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International Journal of Scientific Research in Agricultural Sciences

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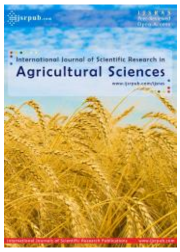
International Journal of Scientific Research in Agricultural Sciences, 3(2), pp. 042-049, 2016
Available online at http://www.ijsrpub.com/ijsras
ISSN: 2345-6795; ©2016; Author(s) retain the copyright of this article
http://dx.doi.org/10.12983/ijsras-2016-p0042-0049



Full Length Research Paper

Growth Performance and Fruit Production of *Sclerocarya birrea* (A. Rich.) Hochst. Provenances in Malawi

Violet Msukwa[1,2], Chimuleke R.Y. Munthali[1], Edward Missanjo[3]*, Clement Z. Chilima[4], Simon A. Mng'omba[5], Willie Sagona[2], Idah Mkwezalamba[2]

[1]Department of Forestry, Mzuzu University, Private Bag 201, Luwinga, Mzuzu 2, Malawi
[2]Forestry Research Institute of Malawi, P.O. Box 270, Zomba, Malawi
[3]Department of Forestry, Malawi College of Forestry and Wildlife, Private Bag 6, Dedza, Malawi
[4]Department of Forestry Headquarters, P.O. Box 30048, Lilongwe 3, Malawi
[5]World Agroforestry Centre, ICRAF-Southern Africa Regional Programme, Chitedze Research Station, P.O. Box 30798, Lilongwe 3, Malawi
*Corresponding Author: edward.em2@gmail.com

Received 19 February 2016; Accepted 12 May 2016

Abstract. Domestication and commercialization of fruits from indigenous trees plays a major role in improving rural livelihoods through nutritional status, household income, entrepreneurial opportunities and economic empowerment. It also plays a role in promoting conservation of biodiversity and the sustainable use of natural resources. This study was conducted to assess twenty-two provenances of *Sclerocarya birrea* (A. Rich.) Hochst. planted in 1999 in Mangochi, Malawi. The trial was assessed for growth traits and fruiting at twelve years of age. The results showed that there were significant (P<0.001) variations among the provenances on diameter at breast height (dbh), tree height, number of branches and number of fruits. Marracuene provenance from Mozambique had the largest (14.2±0.8cm) dbh, the highest number of branches per tree (21±1) and number fruits per tree (795±104) than the other provenances. Kalanga provenance from Swaziland was more superior in tree height (6.10±0.93m) than the other provenances. There was a significant (P<0.05) correlation between number of fruits and dbh and between number of fruits and tree height. A moderate relationship (r=0.405) was observed between number of fruits and dbh, while a weak relationship (r=0.347) was detected between number of fruits and tree height. However, there was no significant (P>0.05) correlation between number of fruits and number of branches. This implies that growth parameters are weak predictors for fruiting hence cannot be used in indirect selection. Therefore, genetic factor is the major determining factor of fruiting. Future studies should concentrate on the reproductive biology of *S. birrea* to facilitate understanding of fruit productivity prior to promoting the species for Agroforestry programmes.

Keywords: correlation, domestication, fruit yield, growth traits, *Sclerocarya birrea*

1. INTRODUCTION

Tree domestication refers to how humans select, manage and propagate trees (Simons and Leakey, 2004). Domestication and commercialization of fruits from indigenous trees plays a major role in improving rural livelihoods through nutritional status, household income, entrepreneurial opportunities and economic empowerment. Addition, it also plays a role in promoting conservation of biodiversity and the sustainable use of natural resources (Akinnifesi et al., 2007). However, producing improved elite cultivars with superior fruit and traits requires conscious domestication (Akinnifesi et al., 2006).

