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Research Application Summary

Yield and physicochemical properties of Marula [*Sclerocarya birrea*] seed oils among nine international provenances tested in Malawi

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Abstract

The study was carried out to assess the yield and physicochemical properties of seed oils among nine international provenances of *Sclecorya birrea* (subspecies caffra and birrea) planted in Malawi. Seed oils were obtained using Soxhlet extraction method while quality parameters were determined using procedures outlined by the Malawi Bureau of Standards. Oil yield was greatest (52.2 %) in subspecies birrea. Oil moisture content, free fatty acid, acid value and peroxide value ranged from 0.06 to 076 %; 1.96 to 4.07 %; 3.91 to 8.13 mg KOH/g and 1.84 to 5.15 meq KOH/g, respectively. Variations in oil yield and physicochemical properties could be attributed to genetic differences and origin of genotypes. The selection of *S. birrea* for oil production and use should be based on both provenance and subspecies levels. Further studies should examine the heritability of the oil content and its physicochemical properties prior to the use of seed for propagation.

Key words: Acid value, free fatty acid, oil yield, peroxide value, seed oil, *Sclecorya birrea*

Résumé

L'étude a été réalisée pour évaluer le rendement et les propriétés physicochimiques des huiles de graines parmi neuf provenances internationales de Sclecorya birrea (sous-espèces caffra et birrea) plantées au Malawi. Les huiles de graines ont été obtenues en utilisant la méthode d'extraction Soxhlet tandis que les paramètres de qualité ont été déterminés en utilisant les procédures décrites par le Bureau des normes du Malawi. Le rendement en huile était le plus élevé (52,2 %) chez la sous-espèce birrea. La teneur en humidité de l'huile, les acides gras libres, l'indice d'acide et de peroxyde variaient de 0,06 à 0,76 % ; 1,96 à 4,07 % ; 3,91 à 8,13 mg KOH/g et 1,84 à 5,15 meq KOH/g, respectivement. Les variations du rendement en huile et des propriétés physicochimiques pourraient être attribuées aux différences génétiques et à l'origine des génotypes. La sélection de S. birrea pour la production et l'utilisation d'huile devrait être basée à la fois sur la provenance et sur les niveaux de sous-espèces. D'autres études devraient examiner l'héritabilité de la teneur en huile et ses propriétés physico-chimiques avant l'utilisation des graines pour la multiplication.

Mots clés: Indice d'acide, acide gras libre, rendement en huile, indice de peroxyde, huile de graines, *Sclecorya birrea*

Introduction

Sclerocarya birrea (Marula) is an indigenous fruit tree that belongs to the family Anacardiaceae and is native to Southern Africa (Mariod and Abdelwahab, 2012). The tree is an important source of seed oil that is mostly valued in both traditional and commercial applications (Vermaak *et al.,* 2011). The oil is used domestically for cooking (Petje, 2008). In Namibia, the edible oil is well branded in local markets (Beckett and PhytoTrade Africa, 2012). In South Africa, the oil is used by local people to preserve meat (Petje, 2008). In the energy sector, the oil is used in the production of biofuels (Moser, 2009). For many years, *S. birrea* seed oil has been used in cosmetic formulations in the international beauty market (Beckett and PhytoTrade Africa, 2012). The oil is said to be resistant to oxidation and is easily absorbed by the skin (World Intellectual Property Organisation, 2011). These qualities have made *S. birrea* seed oil an ideal commercial ingredient in many cosmetic formulations. For example, the oil realizes high prices on the market such that a 63 ml product fetches about $80 (Beckett and PhytoTrade Africa, 2012). Further, in 2008 Namibia raised about $1,700,000 from *S. birrea* seed oil (Light Years Intellectual Property *et al.,* 2008). Currently, the global oil trade is focusing on exploration of wild plants to supplement the existing sources of oil (Attiogbe and Abdul-Razak, 2016). Such demand also highlights the economic potential of *S. birrea* seed oils.

Sclerocarya birrea is one of the indigenous fruit species that were selected for domestication in Malawi to improve the nutritional status and well-being of rural communities through development of products for commercialization (Akinnifesi *et al.,* 2006). Tree domestication has been described as an adaptive process that transforms a wild plant for human use (Stetter *et al.,* 2017). The selection of *S. birrea* for domestication led to the establishment of an international provenance trial in Mangochi (Malawi) in 1999 using seed collected from SADC countries and West Africa (Mali) (Chirwa *et al.,* 2007). Seed collected from provenances in SADC countries belonged to *S. birrea* subspecies *caffra* while one provenance collected from Mali belonged to *S. birrea* subspecies *birrea.*

