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Research Article

Yield and Physicochemical Properties of Marula (*Sclerocarya birrea*) Seed Oils among Nine International Provenances Tested in Malawi

Mussa Kamanula,[1] **Chimuleke Yangontha Munthali**,[1] **and John Finias Kamanula**[2]

[1]*Mzuzu University, Department of Forestry, Private Bag 201, Luwinga, Mzuzu, Malawi*
[2]*Mzuzu University, Department of Chemistry, Private Bag 201, Luwinga, Mzuzu, Malawi*

Correspondence should be addressed to Mussa Kamanula; kamanulamussa@yahoo.com

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Sclerocarya birrea (Marula) is an indigenous fruit tree that is revered for its numerous socioeconomic contributions to human livelihood. Among others, the species is an important source of seed oil that is utilized in various domestic and industrial applications. This study was carried out to assess the yield and physicochemical properties of seed oils among nine international provenances of *Sclerocarya birrea* (subspecies caffra and birrea) planted in Malawi. Seed oils were obtained using the Soxhlet extraction method while quality parameters were determined using procedures described by the Malawi Bureau of Standards. Oil yield was highest (52.2%) in subspecies birrea (Missira provenance; Mali). Oil moisture content, free fatty acids, 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 the origin of genotypes. The selection of *Sclerocarya birrea* for oil production and use should be based on both provenance and subspecies levels. Further studies should study the heritability of the oil content and its physicochemical properties before conclusive decisions on the use of seed for propagation are carried out.

1. Introduction

Sclerocarya birrea commonly known as Marula is an indigenous fruit tree of the family Anacardiaceae [1]. The tree is naturally present in Malawi, Namibia, Botswana, Zimbabwe, Zambia, Mozambique, Swaziland, and South Africa [2]. While being known as the Elephant tree in English, it is known as Mfula in Malawi [3]. The female trees yield edible [4] mango-like fruits which have oil bearing seeds [5]. Domestically, oil is used for cooking and meat preservation [5], whereas the energy sector uses it as the main raw material for the production of biofuels [6]. For many years, *S. birrea* seed oil has also been used in cosmetic formulations by the international beauty markets [2]. The oil is said to be resistant to oxidation and it is easily absorbed by the skin [7]. Such quality attributes have made seed oil a commercial ingredient for many cosmetic formulations. For example, a 63 ml product from the seed oil fetches about $80 [2]. In the year 2008, Namibia raised about $1,700,000 from *S. birrea* seed oil [7]. With such economic potential and the increase in global demand for oils [8], *S. birrea* seed oil could improve the livelihood of many poor communities in developing countries once commercialized.

Sclerocarya birrea is one of the indigenous fruit species that was selected for domestication in Malawi among others such as *Uapaca kirkiana, Strychnos cocculoides, Vangueria infausta*, *Parinari curatellifiolia, Ziziphus mauritiana, Adansonia digitata, Sizygium cordatum* (Gaertner), and *Vitex species* [9]. Tree domestication is described as an adaptive process that transforms a wild plant for human use [10]. The process is done to develop ideotypes that offer a variety of human needs [9]. The selection of *S. birrea* for

domestication led to the establishment of an international provenance trial for the species in Malawi with support from the World Agroforestry Center (WAC) and the Forest Research Institute of Malawi (FRIM) in the year 1999 [11]. Previous research in the trial has shown variations among provenances in terms of mating systems [12], pest susceptibility [13], growth performance and fruit productivity [14], fruit morphological traits [15] as well as nutritional and phytochemical composition [16]. However, scientific information on the quantity and quality of seed oils among the provenances is still scarce. The question is whether the populations (provenances) collected from a far wide geographical distribution (Figure 1) are the same or different in terms of oil quantity and quality. The information on oil quantity and quality (physicochemical properties) is important in determining the oil's specific use [17–19]. Furthermore, the quality of oil provides scientific evidence of the oil's mode of action when used in various industrial applications [2]. It is, therefore, necessary to assess *S. birrea* provenances in terms of their seed oil quantity and quality prior to domestication and commercialization. It has been noted that most domestication programs rely on phenotypic variations to select superior genotypes for fruit species [15]. However, when this method is used, a high proportion of the selected genotypes may be of low quality with undesirable characteristics for specific uses [20]. Thus, decisions on the selection of genotypes for domestication need to be supported with concrete scientific evidence. Laboratory experiments have been credited as a key tool in the selection of breeding resources because they allow hypotheses of cause and effect to be tested [20]. For instance, the objective of this study was to investigate the effect of provenances and subspecies on the quantity and quality of *S. birrea* seed oils.