Sclerocarya birrea (A. Rich) Hochst. is a member of the Anacardiaceae family (Masarirambi and Nxumalo, 2012; Mng'omba, 2012). It is a dioeciously multipurpose fruit tree that is common and widespread species throughout the semi-arid, deciduous savannas of much of sub-Saharan Africa (Shackleton et al., 2002a). Ecological distribution, biological description and uses of *Sclerocarya birrea* are well explained by Mkwezalamba et al. (2015) and Nyoka et al. (2015). Briefly, *Sclerocarya birrea* has been for a long time used to supplement diets in time of critical food shortages and income generation in Southern Africa (Wynberg et al., 2002). FAO estimated that 80% of the populations in developing countries use NTFP to meet their needs in health and nutrition (FAO, 1997). The tree of *Sclerocarya birrea* is famously known because of its fruits which are used to make products of economic importance such as Amalura beer and the oil which are sold worldwide. The oil is highly valued for the cosmetic industry both in Southern Africa and Europe (Shackleton, 2002).

However sustainable supply of *Sclerocarya birrea* fruits is being challenged by the high rate of deforestation and rampant fires taking place in the miombo woodlands (Chirwa et al., 2007). It is envisaged that adequate supply of *Sclerocarya birrea* products can be attained through domestication.

For two decades, the World Agroforestry Centre (ICRAF) has spearheaded research and development activities on tree portfolios for the production of edible fruits in its indigenous tree domestication program in Southern Africa. Some of the ICRAF tree domestication initiatives were focused on *Sclerocarya birrea, Uapaca kirkiana, Strychnos cocculoides, Vangueria infausta, Parinari curatellifiolia, Ziziphus mauritiana, Adansonia digitata, Sizygium cordatum (Gaertner)* and *Vitex species* (Akinnifesi et al., 2008). The philosophy of the ICRAF's Agroforestry Tree Domestication Programme was to build on the desire of local people to cultivate indigenous fruits and nuts and enhance the ways in which these species promote food and nutritional security, increase household income, create employment and diversify farming systems and the rural economy (FAO, 1997).

Sclerocarya birrea was identified as one of the priority Miombo wild fruit tree species for domestication in the SADC region (Akinnifesi et al., 2004). For this reason, an International Provenance Trial of *Sclerocarya birrea* was established in Malawi by ICRAF in conjunction with the Forestry Research Institute of Malawi (FRIM) in 1999 with funds from the Canadian International Development Agency (CIDA). The objective was to ascertain the natural variability in wild populations by evaluating growth and fruiting parameters in order to identify superior genotypes which would be used in the domestication program (Chirwa et al., 2007). According to other researchers (Dawson et al., 1995), understanding of species biology, sources of variations among populations and responses to the environment are paramount to successful domestication. However, growth performance and fruit production information for *S. birrea* are scanty and anecdotal. The information is vital in designing strategies for domestication, conservation and breeding. A preliminary study on growth performance and fruit yielding for a *S. birrea* trial in Malawi was conducted at the age of three years (Chirwa et al., 2007) and seven years (Nyoka et al., 2015) after out-planting and recommended a continuous research for several consecutive years to fully establish the genetic and phenotypic characteristics of *S. birrea*. Therefore, the present study was conducted with an aim to determine the variations in growth performance (Tree height, diameter at breast height, number of branches) and fruit production of *S. birrea* provenances at the age of twelve years.

2. MATERIALS AND METHODS

2.1. Study Site and Experimental Material

The study site and experimental material has been well described by Mkwezalamba et al. (2015) and Nyoka et al. (2015). Briefly, the trial was established in February 1999 in the Palm Forest Research, Mangochi (14°28'S, 35°14'E, and 469 m above sea level) with twenty populations of *S. birrea ssp. caffra* and one population of *S. birrea ssp. birrea* (Table 1). The trial was laid out as a randomized complete block design replicated four times. The plot size was a 20-tree row plot. The spacing was 5 m between row plots and 4 m between trees within a plot. There were therefore 80 trees per population in the test.

2.2. Data Collection

At the age of 12 years after out planting the trees were assessed for diameter at breast height (1.3m) in centimeters, tree height in meters, number of branches and number of fruits. The assessment was done on an individual tree basis. Tree diameter at breast height (dbh) was measured using a caliper. In case of multiple stems per stump the largest was measured and those trees forking below 1.3 m were measured separately and averaged. Tree height was measured using a graduated range rod. The number of branches and fruits per tree were counted and recorded.

