). In Cameroon, agroforestry parklands are mostly practiced in the Sahel region where high population growth, high poverty rate and soil degradation are major constraints. The agroforestry parklands are composed of *Faidherbia albida, Acacia seyel*, *Acacia nilotica*, *Khaya senegalensis*, *Vitellaria paradoxa*, *Adansonia digitata*, *Parkia biglobosa*, *Leucaena spp.* and *Combretum spp.* Sometimes these parklands are assigned names depending on the dominant species in the parkland (Seignobos, 1978; Seignobos, 1982; Raison, 1988). These leguminous trees contribute to soil fertility by the fixation of atmospheric nitrogen and the decomposition of their leaves by soil microorganisms (Payne, 2000). Reforestation programs are established to meet local wood demand and supply forest products while preserving the natural environment. *Faidherbia albida* can be the species of choice for use in reforestation projects because of its importance for shade and forage provision (Ibrahim and Tibin, 2003; World Agroforestry Center 2009). Its inversed phenology makes it very important to the local communities in the regions which grow cereals such as sorghum, cowpea, corn and millet and is also appreciated for its timber and fuel wood (Wickens, 1995; Roupsard *et al.,* 1999). The medicinal value of *F. albida* has also been reported (Tijani *et al.,* 2009; Oluwakanyinsola *et al.,* 2010). There are opportunities to increase both yield and adaptation potentials of the species through an active choice of seed origin. Genetic selection and breeding programs have been initiated in *Faidherbia albida* in Africa with several studies reported on its center of origin (Joly 1991; Vandenbeldt 1991), morphological variation in natural stands (Wickens, 1969), phenotypic variation in seeds and seedlings (Ibrahim, 1996; Dangasuk *et al.,* 1997; Tchatchoua *et al.,* 2019) and genetic diversity using isoenzyme (Joly, 1991). The most recent study (Tchatchoua *et al.,* 2020) on genetic diversity found a low genetic variation in populations from Cameroon and recommended increasing the gene pool in the species. Seeds from East and South African provenances were requested and imported to Cameroon from collections in ICRAF (World Agroforestry Center) Nairobi, Kenya. This study aims to investigate the adaptation potential of 23 provenances of *Faidherbia albida* from across Africa in a trial in the Sudano –Sahelian climatic condition of Cameroon. This will be used to set up improvement programs intended to ensure the survival and sustainability of *Faidherbia albida* in Cameroon as well as its use in reforestation and agroforestry programs.

3 MATERIAL AND METHODS

3.1 Plant Materials: The plant material was obtained as open-pollinated seed consisting of 23 provenances of *F. albida* representing the Sub-Saharan Africa region. Four (4) from Cameroon (Adoumri, Mambang, Mokolo and Moulvoudaye) and 19 from other countries in East and Southern Africa (4 from Ethiopia, 4 from Malawi, 4 from Namibia, 1 from Tanzania, 2 from Zambia and 4 from Zimbabwe) The provenances outside Cameroon were provided by ICRAF, Nairobi (Tab. 1). The trial was established in the nursery farm of the Laboratory of Bioscience, at the National Advanced School of Engineering University of Maroua, Cameroon. The nursery farm is located at latitude 10° to 13° N and longitude 13° to 15° E. This trial was established in May 2020 after the first rainfall in Maroua under a shade with locally constructed thatch roof from the stem of *Pennisetum* species. The Sudano–Sahelian climate of Maroua is characterized by a long dry season (October – May) and a short rainy season (June – September). The annual average precipitation is 750 mm in the plain of Diamare and more than 57% of rainfall per year is distributed in the month of July and August. Annual temperature is around 27^{0}C with a maximum of 35^0 C to 38^0 C from March to April and minimum of 18^0 C from December to January. Relative humidity is 80% in the rainy season and drops to between 30% and 40% and sometimes to 10% in the dry season. The germination medium was a mixture of 2:1:1 forest soil, sand and decomposed manure. Plastic bags of size 24 cm x 13 cm were filled with the germinating medium and seeds were scarified and soaked in water for two hours before sowing. After sowing, the seeds and subsequently the seedlings were watered twice daily very early in the morning and late in the evening. The experimental design was a randomized complete block design with single tree plots consisting of 10 blocks (replicates), each containing 23 columns, representing the 23 treatments or provenances used.

Table 1: Geographical positions of provenances of *F. albida* used as well as trial site