2. Materials and Methods

2.1. Study Area and Experimental Design. Information on the study area is thoroughly described by [11, 14]. The international provenance trial was established in February 1999 in the Palm Forest Reserve in Mangochi district, Malawi. The forest has an altitude of 200 m above sea level with 800–1200 mm and 23.9°C as mean annual rainfall temperatures, respectively. The area has a flat terrain with sandy soils and loamy sand with medium acidity. The seeds used in the trial were collected from provenances within the SADC region (subspecies caffra) and Mali (subspecies birrea) (Figure 1). The experimental treatments were laid out as a randomized complete block design with 4 replicates. Each treatment had a line plot with twenty trees that represented the total possible number of families for each provenance. Spacing was 5 meters between row plots and 4 meters between trees within a plot, translating to eighty trees per population.

2.2. Collection of S. birrea (Subspecies caffra and birrea) Fruits. Healthy, mature, and ripe fruits (Figure 2) from each provenance were collected from the ground (underneath trees) from January to December 2019.

2.3. Processing of S. birrea (Subspecies caffra and birrea) Seed Kernel. Sclerocarya birrea (subspecies caffra and birrea) seeds were obtained after removing the fruit pulp. For 7 days, they were dried under shade (room temperature) at Mzuzu University Chemistry Laboratory. The endocarps of the dried seeds were crushed manually with a hammer to obtain the seed kernels. The obtained seed kernels were then dried under shade for 5 to 7 days (room temperature) until a constant weight was achieved before pounding them using a wooden mortar and pestle. The pounded samples were then placed on a clean white paper (Figure 3).

2.4. Extraction of S. birrea (Subspecies caffra and birrea) Seed Oil. The oil was obtained using the Soxhlet extraction method [21]. Exactly 15 g of dried pounded sample of *S. birrea* (seed kernel (Figure 3) was weighed on an analytical balance (N17250, Asynt, China) before placing it in an extraction thimble in triplicate with a piece of cotton wool 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 timed to heat up continuously for three hours at a temperature range of 40°C to 60°C after which the Soxhlet apparatus was allowed to cool for twenty minutes. After extraction of the oil, the solvent that remained in the flask was removed using a rotary evaporator (RE 111, BUCHI, Switzerland). To eliminate further traces of the solvent, the flasks were exposed to heat in an electric oven at 50°C for five minutes. 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 in tightened glass vials (Figure 4) which were kept at room temperature and ready for physicochemical analyses.

2.5. Determination of Oil Yield. The yield of *S. birrea* (subspecies caffra and birrea) seed oil was calculated using a method described by [22]. Oil yield was calculated as a percentage of total oil present in 15 g of *S. birrea* (subspecies caffra and birrea) seed kernel. For each provenance, oil yield was determined in triplicate and was calculated using the following:

$$\text{Oil yield}\,(\%) = \frac{[W1]}{[W2]} * 100. \quad (1)$$

W1 is the weight (g) of oil and W2 is the weight (g) of the *S. birrea* seed kernel sample.

2.6. Determination of Physicochemical Properties of Oil. While the physical property (moisture content) of *S. birrea* (subspecies caffra and birrea) seed oil was determined by using oven dry method [22], the chemical properties (free fatty acids, acid value, and peroxide value) were determined by titration methods as described by the Malawi Bureau of Standards [23].