2.3. Statistical Analysis

The data on dbh, tree height, number of branches and number of fruits obtained were tested for normality and homogeneity with Kolmogorov-Smirnov D and normal probability plot tests. After the two criteria were met the data were subjected to analysis of variance (ANOVA) using GenStat for Windows version 17 (VSN, 2014). Means were separated with Fischer's least significant difference (LSD) at the 0.05 significance level. Pearson correlation coefficients were calculated to determine the relationship between fruit production and growth traits (dbh, tree height, number of branches).

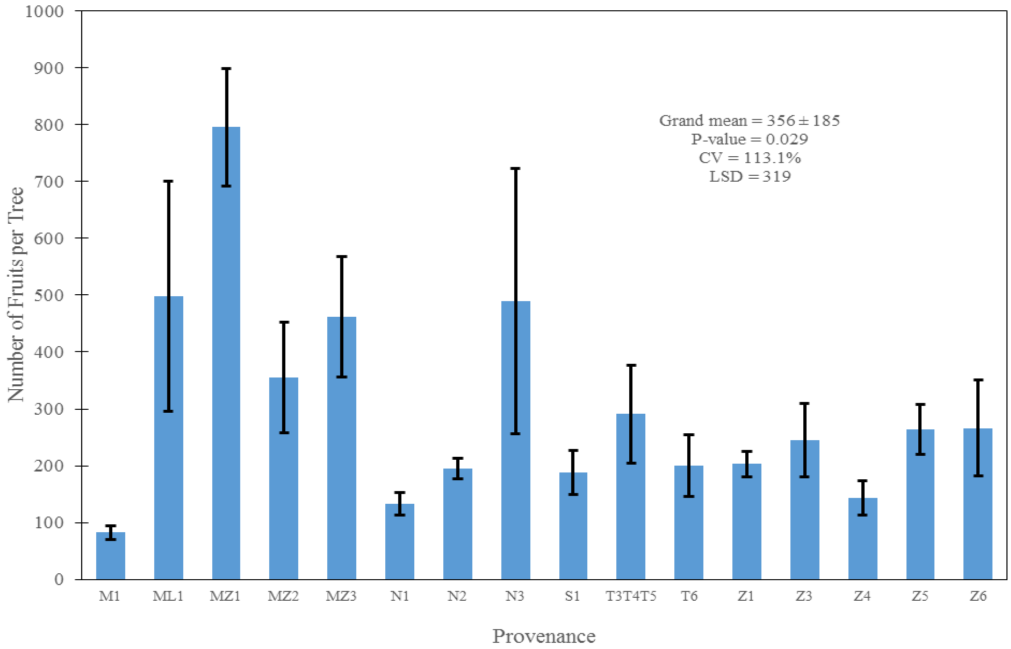


Fig. 1: Variation in number of fruits per tree among provenances of *S. birrea* in Malawi