It has been argued that products from indigenous fruits such as *S. birrea* have great potential to improve livelihoods in terms of their nutritional and economic benefits (Ndabikunze *et al.,* 2010). *Sclerocarya birrea* seed oil is one such product that has demonstrated great economic value. Owing to its economic potential, the oil has the ability to improve livelihood of many rural poor communities once commercialized. Various scholars in Malawi (Mkwezalamba *et al.,* 2015; Msukwa *et al.,* 2016; Msukwa *et al.,* 2019; Msukwa *et al.,* 2021) have conducted studies on S. *birrea* in the international provenance trial and have demonstrated great variations among provenances in terms of fruit morphology, fruit productivity, mating systems and pest susceptibility. Despite several recent studies, there is no information on the quantity and quality of seed oils among the provenances. The question is whether populations (provenances) collected from far wide geographic distribution (Figure 1) are the same or different in terms of oil quantity and quality. It is reported that the quantity and quality (physicochemical properties) of oil is important in determining the use of the oil (Aluyor and Ori-Jesu, 2008; Zaku *et al.,* 2012; Gbenga *et al.,* 2016). Furthermore, the quality of oil provides scientific evidence of the oil's mode of action when used in various applications (Beckett and PhytoTrade Africa, 2012). It is therefore essential to assess *S. birrea* provenances in terms of their oil quantity and quality prior to domestication and commercialization. In the present study, it was hypothesized that *S. birrea* provenances from different geographic localities were significantly different in terms of oil quantity and quality. The

study was therefore designed to assess the yield and physicochemical properties (quality) of *S. birrea* seed oils among nine international provenances being screened in Malawi.

Methodology

Study area and experimental design. The international provenance trial was established in 1999 at the Palm Forest Reserve in Mangochi district, Malawi. Seeds used in the trial were collected from SADC region (subspecies caffra) and Mali (subspecies birrea) (Figure 1). The experimental treatments were laid out as a randomized complete block design with four replicates. Each treatment had a line plot with 20 trees that represented the total possible number of families for each provenance. Spacing was 5 m between row plots and 4 me between trees within a plot, translating to 80 trees per population.

Collection of *S. birrea* (subspecies caffra and birrea) fruits. Health, mature and ripe fruits (Figure 2) from each provenance were collected from the ground (underneath trees) from January to December, 2017 (Table 1). *S. birrea* fruits abscise before maturity and ripening occurs on the ground (Petje, 2008). Fruits from each provenance were kept in a polythene bag which was labelled. The fruits were then transported to Mzuzu University for processing.

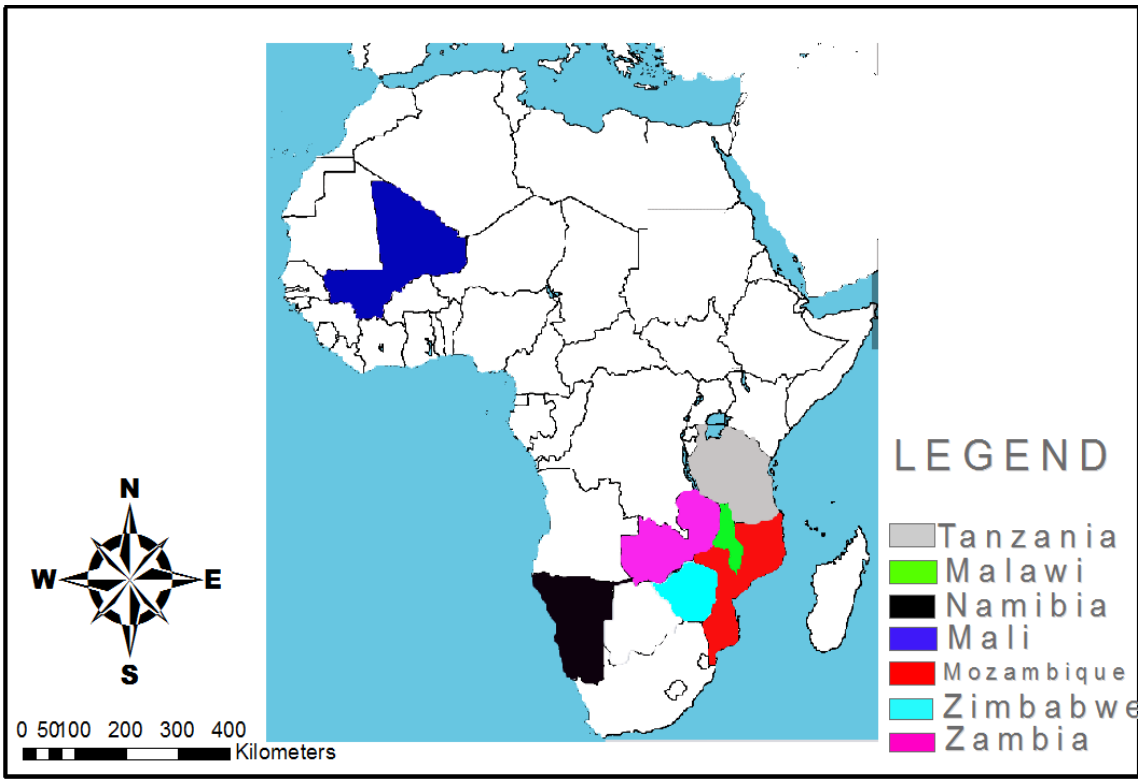

Figure 1. Map of Africa showing countries where *S. birrea* seeds were collected

Figure 2. Phenotype of mature *S. birrea* fruit

Table 1. Sampling time of *S. birrea* populations (countries and provenances)