Regions	Countries	Provenances	Geographical position	Altitude	Rainfall
Center	Cameroon	Adoumri	09° 16'N 13° 50'E	220	875
Center	Cameroon	Mambang	10° 38'N 14° 24'E	577	726
Center	Cameroon	Mokolo	10° 44'N 13° 48'E	600	900
Center	Cameroon	Moulvoudaye	10° 23'N 14° 50'E	340	798
East	Ethiopia	Debre Zeit	8° 48'N 38° 59'E	1900	730
East	Ethiopia	Lake koka	8° 20'N 38° 59'E	1590	600-800
East	Ethiopia	Rama	14° 24'N 38° 47'E	1385	283
East	Ethiopia	South Harar	9° 17'N 42° 06'E	855	402
East	Tanzania	Mfumbi	8° 58'S 34° 19'E	400	552
South	Malawi	Bolero	10° 58'N 33° 43'E	1100	701
South	Malawi	Chawanje	14° 39'S 34° 48'E	600	824
South	Malawi	Lupaso	10° 92'S 38° 9'E	500	1165
South	Malawi	Nwanza River	15° 36'S 34° 31'E	100	811
South	Namibia	Hoanib River	19° 14'S 13° 23'E	700	200
South	Namibia	Kuiseb 60	16° 10'S 34° 46'E	400	80
South	Namibia	Kuiseb 84	17° 14'S 34° 36'E	400	<40
South	Namibia	Okangwati	17° 43'S 13° 26'E	1084	113
South	Zambia	Chinzombo	13° 05'N 32° 45'E	550	958
South	Zambia	Kafue Flats	15° 45'N 26° 01'E	2350	510-1020
South	Zimbabwe	Gonarezhou	21° 16'S 31° 54'E	1000	871
South	Zimbabwe	Mana Pools	15° 45'N 29° 20'E	360	730
South	Zimbabwe	Manyoni River	18° 04'S 28° 15'E	750	660
South	Zimbabwe	Namepi	15° 57'S 29° 27'E	1100	875
Trial site	Cameroon	Maroua	10° 35'N 14°27'E	405	794

3.2 Data collection and statistical Analysis: Growth parameters, consisting of plant height, root collar diameter, number of leaves, number of leaflets, number of branches and the number of pairs of leaflets at the last formed leaf were evaluated from June–August i.e. at 30, 60 and 90 days after sowing (DAS). The data for these parameters provide information on the growth of the different provenances in order to evaluate their performance under the conditions of the Far North Cameroon. The survival rate was assessed at 30, 60 and 90 DAS. The assessment of the number of branches was done quite simply by counting at 90 DAS only. The data collected were tabulated in Microsoft Excel 2007 software, which was also used to calculate the means and standard deviations, and to produce a histogram table. The data collected were also analysed using R software, version 3.5. A Shapiro-Wilk normality test was performed for each parameter according to provenance, country and region. When the data followed the normal distribution (p-value ≥ 0.05), an analysis of variance was performed to see if there were significant differences between provenances, countries or regions. When this was the case (p-value <0.05), Tukey's multiple comparison test was performed to see the levels of the differences. Subsequently, a PCA (Principal Component Analysis) as well as a correlation matrix were carried out in order to see the degree of correlation between the different parameters.

4 RESULTS AND DISCUSSION

4.1 Plant height: Results revealed differences in plant height for various provenances and at all data collection date but only results at 90 DAS are reported here. The best performances based on comparison of the mean for this parameter were shown by seedlings from Rama in Ethiopia, followed respectively by those from Okangwati in Namibia and Chinzombo in Zambia (Table 2). These provenances would probably adapt the best to the conditions of Far-North Cameroon. However, ANOVA revealed no significant difference between provenances for this parameter (p> 0.05). Fredrick *et al.* (2015) reported similar results in that provenances of *F. albida* showed significant differences in seedling height after 1 month and non-significant differences from the second to the fifth months of growth in the nursery. The findings of our research are consistent with those of Bastide and Diallo (1994) but differ from those of Harmand and Njiti (1992) who obtained a significant difference in plant height for different provenances of *F. albida*. Dangasuk *et al.* (2001) also observed significant differences between provenances in a study of early growth in a plantation of sixteen populations of *F. albida* in Kenya. The disparity with the results of this trial could be due to differences in the genotypes of the seeds used in the various studies, as well as differences in the environmental conditions between the sites where the different trials were conducted. Ginwal *et al.* (2005) reported that variation between provenances might be attributed to genetic differences resulting from the adaptation of different provenances to various environmental conditions as well as soil types (Elmagboul *et al.,* 2014). Harmand and Njiti, (1992) collected data on a yearly interval whereas in this trial, it was done after 30 days. A continuous but inconsistent increase in plant height was observed with time from 30 to 90 DAS in line with the findings of Fredrick *et al.* (2015). Diversity in plant height was observed at country level with ANOVA results showing a significant difference in seedling height between countries (p <0.05) as seen in Table 2. The Malawi seed source showed the highest mean value (42.57 cm) at 90 DAS followed by Zambia (41.56 cm) and Zimbabwe (38.28 cm). *F. albida* seedlings from the South African region showed the best performance in terms of plant height at all data collection times with a mean seedling height of 39.80 cm at 90 DAS. It is probable that provenances from this region would better adapt to the conditions of the study area in Cameroon compared to provenances from other regions in this trial. This result is similar to that of Wanyancha (1994), which revealed a better performance in height growth for provenances from the southern African region compared to those from the East, even though the latter trial was carried out in Southern Africa while the former was done in Central Africa. Dangasuk *et al.* (1997) and (2001) in their provenance trials with *F. albida* reported that there was little variation among and within the Southern African and East African provenances in seedling height. However, in the current trial carried out in Central Africa, the local provenances did not perform better than one from other regions in Africa (Fig. 1). Differences in environmental conditions and genetic constitution of the planting material (and genotype-by–environment interactions) could influence growth performance of provenances from the different regions. Burley *et al.* (1986) pointed out that populations (West/Central African) at the limit of the species distribution at the border with the Sahara Desert are subject to high selection pressure and represent a genetically distinct geographic race. ANOVA results among regions in this trial also showed significant differences ($P<0.05$) in seedling height. Variation among provenances in seedling height growth at a common garden site has been reported for most tree species (Shu *et al.,* 2012, Fredrick *et al.,* 2015).