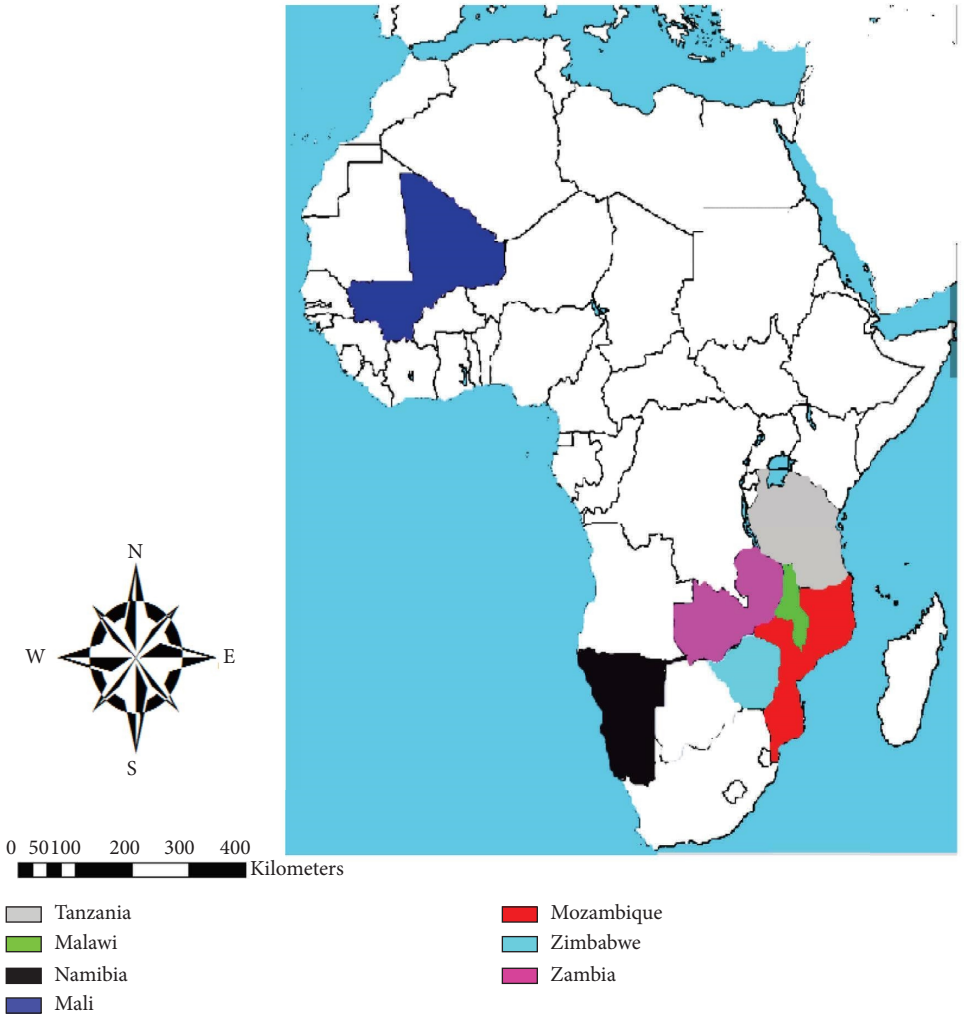

Figure 1: Map of Africa showing countries where *Sclerocarya birrea* seed was collected.

Figure 2: Phenotype of mature *Sclerocarya birrea* fruit.

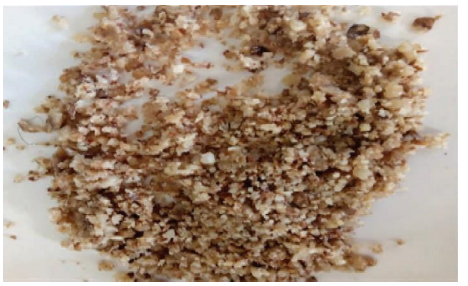

Figure 3: Pounded sample of *Sclerocarya birrea* seed kernel.

2.6.1. Moisture Content. A sample of oil (2 g) was put in a dry and weighed porcelain crucible and then placed in an electric oven (Series 9000, Bosch Electric Hobs, German) set at 105°C. It was heated for 2 hours before removing and allowing it to cool in a desiccator. After cooling, it was accurately weighed on an analytical balance and the mass was recorded (N 17250, Asynt, China). This mass (g) 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 the following:

$$\text{Moisture content}\,(\%) = \frac{[M1\text{–}M2]}{[M1]} * 100. \quad (2)$$

M1 is the mass of the crucible (g) + oil (g) before heating and M2 is the mass of the crucible (g) + oil (g) after heating.

Figure 4: *Sclerocarya birrea* seed oil in glass vials.

2.6.2. Free Fatty Acid (%). The 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) with three to four drops of phenolphthalein indicator was added. The mixture was allowed to heat and boil on a hot plate, after which it was titrated with a standardized solution of 0.25 N 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 acid (FFA) composition (% m/m oleic acid) was then calculated using the following:

$$\text{Free Fatty Acid}\left(\%\,\frac{m}{m}\text{oleic acid}\right) = \frac{[T * C * 28.2]}{m}. \quad (3)$$

T is the titer 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.

2.6.3. Acid Value. The acid value was calculated from the volume of sodium hydroxide obtained from the determination of free fatty acids as shown in the following equation:

$$\text{Acid value} = \frac{[56.1 * T * C]}{m}. \quad (4)$$

T is the titer 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.

