*Cameroon Journal of Biological and Biochemical Sciences, 2025, 33, 37-51.*
*DOI: https://doi.org/10.63342/cjbbs2025.33.04*

CAMEROON JOURNAL OF BIOLOGICAL AND BIOCHEMICAL SCIENCES
Published by the Cameroon Biosciences Society (CBS)

*Research Article*

# Effect of drying and roasting on nutritional composition and lipid oxidation profile of marula (*Sclerocarya birrea*) kernels from Far-North Cameroon

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*Received: 27 Dec 2024, Reviewed: 04 Feb 2025, Revised: 26 Feb 2025, Accepted: 05 Mar 2025, Published: 05 Apr 2025*

**ABSTRACT**

*Sclerocarrya birrea* (Marula) is one of the underutilized wild edible fruit tree species that is grown in Far North Cameroon. The present study investigated the effect of different drying methods on the proximate composition, mineral content, and lipid oxidation of marula kernels consumed in Far-North Cameroon. Sun drying, oven drying, and roasting were employed. The proximate analysis was performed using AOAC methods. Lipid oxidation was evaluated by measuring free fatty acid (FFA), iodine value (IV), peroxide value (PV), p-Anisidine value (p-AV), and thiobarbituric reactive substances (TBARS). Results showed that raw marula kernel contains 7.31% moisture, 4.15% ash, 23.19% proteins, 47.73% lipids, 8.90% carbohydrates, and 7.49% crude fiber. Marula kernels are good sources of phosphorous (P: 1311.88 mg/100g), calcium (Ca: 1144.13 mg/100g), potassium (K: 983.87 mg/100g), zinc (Zn: 7.60 mg/100g), and iron (Fe: 7.04 mg/100g). All the processing methods significantly increased ($P<0.05$) the ash, protein, lipid, and carbohydrate contents of the marula kernel. An increase in Ca, P, K, magnesium (Mg), Fe, and Zn were also noted. During processing, FFA, PV, p-AV, and TBARS increased significantly ($P<0.05$), while IV decreased. Oven drying at 80 °C was the best method, given the high protein content, while roasting for 10 min provided the highest lipid content. The oven-dried sample at 40 °C was found to have the best oil qualities.

**Keywords:** Marula seeds, nutrient composition, drying techniques, roasting, lipid oxidation

**RÉSUMÉ**

Le Marula (*Sclerocarrya birrea*) est l'une des espèces végétales sauvages aux fruits comestibles sous exploités. La présente étude vise à évaluer l'effet de différents traitements sur la composition chimique et l'état d'oxydation lipidique des amandes de marula consommées dans l'Extrême-Nord Cameroun. Les amandes ont été soumis au séchage au soleil, à l'étuve et à la torréfaction. L'analyse de la composition chimique a été réalisée en utilisant la méthode AOAC. L'oxydation lipidique a été évaluée en mesurant les indices de qualités. Les résultats ont montré que les amandes de marula fraîches contiennent 7,31 % d'eau, 4,15 % de cendres, 23,19 % de protéines, 47,73 % de lipides, 8,90 % de glucides et 7,49 % de fibres brutes. Ces amandes sont de bonne source de phosphore (P: 1311,88 mg/100 g), de calcium (Ca : 1144,13 mg/100 g), de potassium (K: 983,87 mg/100 g), de zinc (Zn : 7,60 mg/100 g) et de fer (Fe : 7,04 mg/100 g). Tous les traitements appliqués ont provoqué une augmentation significative de la teneur en nutriments. Pour ce qui est de la qualité de l'huile, tous les traitements appliqués ont provoqué une augmentation significativement ($P<0,05$) des indices d'acides, de peroxydes de p-anisidine et de TBARS. Par contre l'indice d'iode a diminué. Le séchage à l'étude à 80 °C demeure le meilleur traitement qui améliore la quantité de protéines tandis que la torréfaction pendant 10 min fournit une quantité importante de lipides. Le séchage à l'étuve à 40 °C fournit des amandes aux huiles de bonne qualité.

**Mots clés**: Amandes de marula, Composition chimique, Grillage, Séchage, Oxydation des lipides.

## 1. INTRODUCTION

The Sub-Sahara region of Africa contains a vast variety of fauna and flora with potential applications in medicines, cosmetics, and foods. Underutilized edible wild fruits have become a very important part of human nutrition and can be overlooked as far as food security, good health, and income generation are concerned (Aworh, 2015; Bvenura and Sikumar, 2017). Underutilized edible wild fruits contain very essential nutrients such as proteins, dietary fiber, sugars, minerals, and vitamins necessary to maintain good health (Natol et al., 2023).