Table 1: Details of *S. birrea* populations tested in Malawi

Country-Population	Code	Species	Number of families	Latitude	Longitude	Elevation (m)
Malawi						
Chikhwawa	ML1	*S. birrea ssp caffra*	10	16°46'S	35°17'E	100-300
Mangochi	ML2	*S. birrea ssp caffra*	20	14°02'S	34°53'E	200-600
Ntcheu	ML3	*S. birrea ssp caffra*	19	14°39'S	34°46'E	300-600
Rumphi	ML4	*S. birrea ssp caffra*	20	10°59'S	33°45'E	900-1200
Mozambique						
Marracuene	MZ1	*S. birrea ssp caffra*	17	25°58'S	32°95'E	0 – 200
Magunde	MZ2	*S. birrea ssp caffra*	20	24°95'S	32°92'E	0 – 200
Moamba	MZ3	*S. birrea ssp caffra*	20	25°55'S	32°55'E	0 – 200
Namibia						
Oshikondilingo	N1	*S. birrea ssp caffra*	16	17°40'S	15°40'E	1030
Ohangwena	N2	*S. birrea ssp caffra*	15	17°35'S	16°49'E	1144
Kalimbeza	N3	*S. birrea ssp caffra*	20	17°34'S	24°31'E	967
Zambia						
Siavonga	ZA2	*S. birrea ssp caffra*	16	16°30'S	28°00'E	520
Choma	ZA3	*S. birrea ssp caffra*	14	17°00'S	27°00'E	1300
Zimbabwe						
Ngundu	Z1	*S. birrea ssp caffra*	13	20°50'S	32°05'E	457
Mudzi	Z2	*S. birrea ssp caffra*	15	16°17'S	32°45'E	400
Biriwiri	Z3	*S. birrea ssp caffra*	15	19°50'S	32°40'E	1500
Mzarabani	Z4	*S. birrea ssp caffra*	15	16°35'S	32°27'E	600
Matebeleland N*	Z5	*S. birrea ssp caffra*	14	18°00'S	28°00'E	996
Matebeleland S*	Z6	*S. birrea ssp caffra*	15	21°00'S	32°01'E	388
Swaziland						
Kalanga	S1	*S. birrea ssp caffra*	20	26°45'S	31°45'E	239
Tanzania						
Mkata-Kilosa	T3	*S. birrea ssp caffra*	P	7°22'S	37°50'E	430
Ubena-Bangamoyo	T4	*S. birrea ssp caffra*	P	6°11'S	38°10'E	305
Chalinze-Bangamoyo	T5	*S. birrea ssp caffra*	P	6°55'S	38°20'E	550
Magamba-Turiani	T6	*S. birrea ssp caffra*	9	5°40'S	38°12'E	530
Mali						
Missira	M1	*S. birrea ssp birrea*	19	13°43'N	8°27'W	352

P= Pooled provenance due to low seedling numbers during trial establishment; *Locality name not given

3. RESULTS

3.1. Variation in Growth Parameters among Provenances

The results on growth parameters (dbh, tree height and number of branches) are presented in Table 2. The results indicate that there were significant (*P*<0.001) differences among provenances on all the growth traits studied. The dbh ranged from 5.6 cm to 14.2 cm. The most outstanding dbh growth was Marracuene provenance (14.2±0.8 cm) from Mozambique. Superior dbh growth was also attained in Kalimbeza provenance (12.7±1.0 cm) from Namibia, Ngundu provenance (12.1±1.0 cm) from Zimbabwe, Moamba (11.9±1.2 cm) and Magunde (11.7±0.9 cm) provenances from Mozambique. The least dbh growth was Choma (7.0±0.8 cm) and Missira (5.6±1.0 cm) from Zambia and Mali, respectively. The Coefficient of variation in dbh was 52.9%.

The results show that tree height growth ranged from 3.22 m to 6.10 m. The most outstanding tree height growth was Kalanga provenance (6.10±0.93 m) from Swaziland. Greater tree heights growths were also evident in Kalimbeza provenance (5.99±0.31 m) from Namibia and Marracuene provenance (5.82±0.26 m) from Mozambique. The lowest tree heights growth were observed in Rumphi provenance (3.68±0.33 m) from Malawi, Missira provenance from Mali (3.47±0.31 m) and Choma provenance (3.22±0.26 m) from Zambia. The Coefficient of variation was 34.4 %.

The number of branches per tree ranged from 14 to 21. The results indicated that Marracuene provenances from Mozambique had the highest (21±1) number of branches per tree followed by Kalimbeza, Magunde, Mangochi and Missira provenances with 20±1 branches per tree each. Kalanga, Matebeleland South, Mudzi and Rumphi provenances had the least number of branches (14±2). The Coefficient of variation in number of branches per tree was 41.6%.

3.2. Variation in Fruit Productivity among Provenances

There was great variability among the 22 provenances in fruit productivity. Sixteen provenances were fruiting representing 73%. The number of fruits among provenances ranged from 83 to 795 (Figure 1). The most outstanding fruit producer was Marracuene provenance (795±104) from Mozambique. Superior results were also attained in Chikhwawa provenance (498±202) from Malawi, Kalimbeza provenance (489±233) from Namibia and Moamba provenance (462±106) from Mozambique. The least fruit producers were Missira provenance (83±12) from Mali, Oshikondilingo provenance (133±19) from Namibia and Mzarabani provenance (144±30) from Zimbabwe.