Table 2: ANOVA results for effects of provenance, country and region on mean values for plant height

Plant height (cm) at 90 DAS						
Country	**Provenance**	**Plant height (cm)**	**Country**	**Plant height (cm)**	**Region**	**Plant height (cm)**
Cameroon	Adoumri	37.5±19.1	Malawi	42.6±10.6^{b}	South	39.2±12.4^{b}
	Moulvoudaye	29±5.8	Zambia	41.6±11.5^{b}	East	35.3±14.5^{ab}
	Mokolo	25.5±4.9	Zimbabwe	38.3±12.1^{ab}	Center	27.0±9.8^{a}
	Mambang	17±9	Ethiopia	38.2±15.4^{ab}	**P-value**	**0.004**
Ethiopia	Rama	56 (1)	Namibia	32.5±15.2^{ab}		
	South Harar	37.4±14.7	Cameroon	27.0±9.5^{a}		
	Lake Koka	23.5	Tanzania	26.5±9.2 ^{ab}		
	Debre Zeit	NA	**P-value**	**0.00826**		
Tanzania	Mfumbi	26.5±9.2				
	Chawanje	45.7±6.8(3)				
Malawi	Nwanza River	43.3±6.7				
	Lupaso	43				
	Bolero	37.7±22.2				
Namibia	Okangwati	53 (2)				
	Kuiseb 84	33.7±17.9				
	Kuiseb 60	30.5±18.6				
	Hoanib River	26.5±10.2				
Zambia	Kafue Flats	42.3±9.4				
	Chinzombo	41.2±13.1				
Zimbabwe	Mana Pools	41.8±10.6				
	Manyoni River	41.5 0.7				
	Namepi	34.8±13.9				
	Gonarezhou	NA				
	P-value	**0.0734**				

DAS = Days after sowing, NA = Data not available. Means with the same letter are not significantly different at $p < 0.05$.


a)

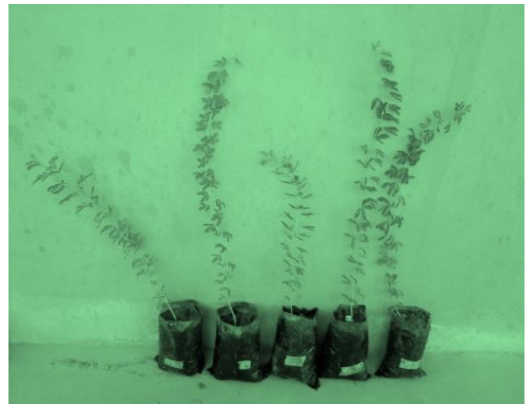
b)

Figure 1: Differences in seedling height: a) Cameroon provenances b) East and Southern Africa provenances

4.2 Root collar diameter: Seedling collar diameter ranged between means of 2 mm for the Lake Koka provenance in Ethiopia and 3.18 mm for the Kafue flats provenance in Zambia at 90 DAS. The development of the largest collar diameter by the latter provenance could mean that it adapted best to the experimental site conditions. The range of values obtained for diameter suggests the existence of genetic variability within and between provenances for that trait. The highest value for collar diameter (2.92 mm) at 90 DAS among source population at the country level was observed in Zambia followed by Zimbabwe (2.77 mm) and Malawi (2.74 mm). Seedlings of *F.albida* from the South African region showed the best performance at 90 DAS with respect to collar diameter. This confirms the positive correlation observed between plant height and collar diameter. Since the South African region showed the best performance for plant height, it follows that it should also have the best performance for collar diameter. There were however no significant differences in collar diameter between provenances, countries and regions as revealed by Kruskal-Wallis rank tests (Tab. 3). These results are contrary to those obtained by Koech *et al.* (2016) who reported significant differences in collar diameter between *F. albida* provenances. This non-compliance could be explained by the fact that the provenances used for the trials were not exactly the same. Differences in study locations and dates could also suggest differences in site and environmental conditions thus, varying results. According to Ibrahim *et al.* (1997) and Fredrick *et al.* (2015), provenances from the Southern African region had larger seedling collar diameters at all ages (months 1 to 5) than those from the Eastern African region, indicating that diameter growth in the early stages could predict diameter growth in the later stages. Dangasuk *et al.* (2001) however observed no significant differences in collar diameter between Southern and East African provenances. The Western African population however showed a significantly lower collar diameter than the two latter populations (Dangasuk *et al.,* 2001). According to Riemenschneider and McMahon (1993), such populations probably have a continuous pattern of genetic differentiation confirming the clonal pattern of variation observed in seed and seedling traits (Dangasuk *et al.,* 1997). Takuathung *et al.* (2012) however warns against the risk of using 'consistency in growth' as the only indicator for seed selection since collar diameter is very sensitive to environment.