Thus, in developing countries, food insecurity can be reduced by motivating rural poor communities to increase their consumption of indigenous fruits as well as fruit-based food supplements.

Marula (*Sclerocarya birrea*) is a member of *the Anacardiaceae* family. In Africa, it is one of the most commonly utilized indigenous wild fruits (Shakleton et al., 2001). The marula tree is a multipurpose tree highly appreciated by the local population, mainly for its fruits, its cosmetic and food oil from the seed, and medicinal purposes from the bark and leaves (Alissa et Ferns, 2017; Street and Prinsloo, 2013).

*Sclerocarya birrea* is an indigenous fruit tree that is revered for its numerous socioeconomic contributions to human life. The tree produces a round fruit, 3 cm in diameter, with a seed consisting of 3 kernels, on average 1.5 cm in length and 0.5-1.0 cm in diameter (Mariod and Abdelwahab, 2012).

The protein content of birrea fruit pulp is low. However, the protein in the kernel is high, about 30 and 40% on a dry matter basis (Rahat et al., 2022). The seeds were found to contain a low proportion of some essential amino acids, including leucine, threonine, lysine, and the phenylalanine/tyrosine pair, when compared with the World Health Organization (WHO) protein standard (Glew et al., 2004). As mentioned by Zimba et al. (2005), oils extracted from plant sources have a rich history of use by local people as a source of food, energy, medicine, and cosmetic applications. The lipid content in the fruit pulps of *Sclerocarya birrea* is below 2%, while in the kernel, the value is about 60% on a dry matter basis. The most saturated fatty acids present in Marula seed oil were palmitic acid (9–12%) and stearic acid (5-8%) (Bvenura and Kambizi, 2024). The kernels of *Sclerocarya birrea* are rich in unsaturated fatty acids and constitute 80% of the total fat. Oleic acid is known to exert good antioxidant activity, and as marula oil is reported by Bvenura and Kambizi (2024) to contain a high content of this fatty acid (70–78%), it could be expected to also exhibit antioxidative properties. These seeds' oil contains appreciable amounts of essential fatty acids (7% linoleic acids, 0.3-8% arachidonic acid) (Glew et al., 2004; Rahat et al., 2022). The unsaturated fatty acids present in marula kernel oil have a biochemical effect on the prevention or treatment of several human diseases. They are also metabolic precursors of eicosanoids such as prostaglandins and leukotrienes, and docosanoids such as protectins and resolvins (Chapkin et al., 2008). These polyunsaturated fatty acids present in Marula kernels may help to prevent coronary heart disease, hypertension, type II diabetes, and insulin resistance. Marula oil has been shown to improve skin hydration and smoothness as well as reduce skin redness (Shoko et al., 2018). Easy absorption, a high proportion of oleic acid, as well as the presence of linoleic acid, all contribute to rendering the oil ideal for tropical applications. The seeds of Marula are rich in minerals and vitamins such as iron, magnesium, calcium, zinc, phosphorous, nicotinic acid, and thiamine (Mariod and Abdelwahab, 2012). The chemical composition of marula seeds varies and depends on the type of soil, climatic conditions, maturities of plants, and their varieties (Glew et al., 2004; Matthew et al., 2019).

The marula seeds are eaten fresh, dried or milled, roasted, and incorporated into vegetables, meat, and soups, making the seeds creditable for imparting flavor to food. The fresh seeds are also incorporated into porridge and boiled meat to enhance the flavor (Petje, 2008). Seed oil is extracted from seeds after different processing by pressing or solvent extraction. Cosmetic formulations with seed oils are designed to protect the skin against exogenous or endogenous damage. The incorporation of seed oils in cosmetic products is crucial to provide a moisturizing effect by forming a skin barrier to prevent water loss. Seed oils also showed antiaging effects by supplying bioactive compounds that nourish the skin. During this processing, more biochemical reactions can take place and affect the nutritional value of seeds. The consequence of the negative effect of seeds was the reduction of the potential health benefits arising from the consumption of seeds (Ozdemir and Devres, 2000). Lipid oxidation occurring during processing strongly affects the shelf life and sensory characteristics of oils and their use in cosmetic formulations. The oxidation degree depends on the content of unsaturated fatty acids in oil, the enzymatic activity, the mineral composition, and the presence of natural antioxidants (Ozdemir and Devres, 2000).