3.3. Relationship between Fruit Production and Growth Traits

There were no significant (*P*>0.05) correlations between number of fruits and number of branches. However, there was a significant (*P*<0.05) correlation between number of fruits and dbh and between number of fruits and tree height. A moderate relationship (r=0.405) was observed between dbh and number of fruits per tree, while a weak relationship (r=0.347) was detected between tree height and number of fruits per tree (Table 3).

4. DISCUSSION

4.1. Variation in Growth Parameters among Provenances

The rate of difference was 60% between the largest and smallest dbh. Marracuene provenance from Mozambique, with a dbh of 14.2±0.8 cm at the age of 12 years maintained its superior as it was also top ranked provenance for dbh at age 7 years after planting (Nyoka et al., 2015). The trait for vigorous vegetative growth is good for selection in the domestication process (Shackleton, 2002). The results also revealed high Coefficient of variation of 52.9% between and within provenances which indicates high variability among the wild genotypes of *S. birrea* that provides more chance for selection to be done both at provenance and individual level in domestication and tree improvement programs. Selection at an individual or family level is highly valued and commonly used by geneticists in selection and breeding program (Zobel and Talbert, 1984). Currently, genetic influence remains the most determining factor in fruit production.

The outstanding tree height growth attained in Kalanga provenance from Swaziland provenance, Kalimbeza provenance from Namibia and Marracuene provenance from Mozambique showed good adaptability to the site. Variability revealed in height growth between the tallest and the shortest provenance was 66%. Similar results were reported in an earlier assessment when the trees were just six months old (Munthali and Chirwa, 1999), at the age of three years (Chirwa et al., 2007) and at the age of seven years (Nyoka et al., 2015) after out planting. Current results mirror what Munthali and Chirwa (1999) noted that under similar environmental conditions the differences in growth were strongly due to the influence of genotype. Earlier studies reported that Marracuene provenance was the only most outstanding; however, the current study has revealed several provenances doing well with Kalanga, Kalimbeza and Marracuene provenances being outperformers signifying good adaptability to the site. This implies that foreign genotypes can be grown in Malawi.

Table 2: Mean diameter at breast height (dbh), height and number of branches per tree of twelve years' old *S. birrea* provenances in Malawi

Country-Population	Code	DBH (cm)	Height (m)	Number of branches per tree
Malawi				
Chikhwawa	ML1	10.7 ± 1.0	4.32 ± 0.31	15 ± 1
Mangochi	ML2	10.6 ± 0.9	5.10 ± 0.27	20 ± 1
Ntcheu	ML3	8.3 ± 0.9	4.61 ± 0.27	17 ± 1
Rumphi	ML4	7.3 ± 1.1	3.68 ± 0.33	14 ± 2
Mozambique				
Marracuene	MZ1	14.2 ± 0.8	5.82 ± 0.26	21 ± 1
Magunde	MZ2	11.7 ± 0.9	5.01 ± 0.27	20 ± 1
Moamba	MZ3	11.9 ± 1.2	4.70 ± 0.38	19 ± 2
Namibia				
Oshikondilingo	N1	7.7 ± 1.7	4.48 ± 0.54	16 ± 2
Ohangwena	N2	7.3 ± 0.9	4.90 ± 0.29	15 ± 1
Kalimbeza	N3	12.7 ± 1.0	5.99 ± 0.31	20 ± 1
Zambia				
Siavonga	ZA2	10.9 ± 1.0	5.21 ± 0.31	19 ± 1
Choma	ZA3	7.0 ± 0.8	3.22 ± 0.26	18 ± 1
Zimbabwe				
Ngundu	Z1	12.1 ± 1.0	4.49 ± 0.31	15 ± 1
Mudzi	Z2	8.5 ± 1.0	4.36 ± 0.31	14 ± 1
Biriwiri	Z3	10.0 ± 1.7	4.59 ± 0.54	17 ± 2
Mzarabani	Z4	9.8 ± 0.8	4.77 ± 0.27	17 ± 1
Matebeleland N	Z5	7.6 ± 1.2	4.26 ± 0.38	15 ± 2
Matebeleland S	Z6	7.9 ± 1.5	4.28 ± 0.46	14 ± 2
Swaziland				
Kalanga	S1	8.7 ± 3.0	6.10 ± 0.93	14 ± 4
Tanzania				
Pooled	T3/T4/T5	11.1 ± 1.0	5.29 ± 0.33	19 ± 2
Magamba-Turiani	T6	9.0 ± 1.1	4.51 ± 0.33	17 ± 2
Mali				
Missira	M1	5.6 ± 1.0	3.47 ± 0.31	20 ± 1
Grand Mean		9.8 ± 1.7	4.66 ± 0.52	17 ± 2
CV (%)		52.9	34.4	41.6
P-value		<0.001	<0.001	<0.001
LSD		3.3	1.03	2