Table 3: ANOVA results for effects of provenance, country and region on mean values of collar diameter

Collar diameter (mm) at 90 DAS						
Country	**Provenance**	**Collar diameter (mm)**	**Country**	**Collar diameter (mm)**	**Region**	**Collar diameter (mm)**
	Adoumri	2.4±0.2	Zambia	2.9±0.6 (1)	South	2.8±0.5
	Mambang	2.3±0.3	Zimbabwe	2.8±0.5 (2)	East	2.5±0.5
Cameroon	Mokolo	2.1±0.1	Malawi	2.7±0.5 (3)	Center	2.2±0.3
	Moulvoudaye	2.1±0.4	Namibia	2.6±0.5	**P-value**	**0.000**
	Rama	3 (2)	Ethiopia	2.5±0.6		
Ethiopia	South Harar	2.5±0.6	Tanzania	2.3±0.3		
	Lake Koka	2	Cameroon	2.2±0.3		
	Debre Zeit	NA	**P-value**	**0. 9979**		
Tanzania	Mfumbi	2.3±0.3				
	Lupaso	3 (2)				
Malawi	Bolero	2.8±0.6				
	Chawanje	2.7±0.4				
	Nwanza River	2.7±0.5				
	Okangwati	3 (2)				
Namibia	Kuiseb 84	3.0±0.6 (2)				
	Kuiseb 60	2.7±0.5				
	Hoanib River	2.2±0.4				
Zambia	Kafue Flats	3.1±0.6 (1)				
	Chinzombo	2.8±0.6				
	Mana Pools	2.9±0.4(3)				
Zimbabwe	Manyoni River	2.8±0.3				
	Namepi	2.6±0.5				
	Gonarezhou	NA				
	P-value	**0.0575**				

DAS = Days after sowing, NA = Data not available.

4.3 Number of leaves: *F. albida* seedlings from the provenance Nwanza River from Malawi recorded the highest mean leaf number (50) at 90 DAS, showing that it was probably best adapted to environmental conditions at the study site among the provenances tested. Although provenances from Cameroon did not show the best performance, they were not significantly different from the best provenances. ANOVA results revealed significant differences in mean leaf number between provenances (p-<0.05). The findings of this trial are similar to those of Dangasuk *et al.* (1997), Koech *et al.* (2016) and Fredrick *et al.* (2015) who observed highly significant differences in leaf number among provenances throughout all stages of growth from months 1 to 5. A variation in mean leaf number per seedling was also observed among countries in this study, ranging from 26 in Namibia to 45 in Malawi. ANOVA results showed significant differences between countries for this parameter ($p < 0.05$). The Central African region showed the highest mean leaf number (40) at 90 DAS with no significant differences between regions (Tab. 4). This is parallel to the findings of Fredrick *et al.* (2015) who observed that the East African provenances showed higher mean leaf number than those of Southern and West African provenances. Fredrick *et al.* (2015) observed significant correlations between some geo-climatic factors and number of leaves suggesting that variation due to seed source origin could affect seedling leaf production.

Nevertheless, variations in this study are likely to be genetic in basis since seeds from all provenances were grown under the same condition.

Table 4. ANOVA results for effects of *F. albida* provenances, country and regions on mean values for number of leaves

Number of leaves at 90 DAS						
Country	**Provenance**	**Number of leaves**	**Country**	**Number of leaves**	**Region**	**Number of leaves**
Cameroon	Mokolo	44.7±7.1^{ab}	Malawi	45.6±14.9 (1) ^{b}	Centre	39.0±14.7
	Adoumri	44.5±17.7^{ab}	Tanzania	42.5±9.2 (2) ^{ab}	South	38.6±14.1
	Moulvoudaye	42.6±13.7^{ab}	Zambia	41.8±12.4 (3) ^{ab}	East	36.25±10.1
	Mambang	21.3±11.9^{ab}	Cameroon	39±14.7^{ab}	**P-Value**	**0.891**
Ethiopia	Rama	49 (3) ^{ab}	Zimbabwe	37.3±11.9^{ab}		
	South Harar	33±8.0^{ab}	Ethiopia	34.2±10.2^{ab}		
	Lake Koka	24^{ab}	Namibia	26.3±13.0^{a}		
	Debre Zeit	NA	**P-Value**	**0.030**		
Tanzania	Mfumbi	42.5±9.2^{ab}				
Malawi	Nwanza River	50.1±14.8 (1) ^{b}				
	Chawanje	47.3±10.4^{ab}				
	Lupaso	40^{ab}				
	Bolero	35±20.2^{ab}				
Namibia	Okangwati	38^{ab}				
	Kuiseb 60	30.7±13.6^{ab}				
	Kuiseb 84	27±11.5^{ab}				
	Hoanib River	20.3±15.1^{a}				
Zambia	Kafue Flats	49.3±8.9 (2) ^{ab}				
	Chinzombo	37.3±12.3^{ab}				
Zimbabwe	Mana Pools	41.9±9.5^{ab}				
	Namepi	35.2±13.6^{ab}				
	Manyoni River	29.5±6.4^{ab}				
	Gonarezhou	NA				
	P-Value	**0.0291**				