Country	Provenance	Subspecies	Maturity time
Malawi	Chikhwawa	*caffra*	April
Mozambique	Marracuene	*caffra*	December
Mozambique	Magunde	*caffra*	January
Mozambique	Moamba	*caffra*	December
Mali	Missira	*birrea*	November
Zimbabwe	Matebeleland	*caffra*	January
Zimbabwe	Ngundu	*caffra*	January
Namibia	Kalimbeza	*caffra*	April
Tanzania	Magamba-Turiani	*caffra*	April

Processing of *S. birrea* (subspecies caffra and birrea) seed kernel. *Sclerocarya birrea* (subspecies caffra and birrea) seeds were obtained after removing the fruit pulp. The seeds were then dried under shade for seven (7) days at Mzuzu University Chemistry Laboratory. The endocarps of the dried seeds were crushed manually with a hammer to obtain the seed kernels. The seed kernels

were then dried under shade for 5 to 7 days until a constant weight was achieved. The kernels were then pounded using a wooden mortar and pestle. The pounded samples of the seed kernel (Figure 3) were then placed on clean white papers.

Figure 3. Pounded sample of *Sclerocarya birrea* seed kernel

Extraction of *S. birrea* (subspecies caffra and birrea) seed oil. Oil from *S. birrea* (subspecies caffra and birrea) seed kernel was obtained using Soxhlet extraction method (A.O.A.C, 1990). Exactly 15 g of dried pounded sample of *S. birrea* (seed kernel (Figure 3) was weighed on an analytical balance (N17250). The sample was then placed in an extraction thimble in triplicate. A piece of a cotton wool was placed inside the extraction thimble to prevent loss of the sample. The extraction thimble was transferred into the Soxhlet extractor and 300 mL of n-hexane (analytical grade) was added. The Soxhlet apparatus was attached to a weighed round bottomed flask which was placed on a heating mantle. The set up was heated continuously for three hours at a temperature range of 40°C to 60°C. After 3 hours, the set up was switched off and allowed to cool for twenty minutes. After extraction of the oil, the solvent that remained in the flasks was removed using a rotary evaporator (RE 111). The flasks were exposed to heat in an electric oven at 50°C for five minutes to eliminate further traces of the solvent. The flask containing the oil was weighed on an analytical balance. The weight of the oil was found by subtracting the weight of the round bottomed flask from the combined weight of the round bottomed flask + oil. The oil was then collected and kept tightened glass vials (Figure 4). The glass vials containing the oil were kept at room temperature ready for physicochemical analyses.

Figure 4. *S. birrea* seed oil in glass vials

Determination of oil yield. The yield of *S. birrea* (subspecies caffra and birrea) seed oil was calculated using a method described by Hashim *et al.* (2015). Oil yield was calculated as a percentage of total oil present in 15 g of *S. birrea* (subspecies caffra and birrea) seed kernel. From each provenance, oil yield was determined in triplicate and was calculated using equation (1).

$$\text{Oil yield (\%)} = [W_1] / [W_2] * 100 \quad \text{Equation 1}$$

W_1 is the weight (g) of oil and W_2 is the weight (g) of S. birrea seed kernel sample.

Determination of physicochemical properties of oil. Physical property (moisture content) of *S. birrea* (subspecies caffra and birrea) seed oil was determined using oven dry method (Abaye *et al.,* 2013) while chemical properties (free fatty acid, acid value and peroxide value) were determined using procedures described by the Malawi Bureau of Standards (1988).

Moisture content. A sample of oil (2 g) was placed in a dry and weighed porcelain crucible. The crucible containing the oil was placed in an electric oven (Series 9000) set at 105°C and was heated for 2 hours. The crucible containing the oil was then removed from the oven and allowed to cool in a desiccator. After cooling, the crucible containing the oil was accurately weighed on an analytical balance and the mass was recorded (N 17250). The mass (g) of the dried oil sample was then calculated by subtracting the mass of oil plus crucible after heating from the mass of oil plus crucible before heating. The procedure was carried out in triplicate. Oil moisture content (%) was then calculated using equation (2).

Moisture content (%) = $[M_1 – M_2] / [M_1] * 100$…… Equation 2

M_1 is mass of crucible (g) + oil (g) before heating and M_2 is mass of crucible (g) + oil (g) after heating.

Free Fatty Acid (%). Oil sample (1 g) was weighed in triplicate and placed into a 250 mL conical flask. A solvent (1:1 diethyl ether and 95 % ethanol) was then added to the oil together with three to four drops of phenolphthalein indicator. The mixture was heated on a hot plate and immediately after boiling had started, the mixture was titrated with a standardized solution of 0.25N sodium hydroxide. A blank titration was also carried out using diethyl ether and 95% ethanol (1:1) and 0.25 N sodium hydroxide. Free fatty acids (FFA) composition (% m/m oleic acid) was then calculated using equation (3).

Free Fatty Acid (% m/m oleic acid) = [T * C * 28.2] / m……..... Equation 3

T is the titre volume of sodium hydroxide, C is the actual concentration of the standard sodium hydroxide solution, m is the mass (g) of the oil sample, and 28.2 is the equivalent weight of oleic acid.

Acid value. Acid value was calculated from the volume of sodium hydroxide obtained from the determination of free fatty acid as shown in equation (4).

Acid value = [56.1 * T * C] / m……Equation 4

T is the titre volume of sodium hydroxide, C is the actual concentration of the sodium hydroxide solution, m is the mass (g) of the oil sample and 56.1 is the equivalent weight of potassium hydroxide.