Many studies have reported the chemical composition of marula seeds in some countries. These include the nutritional composition, polyphenolic compounds, and biological activities of marula fruits (*Sclerocarya birrea*) with their potential food applications (Glew et al., 2004; Abdalbasit and Siddy, 2012; Adam et al., 2015; Mpho et al., 2022). In Cameroon, no study has been reported on the chemical composition of marula seed growth there. There is very limited information on the effect of drying on the nutritional value and lipid quality of marula kernel seeds and oils. Processing eventually affects the final products regarding the nutritional composition of seeds. Lipid oxidation occurring during processing affects shelf life and sensory characteristics of oils and depends on many factors such as concentration of unsaturated fatty acids, enzymatic activity, and

mineral composition. In these studies, we hypothesize that the chemical composition of marula seeds depends on geographical location and on the method of drying. The present study was therefore carried out to assess the effect of drying methods on the chemical composition and lipid quality of marula kernel seed growth in Far-North Cameroon. The scientific information obtained from this experiment could serve as an important input for cosmetic industries, the food industry, human nutrition, and maximum utilization of marula seeds.

## 2. MATERIAL AND METHODS

### 2.1 Plant material

The samples of ripened fresh fruits of marula were collected in May 2021 from marula trees cultivated in Garey, a locality situated in Kaele, a division of Mayo-Sava in the Far-North region of Cameroon. The environmental study is dominated by a Sudano-sahelian climate, which is characterised by two distinct seasons. The region experiences a lengthy dry season, spanning eight months from October to May, followed by a relatively brief four-month rainy season that encompasses the months of June to September. The mean temperature is 28.1 °C, with a minimum of 18 °C in January and a maximum of 40 °C in April and May (Fotsing, 2009). In Kaele, the most common types of vegetation are shrubby savannas and wooded savannahs, with plant species dominated by Anogeissus leiocarpus, Balanites aegyptiaca, Guiera senegalensis, Acacia serjal, Acacia albida, and Acacia Senegal (Fotsing, 2009).

The 3 kg of fresh kernels utilized in this study were procured from *Sclerocarya birrea* fruits, which were initially selected, pulped, and meticulously crushed in the Garey village using the artisanal method. Subsequent to their collection, they were promptly conveyed in polyethylene back to the Food Laboratory in the University of Maroua. In the laboratory, they were divided into two groups.

### 2.2 Dying methods

For the purpose of oven drying, a quantity of 300 grams of marula kernel was arranged in a single layer within aluminium foil dishes with a diameter of 12.6 centimetres. These were then placed in an electric forced air oven of the model G48, which was equipped with a thermostat and a stainless-steel grill (Balay, Zaragoza, Spain). The kernels were dried at 40, 60, and 80 °C for 30 minutes after the set temperature was attained (40, 60, and 80 °C).

In the case of sun-drying, the marula kernels were arranged in a single layer within stainless steel trays of 60 cm in diameter. The kernels were subjected to solar drying by exposure to ambient sunlight between the hours of 8 a.m. and 5 p.m. over a period of three days. The mean daily temperature for the duration of the experiment was 35 degrees Celsius. drying. The dried samples were then submitted for chemical analysis at 0, 1, and 3 days.

Two sub-groups of 200 g of raw marula kernel seeds were roasted in a traditional manner for 5 and 10 minutes, respectively, with continuous stirring. The temperature between the heat sources and cooking pot was maintained between 160 and 190 degrees Celsius.

During drying and roasting, the kernels were turned over at regular intervals to ensure uniform drying. The fresh, oven-dried, sun-dried, and roasted kernels were allowed to return to ambient temperature, then ground in an electric grinder (Panasonic, Kyoto, Japan), packaged in polyethylene plastic bags, and stored in a dry environment for further analysis (chemical composition, lipid qualities).

### 2.3 Oil extraction

80 g of marula kernel flour were soaked in 300 ml of hexane for a period of 72 hours, with agitation occurring at regular intervals. This process was conducted at room temperature (approximately 25 degrees Celsius). Subsequently, the mixture was filtered on Whatman paper no. 4, and the hexane was concentrated under vacuum using rotary evaporation at 40 °C. Subsequently, the supernatant was collected and evaporated, resulting in the production of a solvent-free oil. Subsequently, 1 g of anhydrous sodium sulfate was added to 10 g of oil and held in an oven at 50 °C.