DAS = Days after sowing, NA = Data not available. Means with the same letter are not significantly different at $p < 0.05$

4.4 Number of bi-pinnate leaves: The findings of this trial revealed a variation in the mean number of bi-pinnate leaves which ranged from 36 for seedlings from Hoanib River in Namibia to 113 from Kafue flats in Zambia. There was no significant difference in mean number of bi-pinnate leaves between provenances overall however. It was also observed that some individuals had four while others had up to six leaflets, thus, Nwaza River which had the highest number of leaves did not record the highest number of bi-pinnate leaves. ANOVA results revealed no significant variation in the number of bi-pinnate leaves at the country level. However, Malawi had the highest number of bi-pinnate leaves at 90 DAS. The highest mean number of bi-pinnate leaves (87) at 90 DAS was obtained from the South African region. There was however no significant variation in number of bi-pinnate leaves among regions as revealed by ANOVA results (Tab. 5).

Table 5: ANOVA results for effects of provenances, country and region on mean number of bi-pinnate leaf

Number of bi-pinnate leaves at 90 DAS						
Country	**Provenance**	**Number of bi-pinnate leaves**	**Country**	**Number of bi-pinnate leaves**	**Region**	**Number of bi-pinnate leaves**
Cameroon	Mokolo	89.3 ±14.2	Malawi	99.5 ± 33.3 (1)	South	87.0±33.8
	Moulvoudaye	8696±28.7	Zambia	97.5±33.1 (2)	Centre	78.1±29.3
	Adoumri	84±28.3	Tanzania	86±19.8 (3)	East	73.5±20.8
	Mambang	42.7±23.9	Zimbabwe	80.5±24.7	**P-Value**	**0.391**
Ethiopia	Rama	100 (3)	Cameroon	78.1±29.3		
	South Harar	67±16.2	Ethiopia	69.3±21.0		
	Lake Koka	48	Namibia	65.8±42.0		
	Debre Zeit	NA	**P-Value**	**0.072**		
Tanzania	Mfumbi	86 ±19.8				
Malawi	Nwanza River	108.4±33.6 (2)				
	Lupaso	100 (3)				
	Chawanje	95.3±18.2				
	Bolero	82.7±52.6				
Namibia	Kafue Flats	113.3±21.8 (1)				
	Chinzombo	88±35.9				
	Kuiseb 84	78.7±54.8				
	Okangwati	78				
Zambia	Kuiseb 60	78±46				
	Hoanib River	36.67±31.8				
Zimbabwe	Mana Pools	90.6 ±19.6				
	Manyoni River	75±7.1				
	Namepi	73.4±28.7				
	Gonarezhou	NA				
	P-value	**0.141**				

DAS = Days after sowing, NA = Data not available.

4.5 Number of branches: The outcome of this trial showed no significant differences in mean number of branches at the provenance, country and regional levels. On average, seedlings had only one branch at each level. However, Mana pools recorded the highest mean number of branches (1.88) at the level of the provenances. Among countries Malawi had the highest mean number of branches (1.71) and the South African region had the highest number of branches among regions (Tab. 6). This result contrasts with those of Dangasuk *et al.* (2001) who observed a significant difference in branch number between provenances and regions in 6 month old *F. albida* in a field trial.

Table 6: ANOVA results for mean number of *F. albida* branches per provenance, country and region.

No. of branches at 90 DAS						
Country	**Provenance**	**No. of branches**	**Country**	**No. of branches**	**Region**	**No. of branches**
Cameroon	Moulvoudaye	1.57±1.0	Malawi	1.7±1.2	South	1.5±0.9
	Mambang	1.33±0.6	Zimbabwe	1.7±1.0	Centre	1.3±0.7
	Mokolo	1±00	Tanzania	1.5±0.7	East	1.1±0.4
	Adoumri	1±00	Cameroon	1.3±0.7	**P-Value**	**0.443**
Ethiopia	Rama	1	Zambia	1.3±0.5		
	South Harar	1±00	Namibia	1.2±0.6		
	Lake Koka	1	Ethiopia	1±00		
	Debre Zeit	NA	**P-Value**	**0.097**		
Tanzania	Mfumbi	1.50±0.7				
Malawi	Nwanza River	1.86±1.5 (2)				
	Bolero	1.67±1.5				
	Chawanje	1.67±1.2				
	Lupaso	1				
Namibia	Kafue Flats	1.50±0.6				
	Chinzombo	1.10±0.3				
	Kuiseb 60	1.67±1.2				
	Kuiseb 84	1±00				
Zambia	Okangwati	1				
	Hoanib River	1±00				
Zimbabwe	Mana Pools	1.9±1.5 (1)				
	Namepi	1.7± 0.7 (3)				
	Manyoni River	1±00				
	Gonarezhou	NA				
	P-Value	**0.993**				

DAS = Days after sowing, NA = Data not available.