Peroxide value. Oil sample (5 g) was weighed and placed into a 250 mL glass stoppered conical flask and 30mL of 2:1 glacial acetic acid and chloroform was added while swirling the conical flask until the sample had dissolved in the solution. About 0.5 mL saturated potassium iodide solution (4:3 potassium iodide: distilled water) was added to the oil and the mixture was allowed to stand with occasional shaking for one minute after which 30 mL of distilled water were added. The mixture was titrated with 0.1N standard sodium thiosulphate solution, adding it gradually and with constant and vigorous shaking, until the yellow color had almost disappeared. About 0.5 mL of starch indicator solution (1 %) was added and the titration continued with vigorous shaking of the flask to liberate the iodine from the chloroform layers. Three to four drops of sodium thiosulphate solution were added until the blue color had just disappeared, signaling the end point. A blank titration was carried out in a similar manner using the reagents only. The peroxide value was then calculated using equation (5).

Peroxide value = [T * C * 1000] / m……..……Equation 5

T is the titre volume (mL), C is the concentration of the standard sodium thiosulphate and m is the mass (g) of oil sample.

Data analysis. Values of oil yield (%), moisture content (%) and free fatty acid (%) were subjected to arcsine transformation using Microsoft excel 2013. Measurements of acid value

and peroxide value were tested for normality and homogeneity with Komolgorov-Smirnov using Minitab 17. After meeting the above criteria, data were subjected to one-way analysis of variance using Minitab 17. Significantly different means were separated using Fisher's Least Significant Difference (LSD).

Results

Yield of *S. birrea* (subspecies caffra and birrea) seed oil. Table 2 shows the yield (%) of *S. birrea* (subspecies caffra and birrea) seed oil among nine provenances. There were significant differences (P 0.05) in the oil yield among the nine provenances. Oil yield ranged from 41.1 to 52.2 %. Missira provenance (subspecies birrea) had the highest oil yield (52.2 ± 0.3 %) followed by Moamba (50 ± 0.2 %) (subspecies caffra). The third highest oil yield was for populations of subspecies caffra from Marracuene (48.4 ± 0.1 %) and Kalimbeza (48.1±0.01 %) which were followed by Chikhwawa provenance (47.5 ± 0.2 %) (subspecies caffra). The fithth highest oil yield was for populations of subspecies caffra from Magamba-Turiani (45.3 ± 0.02 %), Magunde (44.8 ± 0.1 %) and Ngundu (44.5 ± 0.2 %). The lowest oil yield (41.1 ± 0.5 %) was for Matebeleland provenance (subspecies caffra).

Physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oil. Table 3 shows the results of physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oils among nine provenances. There were significant differences ($P \leq 0.05$) in moisture content, free fatty acid composition, acid value and peroxide value of the seed oils from the nine provenances.

Moisture content. The oil moisture content was highest (0.76 ± 0.01 %) in Matebeleland provenance (subspecies caffra) followed by Kalimbeza (0.65 ± 0.03 %) (subspecies caffra). The third highest moisture content were for Magamba-Turiani (0.45 ± 0.01 %) (subspecies caffra) and Magunde (0.42 ± 0.02 %) (subspecies caffra). The fourth highest moisture values were for populations of subspecies caffra from Moamba (0.33 ± 0.02 %) and Marracuene (0.32 ± 0.01 %).

Table 2. Yield of *S. birrea* (subspecies caffra and birrea) seed oil among nine provenances

Country	Provenance	Subspecies	Oil yield (%)
Malawi	Chikhwawa	caffra	47.5 ± 0.2 ^{d}
Mozambique	Marracuene	caffra	48.4 ± 0.1 ^{c}
Magunde	Magunde	caffra	44.8 ± 0.1 ^{e}
Mozambique	Moamba	caffra	50.0 ± 0.2 ^{b}
Mali	Missira	birrea	52.2 ± 0.3 ^{a}
Zimbabwe	Matebeleland	caffra	41.1 ± 0.5 ^{f}
Zimbabwe	Ngundu	caffra	44.5 ± 0.2 ^{e}
Namibia	Kalimbeza	caffra	48.1 ± 0.01^{cd}
Tanzania	Magamba-Turiani	caffra	45.3 ± 0.02 ^{e}

*Means with different superscripts within a column are statistically different ($P \leq 0.05$).
*Mean values are followed by standard error.

The lowest moisture contents were from Ngundu (0.09 ± 0.01 %) (subspecies caffra), Missira (0.07 ± 0.01 %) (subspecies birrea) and Chikhwawa (0.06 ± 0.01 %) (subspecies caffra).

Free fatty acid. Free fatty acid composition was highest (4.07 ± 0.02 %) in Missira provenance (subspecies birrea) followed by Marracuene (3.24 ± 0.01 %) (subspecies caffra), Chikhwawa (3.22 ± 0.03 %) (subspecies caffra) and Kalimbeza (3.19 ± 0.02 %) (subspecies caffra). The third highest values of free fatty acid were for subspecies caffra from Magunde (3.16 ± 0.01 %) and Moamba (3.11 ± 0.02 %). The fourth highest values of free fatty acid were for subspecies caffra from Matebeleland (2.15 ± 0.01 %) and Ngundu (2.13 ± 0.01 %) while the lowest value (1.96 ± 0.02 %) was for Magamba-Turiani (subspecies caffra).