Note: mean values are followed by standard errors

Table 3: Relationship between fruit production and growth traits in *S. birrea* in Malawi

	Number of fruits	Tree height	Number of branches
Diameter at breast height	0.405*	0.545**	0.220*
Number of fruits		0.347*	0.065^{ns}
Tree height			0.052^{ns}

** Significant at *P*<0.001,* significant at *P*<0.05 and ^{ns} not significant with r–values

The mean difference was 50% between the highest and lowest number of branches. Several provenances in the trial performed well in this trait more especially, Marracuene and Moamba from Mozambique, Mangochi from Malawi, Kalimbeza from Namibia, pooled seed lot from Tanzania and Missira from Mali, implying an additive gene across the region (White et al., 2007). Marracuene provenance has revealed a trait of producing heavy branches, a characteristic which was also noted during earlier assessment by profuse branching (Chirwa et al., 2007) while Missira provenance produces many small and short branches. Coefficient of variation in number of branches was 41.6% indicating substantial variability in the wild populations of *S. birrea* which makes it suitable for domestication because selection for improvement would be possible (Zobel and Talbert, 1984).

4.2. Variation in Number of Fruits per Tree among Provenances

The present results have revealed substantial variation in fruit production among provenances considering the difference between the highest and lowest means among provenances which was 90%. Within provenance fruiting variation is vital in breeding and domestication programmes because selection is made possible both at provenance and individual tree level (Zobel and Talbert, 1984) for example the Chikhwawa provenance from Malawi could fail at provenance level in dbh growth but could be sported most outstanding at an individual level (data not shown). Presently 73% of the total numbers of families are fruiting. It is not yet established whether the non-fruiting families are still adolescence or males. This could imply that other provenances are early fruit producers while others are late fruit producers. However, Hall et al. (2002) reported year-to-year variation in flowering and fruiting. Furthermore, Munjuga (2000) also reported that many individual trees of subsp. *birrea* become reproductively inactive in a season following a normal fruiting season. However, Queenborough (2005) reported that fruit production is highly affected by sex ratio and spatial arrangement in dioecious species as these two greatly affect pollination. But the current studies have not analysed sex ratio and spatial arrangement. Hence future studies should concentrate on reproductive biology to facilitate the understanding of fruit productivity.

However, according to other researchers (Munthali and Chirwa, 1999) variation among the 22 provenances in growth traits and fruit production is attributable to genetic influence because they are grown under a homogenous type of environment which means that variations due to environment and interaction between the environment and genotype are silent or neutralized by the common environment.

4.3 Correlation between Growth Traits and Number of Fruits

The results revealed a significant and moderate positive relationship (r=0.405) between dbh and fruit productivity which means there is potential for large diameters to produce more fruits but currently the trait cannot be used in indirect selection because it is relatively weak. Furthermore, tree height showed a significant and weak relationship (r=0.347) in fruit productivity. This implies that height is a weak predictor for fruit production hence cannot be used in indirect selection. Despite, the great variability in number of branches, results revealed a very weak positive relationship (r=0.065) between number of branches and fruit productivity, hence this trait cannot also be used in indirect selection for fruit production because having many branches does not seem to relate well with fruit production. Similar results have also been reported elsewhere (Nyoka et al., 2015; Botelle et al., 2003; Shackleton, 2002). In contrast, Gouwakinnou et al. (2011) reported a weak relationship between tree diameter and fruit production in *S. birrea ssp. birrea,* while Shackleton et al. (2002b) reported a significant positive relationship between fruit production and tree size in the Amalura fruit inventory study conducted at Bushbuckridge in South Africa. The difference with the current study is that Shackleton et al. (2002b) used large diameter trees (40–60cm) that might have an influence in fruit production.