4.6 Number of bi-pinnate leaves at the last formed leaf: This parameter, like leaf area provides information on the photosynthetic activity of the plant as the higher number of blooming leaf pairs implies a higher rate of photosynthesis. A significant difference was observed between provenances with Chawanje showing the highest (15) mean number of bi-pinnate leaves at the last open axillary bud. This could possibly mean the existence of a great genetic variability as shown by Koech *et al.* (2016) in a test on the "variation of the response of *F. albida* provenances from East and Southern Africa to water supply. Malawi recorded the highest mean value (13.29) at 90 DAS and ANOVA revealed a significant variation among countries for this parameter. The South African region stood out with the highest mean number (11.43) of bi-pinnate leaves at the youngest open axillary bud which was significantly higher than the Central African region but showed no significant difference with the East African region (Tab. 7). These results suggest the possibly of a better adaptability of provenances from the South compared to those from the East for this trait. The result of this trial is at variance with those of Wanyancha, (1994) on the genetic variation of *Acacia albida* and its agroforestry potential in Zimbabwe however.

Table 7: ANOVA results for mean number of bi-pinnate leaves of *F. albida* at the youngest open axillary bud per provenance, country and region.

bi-pinnate leaves at youngest open axillary bud at 90 DAS						
Country	**Provenance**	**bi-pinnate leaves at youngest open axillary bud**	**Country**	**bi-pinnate leaves at youngest open axillary bud**	**Region**	**bi-pinnate leaves at youngest open axillary bud**
Cameroon	Adoumri	7.5±0.7[a]	Malawi	13.3±4.1 (1) [b]	South	11.4±4.2[a]
	Mambang	7±1[a]	Zambia	12.2±3.9 (2) [b]	East	9.9±1.6 [b]
	Moulvoudaye	6.4±2.2[a]	Namibia	10.7±5.4 (3) [ab]	Centre	6.6±1.6[b]
	Mokolo	6±1[a]	Ethiopia	10.3±1.6[ab]	**P-Value**	**0.000**
Ethiopia	Lake Koka	12[ab]	Zimbabwe	9.9±3.6[ab]		
	South Harar	10.3±1.7[ab]	Tanzania	8.5±0.7[ab]		
	Rama	9[a]	Cameroon	6.6±1.6[a]		
	Debre Zeit	NA	**P-Value**	**0.000**		
Tanzania	Mfumbi	8.5±0.7[a]				
	Chawanje	15.7±4.2 (1) [b]				
Malawi	Bolero	13.3±1.5[b]				
	Nwanza River	12.7±4.9[b]				
	Lupaso	10[ab]				
Namibia	Chinzombo	12.9±3.8[b]				
	Kafue Flats	11±4.1[ab]				
	Kuiseb 60	14.3±3.1 (2) [b]				
	Kuiseb 84	11±4.4[ab]				
Zambia	Hoanib River	8±2[a]				
	Okangwati	7[a]				
Zimbabwe	Namepi	9.3±3.2[ab]				
	Manyoni River	13.5±7.8 (3) [b]				
	Mana Pools	9.8±3.1[ab]				
	Gonarezhou	NA				
	P-Value	**0.016**				

DAS = Days after sowing, NA = Data not available. Means with the same letter are not significantly different at $p < 0.05$

5 Survival Rate

5.1 Provenance, country and region effects: The rate of survival is an indicator of adaptability of plants from a provenance to site conditions. A decrease in survival rate was observed throughout the trial ranging from 59.56% at 30 DAS to 36.09 % at 90 DAS. These results are in line with those of Vandenbeldt (1992) and Bastide and Diallo (1994), who reported a high mortality rate *in F. albida.* A continuous decrease in survival rate was observed from 30 DAS to 90 DAS for most provenances with some (Debre zeit and Gonarezhou) having completely died out at 90 DAS. Exceptionally, two provenances (Chinzomo and Namepi Mana pools) maintained 100 % survival rate at the end of the trial. The latter provenances seemed to be better adapted to the study site conditions whereas others were much less so (Fig. 2). This signifies the existence of genetic diversity for survival within *F. albida* provenances as reported by Koech *et al.* (2016) in a trial on the variation in the response of East and Southern African provenances of *F. albida* plants to water supply in a greenhouse. Zambia showed the highest survival rate (80 %) at 90 DAS followed by Zimbabwe with 50 % (Fig. 3). The South African region had the best performance in terms of seedling survival compared to the Central and East African regions (Fig. 4). It is possible that plants from the South African region are better adapted to the study site conditions. The result of this study parallels those of Vandenbeldt (1992), who observed that plants from southern Africa completely died out in a provenance trial in Niger whereas those from West Africa survived.