### 2.4 Analytical Methods

#### 2.4.1 Proximate Analysis of Marula Kernels

The proximate composition of fresh, oven-dried, sun-dried, and roasted marula kernels was analysed. The moisture content was determined using the analytical method (AOAC, 2000). The samples were subjected to drying at 105 °C for an extended period until a constant weight was attained. The ash content was determined by subjecting the marula kernels to combustion at 550 °C in a furnace oven, in accordance with the AOAC method (AOAC, 2000). The protein content was calculated by converting the nitrogen content, which was determined by the combustion method (NX6.25) (AOAC, 2000). The lipid content was determined utilizing a Soxhlet apparatus with hexane, in accordance with the fundamental methodology outlined in reference (AOAC, 2000). The crude fiber content was determined using a fiber gauge in accordance with the conventional method (AOAC, 1990). The carbohydrate content was calculated as the difference. All samples were subjected to analysis in triplicate.

#### 2.4.2 Determination of Mineral Composition

The determination of minerals was conducted by ashing marula kernels at 550 °C and boiling the resulting ash in a beaker with 10 mL of 20% HCl. The solution was then filtered into a 100 mL standard flash, and the mineral content was determined. The concentrations of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), zinc (Zn), and copper (Cu) were determined by atomic absorption spectrometry (Varian 220FS Spectr AA, Les Ulis, France). A reference sample from the daily routine in the laboratory was used for quality control purposes. Certified reference material 1570a was purchased from the National Institute of Standards and Technology (Gaithersburg, USA). Following the initial standardization of techniques during a pilot study, the samples were treated identically (Tuzen et al., 2004). Mineral contents of the samples were determined from calibration curves of standard minerals. All samples were analysed in triplicate.

#### 2.4.3 Determination of oil quality indexes

The free fatty acid content and peroxide value of marula kernel oils were determined according to the AFNOR procedures (AFNOR, 1971). The procedures described by O'keefe and Pike (2010) and Drapper and Hadley (1990) were respectively used to evaluate the iodine and thiobarbituric acid values in marula kernel oils. The *P*-anisidine value was determined according to a modification of AOCS's official method Cd 18-90 (AOCS, 1998). The total oxidation (TOTOX) values of oil samples were determined based on the obtained peroxide and p-anosine values using the equation TOTOX value = PV + AV, according to Shahidi and Wanasundara (2008).

### 2.5 Statistical analysis

The results reported are the averages of three replications. Data were analyzed by one-way analysis of variance (ANOVA) using Statistical Package of Social Science (SPSS 16.0 version). A comparison was made between species and treatments. Differences were considered significant at $P<0.05$ using the Duncan multiple range test.

## 3. RESULTS AND DISCUSSION

### 3.1 Proximate composition

Table 1 shows the proximate composition of raw and dried marula kernels. The raw sample contained 7.13% moisture, 4.15% ash, 23.19% crude protein, 47.73% oils, 8.90% carbohydrates, and 7.49% crude fiber. The moisture content of raw marula kernels obtained in the present study is higher than that found by Sama et al. (2022) in marula kernels from Ouahagouya, Burkina Faso. The ash content, an indicator of mineral content, recorded in this work is comparable to the 4.1% recorded by Sama et al. (2022) in Burkina Faso, but higher than the 3.4% value obtained by Adam et al. (2015) in Sudan from marula seeds. The crude protein recorded in the raw sample is lower than the 47.21% value obtained by Mdziniso et al. (2016) in Marula kernel from Swaziland. The oil content of raw samples of maruala was lower when compared to the value (60.9%) recorded by Adam et al. (2002) for marula kernel in Sudan. The presence of crude fiber in raw kernels indicates that their consumption has many health benefits. They may help to reduce the risk of heart disease and improve glucose tolerance by delaying the transport of carbohydrates to the small intestine (He et al., 2022). Research has shown that the climatic conditions of plant species, including rainfall and temperature, are the most important climatic parameters influencing species' seed size and seed chemical composition (Sidina et al., 2009).