Acid value. Acid value was highest (8.13 ± 0.05 mg KOH/g) in Missira provenance (subspecies birrea) followed by populations of subspecies caffra from Marracuene (6.49 ± 0.06 mg KOH/g), Chikhwawa (6.44 ± 0.06 mg KOH/g), Kalimbeza (6.37 ± 0.05 mg KOH/g), Magunde (6.33 ± 0.03 mg KOH/g) and Moamba (6.22 ± 0.05 mg KOH/g). The third highest values were for subspecies caffra from Matebeleland (4.29 ± 0.03 mg KOH/g) and Ngundu (4.25 ± 0.03 mg KOH/g). The lowest acid value (3.91 ± 0.02 mg KOH/g) was for Magamba-Turiani provenance (subspecies caffra).

Peroxide value. Peroxide value ranged from 1.84 to 5.15 meq KOH/g and nine categories were established. The highest peroxide value (5.15 ± 0.03 meq KOH/g) was for Magamba-Turiani provenance (subspecies caffra) followed by Magunde (3.93 ± 0.04 meq KOH/g) (subspecies caffra). The third highest peroxide value (3.87 ± 0.06 meq KOH) was for Marracuene (subspecies caffra) which was followed by Moamba (3.19 ± 0.01 meq KOH/g) (subspecies caffra). The fifth highest peroxide value was for Kalimbeza (3.11 ± 0.02 meq KOH/g) (subspecies caffra) followed by Missira (3.02±0.01 meq KOH/g) (subspecies birrea). The seventh highest peroxide value (2.15 ± 0.01 meq KHO/g) was for Chikhwawa provenance (subspecies caffra) which was followed by Matebeleland (2.05 ± 0.01 meq KOH/g) (subspecies caffra). The lowest peroxide value (1.84 ± 0.02 meq KOH/g) was for Ngundu provenance (subspecies caffra).

Table 3. Physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oil among nine provenances

Provenance	Subsp.	MC (%)	FFA (%) AV	(mg KOH/g)	PV(meq KOH/g)
Chikhwawa	*caffra*	0.06±.01^{e}	3.22±.01^{b}	6.44±.03^{b}	2.15±.01^{g}
Marracuene	*caffra*	0.32±.01^{d}	3.24±.01^{b}	6.49±.03^{b}	3.87±.03^{c}
Magunde	*caffra*	0.42±.01^{c}	3.16±.01^{c}	6.33±.01^{bc}	3.93±.02^{b}
Moamba	*caffra*	0.33±.01^{d}	3.11±.01^{c}	6.22±.02^{bc}	3.19±.01^{d}
Matebeleland	*caffra*	0.76±.01^{a}	2.15±.01^{d}	4.29±.01^{d}	2.05±.01^{h}
Ngundu	*caffra*	0.09±.01^{e}	2.13±.01^{d}	4.25±.01^{d}	1.84±.01^{i}
Magamba-Turiani	*caffra*	0.45±.01^{c}	1.96±.01^{e}	3.91±.02^{e}	5.15±.02^{a}
Kalimbeza	*caffra*	0.65±.01^{b}	3.19±.01^{b}	6.37±.02^{bc}	3.11±.01^{e}
Missira	*birrea*	0.07±.01e	4.07±.01^{a}	8.13±.02^{a}	3.02±.01^{f}

*Means with different superscripts within a column are statistically different (P 0.05).
*Mean values are followed by standard error.
*MC = moisture content; FFA = free fatty acid; AV = acid value and PV = peroxide value.

Discussion

Yield of *S. birrea* (subspecies caffra and birrea) seed oil. Results of the study (Table 2) demonstrated significant variations in the yield of *S. birrea* (subspecies caffra and birrea) seed oil from different provenances. It is reported that variations in oil content are influenced by genetic factors (Peric *et al.,* 2012), species origin (Zaku *et al.,* 2012) as well as environmental factors (Kakar and Soomro *et al.,* 2001; Bellaloui *et al.,* 2013). The variations in oil content observed in the present study could be attributed to genetic factors associated with origin of genotypes (provenances) since all populations were raised in the same environment. Wimalasiri (2015) argued that the origin of genotype (seed source or provenance) reflects climatic and geographic differences such as temperature and rainfall of which genotypes adapt to such conditions. Perhaps *S. birrea* subspecies birrea from Missira (Mali) has adapted to its original ecological conditions and genetically evolved high oil content. The highest oil content (52.2 %) in this study is also greater than the seed oil content (46.4 %) of *S. birrea* subspecies caffra from Northern Ghana (Attiogbe and Abdul-Razak, 2016). This variation could also possibly be influenced by genetic differences, environmental variation and origin of genotypes. Azam *et al.* (2005) and Sneha *et al.* (2009) reported that oil content in the range of 30 to 60 % are suitable for the production of biodiesel. The range of oil content in the present study (41.2 to 52.3 %) therefore shows that oils from all the provenances and subspecies have the potential for biodiesel production.

Physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oil. The results show significant variations in physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oils among populations from various geographic localities (Table 3). It is reported that differences in physicochemical properties of seed oils are influenced by genetic variation (Ruuska *et al.,* 2002; Hobbs *et al.,* 2004), species origin and environmental variation (Jessinta *et al.,* 2014). In the present study *S. birrea* populations were grown in the same environment and probably the variations in physicochemical properties of the seed oils could be attributed to the genetic make-up of the populations as well as the origin of the genotypes. The variations in physicochemical properties (quality parameters) indicate possibility of multiple use of the oils emanating from various provenances as highlighted by Zaku *et al.* (2012) and Gbenga *et al.* (2016).

Moisture content. The amount of water present in oil has a significant impact on both storage and utilization of the oil. In the present study oil moisture content ranged from 0.06 to 0.76 %. These values are lower than the moisture content of Jathropha (2.39 %) and Neem (2.53 %) seed oil (Zaku *et al.,* 2012). These variations may have been influenced by genetic make up of the species. Abayeh *et al.* (2013) reported that moisture content of less than 4.6 % increases the shelf-life of oils. The moisture levels in this study therefore indicate that oils from all the provenances and subspecies could have a long shelf-life. Canakci and Van Gerpen (2001) argued that oils with moisture content of over 0.1 % decrease biodiesel yield during transesterification process due to the formation of soap. Chikhwawa, Missira and Ngundu provenances with oil moisture contents of 0.06, 0.07 and 0.09 % respectively, would therefore yield more biodiesel than the rest of the provenances. On the other hand, oils with significantly higher moisture content produces more soap than those with lower moisture content (Moser, 2009). Matebeleland provenance with the highest oil moisture content of 0.76% would therefore yield more soap than the rest of the provenances.

Free fatty acid. Free fatty acid ranged from 1.96 to 4.07 % which was lower than the free fatty acid composition (20.7 %) of *S. birrea* subspecies caffra seed oil from Bauchi, Nigeria (Robinson

et al., 2012). These variations could also be attributed to genetic make up of populations, origin of populations or environmental differences. Free fatty acid composition is one of the considerations in feedstock selection for biodiesel production (Kumar *et al.,* 2007). Zaku *et al.* (2012) reported that oils with high free fatty acids yield a lesser amount of biodiesel and that transesterification can only be achieved when free fatty acid value is 1 % or 2 %. The results in Table 3 indicate that all the oils had higher free fatty acid composition except for Magamba-Turiani (1.96 %); as such the oils can not be immediately transesterified. However, Zaku *et al.* (2012) reported that acid esterification could be used to reduce the values to 2 % in order to optimize the biodiesel yield. Aremu *et al.* (2015) noted that unsaturated fatty acids such as oleic acid are essential in human nutrition and helps in reducing cholesterol levels. Therefore, oils from provenances such as Missira (subspecies birrea) with high proportion of oleic acid (4.07%) could form high nutritious edible oils. Oils with high oleic acid content have also been described to improve lubrication properties (Robinson *et al.,* 2012). Oils from Missira provenance (subspecies birrea) with significant levels of oleic acid could therefore synthesize best lubricants.

Acid value. Results of the study (Table 3) show that the acid value ranged from 3.91 to 8.13 mg KOH/g. These values are lower than the acid value (41.4 mg KOH/g) of *S. birrea* subspecies caffra seed oil from Bauchi, Nigeria (Robinson *et al.,* 2012). Such variations could be attributed to genetic make up of populations, origin of populations as well as the environment. Oil acidity is an important parameter that indicates the presence of free fatty acid and other non-lipid acid compounds and therefore determining the edibility of oil (Abayeh *et al.,* 2013). Abaye *et al.* (1998) reported that oils with maximum acid value of 4.0 mg KOH/g are suitable for consumption. The acid value for Magamba-Turiana provenance (3.91 mg KOH/g) indicates the oil could be suitable for human consumption. Aremu *et al.* (2015) reported that oils with low acid values are stable over a long period time than oils with higher acid values. As such, oils from Magamba-Turiani provenance (subspecies caffra) with low acid value could be stable over a long period of time than the oils from the other provenances.

Peroxide value. Peroxide values ranged from 1.84 to 5.5 meq KOH/g. The values are higher than the peroxide value (1.3 meq KOH/g) of *S. birrea* subspecies caffra seed oil from Ghana (Attiogbe and Abdul-Razak, 2016). This variation could be attributed to environmental variation or genetic differences associated with origin of genotypes / provenance. Peroxide value measures the content of hydroperoxides and is an indicator of oil's resistance to oxidation (Olasunkanmi *et al.,* 2017). Low peroxide values indicate high resistance to oxidation and hence long period of storage with minimum deterioration (Adepoju *et al.,* 2012). The low peroxide value (1.84 meq KOH/g) of oils from Ngundu provenance (subspecies caffra) (Table 3) therefore indicates that the oil is more resistant to oxidation and can be stored for a long time while exhibiting minimal deterioration. The Standard Organization of Nigeria (2004) reported that oils with maximum peroxide value of 10 meq KOH/g are suitable for the production of hair creams. In the present study the peroxide values (1.84 to 5.5 meq KOH/g) indicate that seed oils from all the genotypes / provenances / subspecies are suitable for producing hair creams. Abayeh *et al.* (1998) attested that oils with maximum peroxide value of 10 meq KOH/g qualify as edible oils due to their stability. Gunstone (2006) further added that edible oils must be oxidatively stable to prevent food from becoming rancid. Results of peroxide value in the present study also suggest that oils from all provenances and subspecies qualify as edible oils.