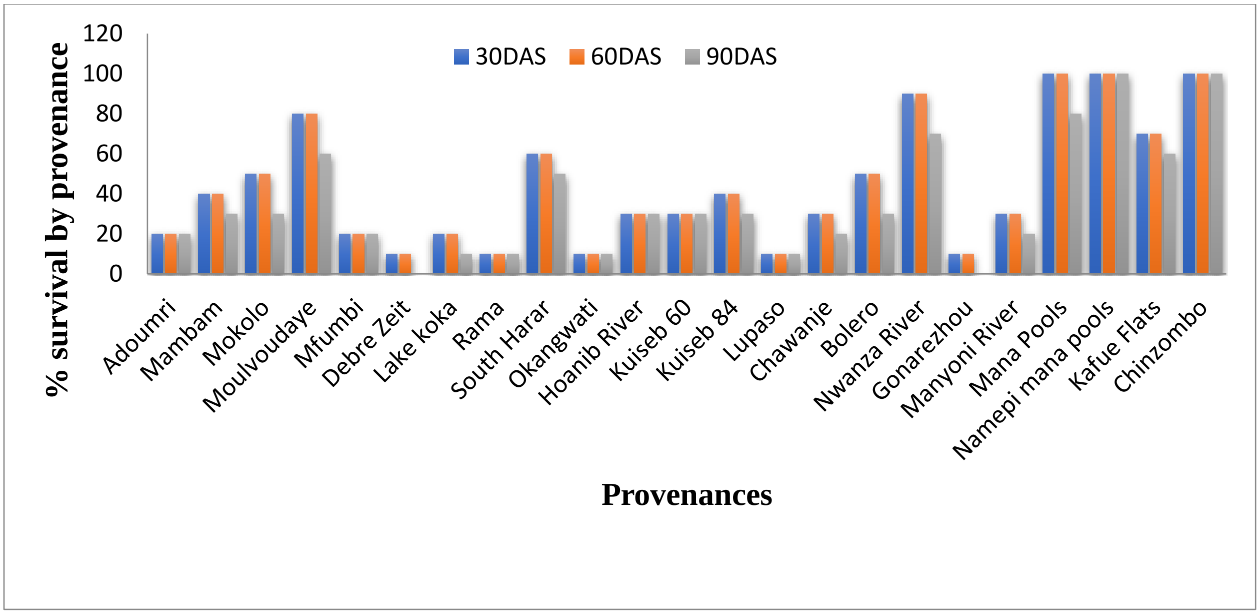

Figure 2. Seedling survival of *F. albida* seed provenances at 30, 60 and 90 DAS

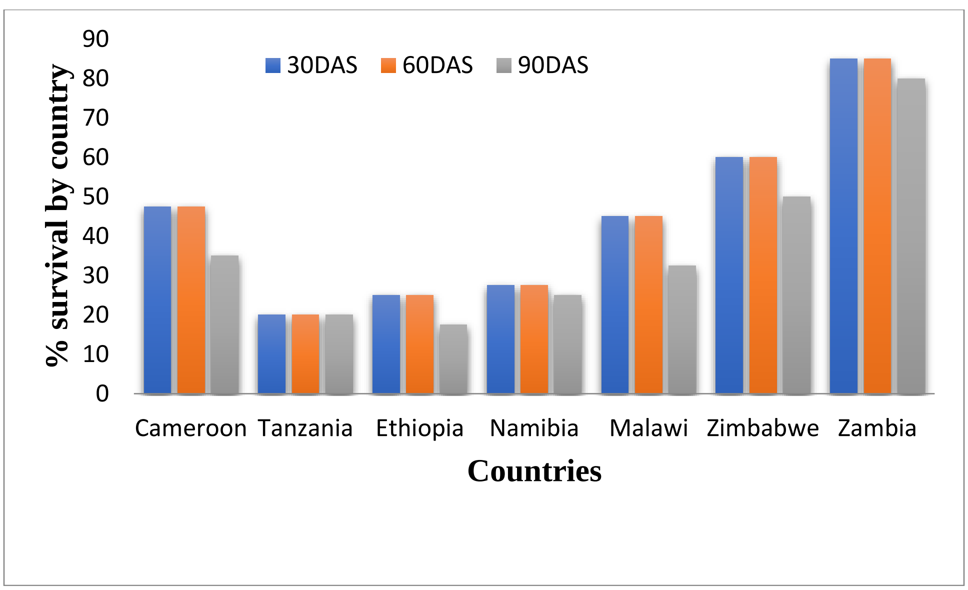

Figure 3: Seedling survival of *F. albida* in relation to country of seed origin

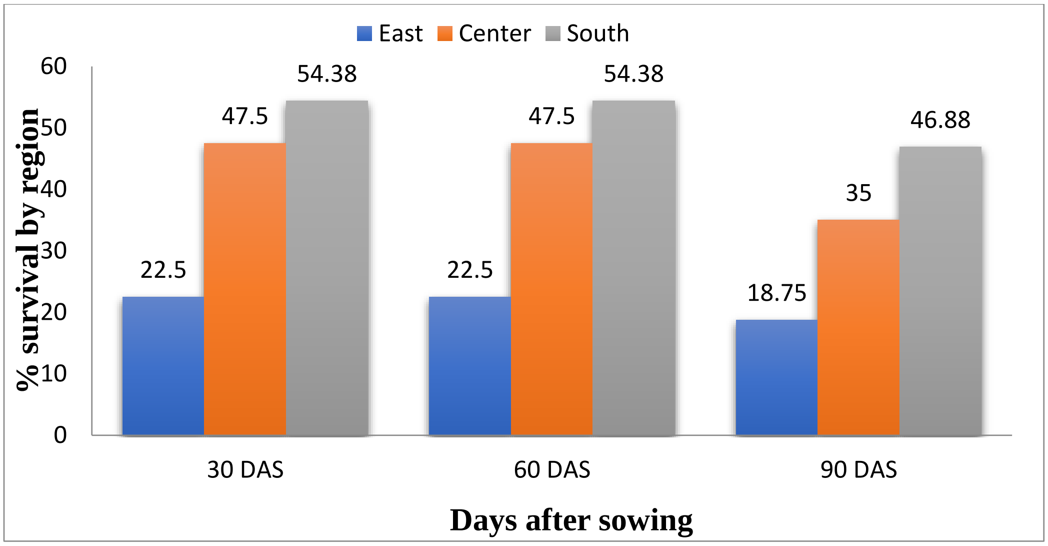

Figure 4. Survival rate of *F. albida* seedlings with respect to region of seed origin.