2.6.4. Peroxide Value. The oil sample (5 g) was weighed and placed into a 250 mL glass stoppered conical flask and 30 mL 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 was added. The mixture was titrated with 0.1 N standard sodium thiosulphate solution, adding it gradually and with constant and vigorous shaking, until the yellow color had almost disappeared. Starch indicator solution (1%) of 0.5 mL was added as the titration continued with vigorous shaking of the flask to liberate the iodine from the chloroform layer. Three to four drops of sodium thiosulphate solution were added until the blue color had just disappeared, signaling the endpoint. A blank titration was carried out in a similar manner using the reagents only. The peroxide value was then calculated using the following:

$$\text{Peroxide value} = \frac{[T * C * 1000]}{m}. \quad (5)$$

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

2.7. Data Analysis. Values of oil yield (%), moisture content (%), and free fatty acids (%) were subjected to arcsine transformation using Microsoft Excel 2013. Measurements of acid values and peroxide values were tested for normality and homogeneity with Kolmogorov–Smirnov using Minitab 17. After meeting the above criteria, data were subjected to a one-way analysis of variance using Minitab 17. Significantly different means were separated using Fisher's Least Significant Difference (LSD).

3. Results

3.1. Yield of S. birrea (Subspecies caffra and birrea) Seed Oil. Table 1 shows the yield (%) of *S. birrea* (subspecies caffra and birrea) seed oil among the nine provenances. There were significant differences ($P \leq 0.05$) in the oil yield. The West African provenance (Missira) from Mali, which contains subspecies birrea, recorded the highest oil quantity ($52.2 \pm 0.3\%$) among the nine provenances. Moamba (Mozambique), which contains subspecies caffra, followed by $50 \pm 0.2\%$ while Matebeleland (Zimbabwe) had the lowest oil yield of $41.1 \pm 0.5\%$.

3.2. Physicochemical Properties of S. birrea (Subspecies caffra and birrea) Seed Oil. Table 2 shows the results of the physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oils among nine provenances. Significant differences ($P \leq 0.05$) in moisture content, free fatty acid composition, acid value, and peroxide value of the seed oils were noted.

3.2.1. Moisture Content. The oil moisture content ranged from 0.06% to 0.76%. The highest quantity was in Matebeleland provenance ($0.76 \pm 0.01\%$) (subspecies caffra) of Zimbabwe which was followed by Kalimbeza ($0.65 \pm 0.03\%$) (subspecies caffra) of Namibia. The lowest moisture content was recorded in Ngundu ($0.09 \pm 0.01\%$) (subspecies caffra), Missira ($0.07 \pm 0.01\%$) (subspecies birrea), and Chikhwawa ($0.06 \pm 0.01\%$) (subspecies caffra).

3.2.2. Free Fatty Acid. Free fatty acid composition ranged from 1.96 to 4.07%. The highest amount was in Missira provenance ($4.07 \pm 0.02\%$) (subspecies birrea) which was followed by Marracuene ($3.24 \pm 0.01\%$) (subspecies caffra), Chikhwawa ($3.22 \pm 0.03\%$) (subspecies caffra) and

Table 1: Yield of *Sclerocarya 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}

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

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

Provenance	Subspecies	MC (%)	FFA (%)	AV (mg·KOH/g)	PV (meq·KOH/g)
Chikhwawa	*caffra*	0.06 ± 0.01^{e}	3.22 ± 0.01^{b}	6.44 ± 0.03^{b}	2.15 ± 0.01^{g}
Marracuene	*caffra*	0.32 ± 0.01^{d}	3.24 ± 0.01^{b}	6.49 ± 0.03^{b}	3.87 ± 0.03^{c}
Magunde	*caffra*	0.42 ± 0.01^{c}	3.16 ± 0.01^{c}	6.33 ± 0.01^{bc}	3.93 ± 0.02^{b}
Moamba	*caffra*	0.33 ± 0.01^{d}	3.11 ± 0.01^{c}	6.22 ± 0.02^{bc}	3.19 ± 0.01^{d}
Matebeleland	*caffra*	0.76 ± 0.01^{a}	2.15 ± 0.01^{d}	4.29 ± 0.01^{d}	2.05 ± 0.01^{h}
Ngundu	*caffra*	0.09 ± 0.01^{e}	2.13 ± 0.01^{d}	4.25 ± 0.01^{d}	1.84 ± 0.01^{i}
Magamba-Turiani	*caffra*	0.45 ± 0.01^{c}	1.96 ± 0.01^{e}	3.91 ± 0.02^{e}	5.15 ± 0.02^{a}
Kalimbeza	*caffra*	0.65 ± 0.01^{b}	3.19 ± 0.01^{b}	6.37 ± 0.02^{bc}	3.11 ± 0.01^{e}
Missira	*birrea*	0.07 ± 0.01^{e}	4.07 ± 0.01^{a}	8.13 ± 0.02^{a}	3.02 ± 0.01^{f}

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

Kalimbeza ($3.19 \pm 0.02\%$) (subspecies caffra). The lowest value ($1.96 \pm 0.02\%$) was in Magamba-Turiani (subspecies caffra) the provenance of Tanzania.