Conclusion and Recommendations

The study has shown that the yield and physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oils from different provenances are significantly different when the genotypes are raised in the same environment. The variations could therefore be attributed to genetic make up of the populations as well as the origin of the genotypes (provenances). The selection of *S. birrea* genotypes for oil production and use should therefore consider both provenance and subspecies levels. Further studies should study the heritability of the oil content and its physicochemical properties prior to the use of seed for propagation.

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References

A.O.A.C. 1990. Association of official analytical chemists: Official Methods of Analysis of the AOAC. 15th edn. Washington D.C, U.S.A.

Abayeh, O.J., Aina, E.A. and Okuonghae, C.O. 1998. Oil content and oil quality characteristics of some Nigerian oil seeds. *Journal of Pure and Applied Sciences* 1 (1):17-23.

Abayeh, O.M, Garba, I.H., Adamu, H.M. and Abayeh, O.J. 2013. Quality characteristics of *Luffa aegyptiaca* seed oil. *International Journal of Scientific and Engineering Research* 4 (4):11–16.

Adepoju, T.F., Olawale, O., Okunola, A.A. and Olatunji, E.M. 2014. Solvent extraction of oil from soursop oilseeds and its quality characterization. *International Journal of Sustainable Energy and Environmental Research* (2):80–89.

Akinnifesi, F.K., Kwesiga, F., Mhango, J., Chilanga, T., Mkonda, T., Kadu, C.A.C., Kadzere, I., Mithofer, D., Saka, J.D.K., Sileshi, G., Ramadhani, T. and Dhliwayo, P. 2006. Towards the development of miombo fruit trees as commercial tree crops in Southern Africa. *Forest, Trees and Livelihoods* 16 (1):103-121.

Aluyor, E.O. and Ori-Jesu, M. 2008. The use of antioxidants in vegetable oils: A review. *African Journal of Biotechnology* 7 (25):4836-4842.

Aremu, M.O., Ibrahim, H. and Bamidele, T.O. 2015. Physicochemical characteristics of the oils extracted from some Nigerian plant foods – A review. *Chemical and Process Engineering Research* 32: 36-52.

Attiogbe, F.K. and Abdul-Razak, T. 2016. Evaluation of the physicochemical properties of Northern Ghana *Sclerocarya birrea* seed oil and proximate analysis of the process waste. *African Journal of Food Science* 10 (4): 48-53.

Azam, M.M., Waris, A. and Nahar, N.M. 2005. Prospect and potential of fatty acid methyl esters of some nontraditional seed oil for use as biodiesel in India. *Biomass and Bioenergy* 29: 293-302.

Beckett, K. and PhytoTrade Africa. 2012. Marula oil value chain analysis. Millennium challenge

account.[online]. Available from <http://www.theeis.com/data/literature/Marula%20Oil> [Accessed 1 May2017].

Bellaloui, N., Mengestu, A. and Kassem, M.A. 2013. Effects of genetics and environment on fatty acid stability in soybean seed. *Food and Nutrition Sciences* 4: 165-175.

Canakci, M. and Van Gerpen, J. 2001. Biodiesel production from oils and fats with high free fatty acids. *American Society of Agricultural Engineers* 44 (6):1429-1436.

Chirwa, P.W., Bwanali, R.J., Meke, G., Sagona, W., Munthali, C.R.Y. and Mwabumba, L. 2007. Growth and phenology of a three to four-year-old *Sclerocarya birrea* International provenance trial in Malawi. *Southern Hemisphere Forestry Journal* 69 (1): 49-54.

Gbenga, A., Karimu, A. O. and Jide, A. O. 2016. Physicochemical and antibacterial evaluation of oil extracted from ripe and unripe pawpaw seed (*Carica papaya*). *Research Journal of Food Science and Nutrition* 1 (1):10–14.

Gunstone, F.D. 2006. Modifying lipids for use in foods. Wood Head Publishing Limited.

Hashim, A.B., Giwa, S.O., Ibrahim, M. and Giwa, A. 2015. Finding the optimum parameters for oil extraction from Sesame seed using response surface methodology. *International Journal of Scientific Research and Management Studies* 2 (1):1-13.

Hobbs, D.H., Flintham, J.E. and Hills, M.J. 2004. Genetic control of storage oil synthesis in seeds of Arabidopsis. *Plant Physiology* 136 (2):3341-3349.

Jessinta, S., Azhari, H.N., Saiful, N.T. and Abdurahman, N. 2014. Impact of geographic variation on physicochemical properties of Neem (*Azadirachta indica*) seed oil. *International Journal of Pharmaceutical Sciences and Research* 5 (10):4406-4413.

Kakar, A.A. and Soomro, A.G. 2001. Effect of water stress on the growth, oil content of sunflower. *Pakistan Journal of Agricultural Science* 38:73–74.