Table 8. Correlation matrix between measured parameters

Growth traits	Dia	Ht	Nb	NL	Nf	Npf
Dia	1	0.57	0.11	0.51	0.59	0.36
Ht	0.57	1	-0.18	0.58	0.65	0.41
Nb	0.11	-0,18	1	0.26	0.16	-0,14
NL	0.51	0.58	0.26	1	0.92	0.08
Nf	0.59	0.65	0.16	0.92	1	0.27
Npf	0.36	0.41	-0,14	0.08	0.27	1

HT: Height of the plant **Dia:** Root collar diameter **NB:** Number of branches **NL:** Number of leaves **Nf:** Number of leaflet **Npf:** Number of bi-pinnate leaves.

A PCA conducted for all measured parameters revealed a positive correlation between plant height and root collar diameter which were also positively correlated with number of leaves (Tab. 8). An increase in root collar diameter resulted in a corresponding increase in plant height, number of leaves and number of leaflets. One of these parameters can thus serve as a function of the others. A positive correlation was also observed between collar diameter and seed length (data not reported here), in line with Frederick *et al.* (2015) in a study on the provenance variation in seed morphological characteristics, germination and early seeding growth of *F. albida.* On the other hand, the number of branches was negatively correlated to plant height and number of pairs of leaflets at the last open leaf. Loha *et al.* (2006) and Shu *et al.* (2012) observed that correlated quantitative characters are very important for an improvement program, as the improvement of one character may cause concurrent changes in the other character.

6 CONCLUSION

The advantages of *F. albida* are well known. The species is well suited to the agroforestry systems in the Sahel zone because of the multiple services and products it offers (nitrogen fixation, erosion control, supply of timber, firewood and forage). The species evolves in harsh and severe conditions characterized by rare and irregular precipitation, high temperature, as well as high evaporation amplified by winds blowing almost all year round. It is however, highly threatened in the far North region of Cameroon by human activities and climate change. The extirpation of the species would risk food security for many in the region thus, the necessity to put in place a tree improvement program to ensure its perpetuity. This trial on the performance evaluation of 23 provenances from across the natural range of *Faidherbia albida* in a common garden in the Far North region of Cameroon, was aimed at better determining the diversity of adaptability to this environment for subsequent application in local tree improvement. Plant height measurements between 17 ± 9 cm (Mambang) and 56 cm (Rama) revealed a large variation in seedling growth potential at this site. With such rapid growth, the provenance of Rama would more readily escape damage caused by animals. Kafue flats provenance expressed the best performance (3.18 mm) for root collar diameter increment. The provenance of Nwanza River had the greatest number of leaves (51.14 ± 14.78), followed by Kafue Flats (49.33 ± 8.98) and Rama (49). The number of pairs of leaflets at the last open leaf had a minimum of 6 ± 1 (Mokolo) and a maximum of 15.67 ± 4.16 (Chawanje). The provenance Chawanje should therefore have a more intense photosynthetic activity than that of the other provenances during the trial period. A few individuals from the provenance Mana pools had two to three branches at the end of the test being the best performance in this trait. The provenance Nwanza River was among the best performance for number of leaves, number of bi-pinnate leaf, number on branches and survival. This provenance should thus adapt better overall than the others to the conditions of this trial and could therefore contribute to increasing the genetic diversity of *F. albida* in Cameroon through incorporation with, or through breeding with native populations. Malawi in South Africa had the highest values for growth traits at the country level, contributed equally by all the provenances within that country. However, Rama in East Africa was observed to have registered the highest values among provenances overall for growth traits. In this experiment, some provenances expressed better performance in survival than others. For example, the provenances of Chinzombo and Namepi Mana Pools both had less mortality in their seeded individuals than other provenances until the end of the test, each exhibiting a survival rate of 100%. These provenances are possibly adapted better than all others to the overall conditions of the test. Rama ranked highest in growth traits but lowest in survival rate and number of branches. Although this East Africa provenance did well in growth traits, survival was very low in the trial. Generally, provenances from the South African region expressed the best performance in this study being highest in both growth characteristics and survival. These provenances could positively contribute to increasing the genetic diversity of *F. albida* resources in Cameroon for establishment of tree improvement program by breeders. This field trial result may not be a complete surprise given that on-going genotyping results indicated that provenances from Cameroon may have originated from East Africa (personal communication) and low performance from both regions is an indication of similarity in their genotypes as well as their phenotypes. The ongoing genotyping results from these provenances should be able to confirm this observation. Through this study, provenances with high survival rate as well as good growth performance in the Far North region of Cameroon have been identified which therefore are likely to have the capacity to adapt well in this zone.

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