3.2.3. Acid Value. The 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 lowest acid value (3.91 ± 0.02 mg·KOH/g) was in Magamba-Turiani provenance (subspecies caffra).

3.2.4. Peroxide Value. Peroxide values ranged from 1.84 to 5.15 meq·KOH/g and nine categories were established (Table 2). The highest peroxide value (5.15 ± 0.03 meq·KOH/g) was noted in Magamba-Turiani provenance (subspecies caffra) which was followed by Magunde (3.93 ± 0.04 meq·KOH/g) (subspecies caffra). The lowest peroxide value (1.84 ± 0.02 meq·KOH/g) was recorded in Ngundu provenance (subspecies caffra).

4. Discussion

4.1. Yield of S. birrea (Subspecies caffra and birrea) Seed Oil. Results of the study (Table 1) have demonstrated significant variations in the yield of *S. birrea* (subspecies caffra and birrea) seed oil originating from different geographical areas. The findings have further revealed that subspecies birrea contains the highest amount of seed oil compared to subspecies caffra despite the two being raised in a similar environment. The highest oil content (52.2%) in this study is comparable to the one reported in the *S. birrea* subspecies caffra (53%) from Sudan [24] but greater than that of *S. birrea* subspecies caffra (46.4%) from Northern Ghana [25]. It is reported that variations in oil content are influenced by genetic factors [26], species origin [18], as well as environmental factors [27]. Since all populations were raised in the same environment, the variations observed in this study could be attributed to adapted genetic factors associated with the origin of genotypes (provenances), these reflect climatic and geographic differences such as temperature and rainfall [28]. Perhaps subspecies birrea from Missira (Mali) has adapted to its natural ecological conditions and has since evolved a high oil content. The quantity of oil present in a raw material is an important factor that determines its use. For instance, oil quantities in the range of 30 to 60% are suitable for the production of biodiesel [29, 30]. The range of oil content in the present study (41.2 to 52.3%) therefore shows that the seed oils from all provenances and subspecies have the potential for biodiesel production.

4.2. Physicochemical Properties of S. birrea (Subspecies caffra and birrea) Seed Oil. Results of the study have shown significant variations in the physicochemical properties of *S. birrea* (subspecies caffra and birrea) seed oils among populations from various geographic localities (Table 2). It is reported that differences in the physicochemical properties

of seed oils are influenced by species origin, environment [31], and genetic variation [30]. Since the *S. birrea* populations were grown in the same environment, the variations in the physicochemical properties of the seed oils could probably be attributed to the genetics and origin of the genotypes. The variations in physicochemical properties (quality parameters) indicate that the oils from different provenances could be of multiple uses [18, 19].

4.2.1. Moisture Content. The oil moisture content ranged from 0.06 to 0.76%, lower than the value (4.3%) reported in the *S. birrea* subspecies caffra from Bauchi, Nigeria [32]. This variation could be attributed to genetic differences, the origin of genotypes as well as environmental factors [30, 31]. In addition, the values of oil moisture content in the present study are lower than that of other conventional seed oils such as Jathropha (2.39%) and Neem (2.53%) [18]. The amount of water present in oil has a significant impact on both storage and utilization. It is reported that a moisture content of less than 4.6% increases the shelf life of oils [22]. The moisture levels in this study, therefore, indicate that oils from all the provenances and subspecies may have a long shelf life. Oils with a moisture content of up to 0.1% have been reported to decrease biodiesel yield during the transesterification process due to the formation of soap [33]. Chikhwawa, Missira, and Ngundu provenances with oil moisture contents of 0.06, 0.07, and 0.09%, respectively, could, therefore, yield more biodiesel than the rest of the provenances. On the other hand, oils with significantly higher moisture content produce more soap than those with lower moisture content [6]. Matebeleland provenance (subspecies caffra) with the highest oil moisture content of 0.76% could therefore yield more soap than the rest of the provenances.