Layton, R., Tiffen, P., Layton, D., Dressler, A., Chu, M., Sarkissian, H. and Popovic, B. 2008. Distinctive values in African exports: How Intellectual Property can raise export income to alleviate poverty. Light Years Intellectual Property. Washington DC. [online] Available f r o m <www.lightyearsip.net> [Accessed 8 May 2017].

Malawi Bureau of Standards. 1988. Edible oils and fats: Methods of analysis. [online] Available from www.mbs@mbsmw.org [Accessed 4 April 2017].

Mariod, A.A. and Abdelwahab, S.I. 2012. *Sclerocarya birrea* (Marula), an African tree of nutritional and medicinal uses: A review. *Food Reviews International* 28 (4):375-388.

Mkwezalamba, I., Munthali, C.R.Y. and Missanjo, E. 2015. Phenotypic variation in fruit morphology among provenances of *Sclerocarya birrea* (A. Rich.) Hochst. *International Journal of Forestry Research* pp.1-8.

Moser, B.R. 2009. Comparative oxidative stability of fatty acid alkyl esters by accelerated methods. *Journal of American Oil Chemical Society* 45: 229-266.

Msukwa, V., Munthali, C., Nyoka, B., Missanjo, E., Kamanga, M., Graziosi, I. and Msiska, V. 2021. Foliage pests of Marula (*Sclerocarya birrea*) in Malawi: susceptibility of different provenances. *Agroforestry Systems* 95 (3):383-395.

Msukwa, V., Munthali, C.R.Y., Missanjo, E., Chilima, C.Z., Mng'omba, S.A., Sagona, W. and Mkwezalamba, I. 2016. Growth performance and fruit production of *Sclerocarya birrea* (A. Rich.) Hochst. *International Journal of Scientific Research in Agricultural Sciences* 3 (2):42-49.

Msukwa, V., Munthali, C.R.Y., Nyoka, B.I., Missanjo, E., Muchugi, A., Okia, C., Kang'ethe, S. and Jenya, H. 2019. Mating system among provenances of *Sclerocarya birrea* (A. Rich) Hochst. *International Journal of Forestry Research* Article ID 8681238, 1-10.

Ndabikunze, B.K., Masambu, B.N. and Tiisekwa, B.M. 2010. Vitamin C and mineral contents, acceptability and shelf life of juice prepared from four indigenous fruits of the Miombo woodlands of Tanzania. *Journal of Food, Agriculture and Environment* 2:91-96.

Olasunkanmi, G. S. and Omolayo, F. T. 2017. Fatty acid profile, physico-chemical and functional properties of oil and protein isolate simultaneously extracted from sesame (*Sesamum indicum*) seed. *Annals Food Science and Technology* 18 (1):1–10.

Peric, V., Nikolic, A., Drinic, S.M., Kravic, N. and Kovacevic, D. 2012. Characterization of soybean varieties based on protein and oil content. pp.64–67.[online] Available from <http// www.semenarska.rs> [Accessed on 5 May 2017].

Petje, K.F. 2008. Determination of fruit yield and fruit quality in Marula (*Sclerocarya birrea* subsp. *caffra*) selections. MSc Thesis, University of Pretoria, South Africa.

Robinson, E., Lukman, A. and Bello, A. 2012. Investigation of extracted *Sclerocarya birrea* seed oil as a bioenergy resource for compression ignition engines. *International Journal of Agricultural and Biological Engineering* 5 (3):59-67.

Ruuska, S.A., Girke, T., Benning, C. and Ohlorogge, J. B. 2002. Contrapuntal networks of gene expression during Arabidopsis seed filling. *Plant Cell* 14: 1191-1206.

Sneha, K., Athalye, R., Garcia, A. and Zhiyou, W. 2009. Use of biodiesel-derived crude glycerol for producing eicosapentaenoic acid (EPA) by the fungus *Pythium irregular*. *Journal of Agriculture Food and Chemistry* 57 (7):2739-2744.

Standard Organization of Nigeria. 2004. Standards for hair cream: ICS71.100.70.

Stetter, M.G., Gates, D.J., Mei, W. and Ross-Ibara, J. 2017. How to make a domesticate. PeerJpreprints. [online] Available from <https://doi.org/10.7287/peerj.preprints.2902v1> [Accessed 17 May 2017].

Vermaak, I,. Kamatou, G.P.P., Komane-Mofokenf, B., Viljoen, A.M. and Beckett, K. 2011. African seed oils of commercial importance - Cosmetic applications. *South African Journal of Botany* 77: 920-933.

Wimalasiri, D.C. 2015. Genetic diversity, nutritional and biological activity of *Momordica cochinchinensis* (Cucurbitaceae). RMIT University, Sri Lanka.

World Intellectual Property Organisation. 2011. A tree and traditional knowledge: A recipe for development. World Trade Organisation. [online]. Available from <http://www.oecd.org/ aidfortrade/47764748.pdf> [Accessed 24 April 2017].

Zaku, S. G., Emmanuel, S.A, Isa, A.H. and Kabir, A. 2012. Comparative studies on the functional properties of Neem, Jatropha, Castor, and Moringa seed oil as potential feedstock for biodiesel production in Nigeria. *Global Journal of Science Frontier Research Chemistry* 12 (7):2249-4626.