The present study has revealed that growth parameters are weak predictors of fruit production, hence genetic factor is the major determining factor of fruit production. Basing on the results of the current study and earlier studies (Nyoka et al., 2015; Chirwa et al., 2007), Marracuene provenance from Mozambique had shown genetic superiority in all the traits assessed indicating a high potential for selection in the domestication process. However, future studies should concentrate on the reproductive biology of *S. birrea* to facilitate understanding of fruit productivity prior to promoting the species for Agroforestry programmes. Investigation of best and quick propagation methods for the superior genotypes should also be carried out.

5. CONCLUSION

The present study has revealed there were significant variations among the provenances on dbh, tree height, number of branches and number of fruits. Marracuene provenance from Mozambique had the largest dbh, highest number of branches and number fruits than the other provenances. Kalanga provenance from Swaziland was more superior in tree height than the other provenances. There was a significant correlation between number of fruits and dbh and between number of fruits and height. A moderate relationship was observed between a number of fruits and dbh, while a weak relationship was detected between number of fruits and height. However, there was no significant correlation between number of fruits and number of branches. This implies that growth parameters are weak predictors for fruit production hence cannot be used in indirect selection. Therefore, genetic factor is the major determining factor of fruit production. Future studies should concentrate on the reproductive biology of *S. birrea* to facilitate understanding of fruit productivity prior to promoting the species for Agroforestry programmes.

Investigation of best and quick propagation methods for the superior genotypes should also be carried out.

ACKNOWLEDGMENT

The authors are grateful to the staff at Forestry Research Institute of Malawi (FRIM) for the technical assistance and ICRAF for financial assistance in the management of the trial.

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Violet Msukwa, is a BSc holder. She obtained Bachelor of Science degree in Forestry at Mzuzu University in 2014. She has worked in the field of forestry for 28 years at various grades in the fields of forestry extension and research. Currently she is working with the Forestry Research Institute of Malawi responsible for tree seed procurement and distribution.

Dr. Chimuleke Munthali, is an alumni of University of Malawi, and University of Stellenbosch with academic training in Agriculture and Forest science at the respective institutions. He is presently working as an Associate Professor in Forestry at Mzuzu University. His research interest is in the reproductive biology and commercialization of indigenous fruit trees, with particular reference to Adansonia digitata L.

Edward Missanjo, is a PhD student in Wood Science at Kyushu University, Japan. He obtained Master of Science degree from University of Zimbabwe in 2010 and Bachelors of Science degree from Mzuzu University in 2003. He has published numerous articles in professional journals. He is working on genetic parameters of wood parameters for fast grown trees. His main fields are Biometry, Quantitative and Statistical Genetics, Research Methods and Design, Selection, Forest Mensuration and Inventory, Wood anatomy, and Forest Management.

Clement Chilima, is the Director of Forestry in the Ministry of Natural Resources, Energy and Mining in Malawi. He holds a Doctorate Degree in Applied Entomology obtained at the Imperial College in London in 2000. Until April 2015, Clement Chilima was working at the Forestry Research Institute of Malawi, as head of research and forestry entomologist. He has published several articles and contributed to book chapters in forest insect pest management.

Simon Mng'omba, is a horticulturist, works at World Agroforestry Centre (ICRAF), Chitedze Research Station as a Researcher. He holds a Doctorate Degree and has published several articles and contributed to book chapters in Agroforestry.

Willie Sagona, is a Research Scientist working with Forestry Research Institute of Malawi (FRIM). He has a Master of Science degree (pending) and Bachelors of Science degree from University of Malawi (Chancellor College). He has published papers in different professional journals. His main area of interest is Trees Outside Forests, Agroforestry, Soil and Water studies.

Ida Mkwezalamba, is a Forestry Research Officer at Forestry Research Institute of Malawi responsible for laboratory and nursery seed quality testing. She obtained her Bachelor of Science in forestry from Mzuzu University in 2015. She has published articles in different professional journals. Her main fields are seed technology, tree improvement, Silviculture, Biometry, Research methods and design, and Environmental management.