4.2.2. Free Fatty Acid. Values of free fatty acid ranged from 1.96 to 4.07%, slightly comparable to the free fatty acid composition (2.11%) of *S. birrea* subspecies caffra from Northern Ghana [25] but lower than the free fatty acid composition (20.7%) of *S. birrea* subspecies caffra seed oil from Bauchi, Nigeria [34]. These variations could also be attributed to the genetic makeup of populations, the origin of populations, and environmental differences. Free fatty acid composition is one of the considerations in feedstock selection for biodiesel production [35]. Oils with high free fatty acids yield a lesser amount of biodiesel and that transesterification can only be achieved when the free fatty acid value is 1% or 2% [18]. The results in Table 2 indicate that all the provenances in the present study have higher free fatty acid composition except for Magamba-Turiani (1.96%); as such, the oils cannot be directly trans-esterified. However, it is noted that acid esterification can be used to reduce the high values to 2% in order to optimize the biodiesel yield [18]. Unsaturated fatty acids such as oleic acid are essential in human nutrition and help in reducing cholesterol levels [36]. The oils from provenances such as Missira (subspecies birrea) with a high proportion of oleic acid (4.07%) could form highly nutritious edible oils. On the other hand, oils with high content of oleic acid have been reported to improve lubrication properties [34]. Oils from Missira provenance (subspecies birrea) with significant levels of oleic acid could therefore synthesize the best lubricants than oils from the rest of the provenances.

4.2.3. Acid Value. Results of the study (Table 2) 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 [34] but slightly higher than the acid value (2.52%) of *S. birrea* subspecies caffra seed oil from Northern Ghana [25]. These variations could be attributed to the genetic makeup and origin of populations as well as environmental factors. The edibility of the oil is determined by oil acidity and the presence of free fatty acids and other nonlipid acids [22]. Oils with low acid values are stable over a longer period of time than those with high acid values [36].

The maximum acid value suitable for consumption is 4.0 mg·KOH/g [37]. Magamba-Turiana registering a (3.91 mg·KOH/g) could be recommended for human consumption and with its low acid value, could show stability over a period of time than oils from the other provenances.

4.2.4. Peroxide Value. Peroxide values ranged from 1.84 to 5.5 meq·KOH/g, higher than that of *S. birrea* subspecies caffra seed oil (10.5 meq·KOH/g) from Bauchi, Nigeria [32] but slightly comparable to peroxide value (4.58 meq·KOH/g) of other *S. birrea* populations from the same area of Bauchi, Nigeria [34]. This variation could be attributed to genetic factors or genetic factors that are associated with the origin of populations. Peroxide value measures the content of hydroperoxides and is an indicator of oil's resistance to oxidation [38]. Lower values indicate high resistance to oxidation and a longer storage period while exhibiting minimum deterioration [39]. Ngundu provenance (subspecies caffra) oils that have a low peroxide value of (1.84 meq·KOH/g), could, therefore, exhibit high resistance to oxidation and minimum deterioration.

On the other hand, the Standard Organization of Nigeria [40] reported that oils with a maximum peroxide value of 10 meq·KOH/g are suitable for the production of hair creams. This attests to all seed oils from all genotypes/provenances and subspecies having a range of peroxide values (1.84 to 5.5 meq·KOH/g) in the present study. Oils with a maximum peroxide value of 10 meq·KOH/g also qualify as edible oils due to their stability [37]; however, they must be oxidatively stable to prevent food from becoming rancid [41]. Results of peroxide values (Table 2) suggest that oils from all provenances and subspecies qualify as edible oils.

5. Conclusions and Recommendations

The present work aimed to assess the provenances of *S. birrea* (subspecies caffra and birrea) in terms of yield and physicochemical properties of their seed oils. The study has shown that the yield and physicochemical properties of

S. birrea seed oils from different geographic localities and different subspecies vary significantly despite the genotypes raised in a similar environment. Subspecies birrea originating from Missira (Mali) has been shown to contain the highest quantity of seed oil. The variations observed could be attributed to the genetic makeup and origin of the genotypes (provenance). The different chemical characteristics of the seed oils show the possibility of developing various products; however, the selection of *S. birrea* for oil production should consider the provenance/origin of genotypes and subspecies. Further studies should study the heritability of the oil content and quality properties prior to the use of seed for propagation. Tree-to-tree variation in terms of oil quantity and quality to fully utilize the variations that exist within the species is also a gap that further studies can look at.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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