**Table 1:** Effect of processing methods on proximate composition (%) of marula kernel

| Samples | Moisture | Ash | Proteins | Lipids | Carbohydrates | Crude fiber |
|---|---|---|---|---|---|---|
| Raw | 7.31±0.50$^{a}$ | 4.15±0.01$^{f}$ | 23.19±0.18$^{d}$ | 47.73±0.06$^{e}$ | 8.90±0.09$^{b}$ | 7.49±0.01$^{a}$ |
| Oven-dried at 40 °C | 5.56±0.03$^{b}$ | 4.83±0.04$^{de}$ | 24.60±0.10$^{b}$ | 48.91±0.25$^{e}$ | 9.47±0.03$^{a}$ | 6.73±0.12$^{b}$ |
| Oven-dried at 60 °C | 4.69±0.23$^{c}$ | 5.26±0.06$^{cd}$ | 24.67±0.25$^{b}$ | 50.77±0.13$^{d}$ | 9.32±0.45$^{ab}$ | 5.28±0.16$^{c}$ |
| Oven-dried at 80 °C | 3.99±0.08$^{e}$ | 5.14±0.06cd | 25.31±0.24$^{a}$ | 52.50±0.20$^{c}$ | 8.34±0.25$^{cd}$ | 4.72±0.06$^{d}$ |
| Solar-dried for 1 day | 5.15±0.05$^{bc}$ | 4.37±0.15$^{ef}$ | 23.80±0.08$^{c}$ | 50.96±0.38$^{d}$ | 9.15±0.06$^{ab}$ | 6.57±0.13$^{b}$ |
| Solar-dried for 3 days | 3.30±0.12$^{f}$ | 5.71±0.13$^{c}$ | 24.26±0.16$^{bc}$ | 53.42±0.50$^{c}$ | 8.85±0.08$^{b}$ | 4.66±0.09$^{d}$ |
| Roasted for 5 min | 3.09±0.10$^{f}$ | 6.90±0.26$^{b}$ | 21.28±0.13$^{e}$ | 54.90±0.71$^{b}$ | 8.46±0.04$^{c}$ | 4.37±0.36$^{d}$ |
| Roasted for 10 min | 2.36±0.06$^{g}$ | 7.81±0.23$^{a}$ | 20.08±0.10$^{f}$ | 56.96±0.44$^{a}$ | 8.01±0.11$^{d}$ | 4.39±0.02$^{d}$ |

Values are means ± standard error (n=3). Mean values in the same column with different superscript letters are significant differences (P<0.05)

The results of the present study also show that the different drying methods significantly (P<0.05) affected the proximate composition of marula kernels. Oven drying, sun drying, and roasting significantly (P<0.05) reduced the moisture content of marula kernels. This moisture content decreases with an increase in drying temperature, sun drying, and roasting time. The traditionally roasted sample at 5 and 10 minutes gave the lowest moisture content, while the sample dried at 40°C for 30 minutes gave the higher moisture content. The high moisture content leads to bacterial and fungal attack and also insect infestation, causing a reduction in product quality and safety. Oyenga et al. (2013) have shown that low moisture content in food samples reduces the microbial activity and increases the storage period of the food product.

The ash content of marula kernel increased from 4.15% in raw samples to 7.81% in traditionally roasted samples for 10 minutes. Statistically, oven-dried samples at 60 and 80 °C had the same ash content. These results are inconsistent with those of Tenyang et al. (2017) and Seena et al. (2006) who found a decrease in the ash content of sesame and *Canavalia cathartica*, respectively, during the roasting process.

Oven drying and sun drying, as compared to roasting, increased the protein content of marula seeds, and oven-dried samples at 80 °C for 30 min presented the highest protein content. The reduction in protein content during roasting for 10 minutes was greater than that observed in samples roasted for 5 minutes. The oven-dried samples at 40°C and 60°C presented the same protein content. The same trend was observed by Ezegbe et al. (2003) during the roasting of *Mucuna pruriens*. The decrease in protein content during roasting could be due to the heating applied during processing. The consumption of oven-dried and sun-dried marula seeds can be encouraged because they have a high protein content, which could help to prevent some problems due to protein deficiencies.

With the exception of oven drying at 40 °C, all processing techniques resulted in a notable elevation in the lipid content of marula kernels. The lipid content for all the different processing methods ranged between 47.91% and 56.96%. Traditional roasting for 10 minutes had the greatest impact on lipid content. A statistically significant increase (P < 0.05) in lipid content was observed with an increase in drying and roasting time. Tenyang et al. (2017) also documented a comparable increase in the lipid content of sesame seeds during roasting. The observed increase in lipid content is in good agreement with the findings of El-Badrawy et al. (2007) on roasted peanuts. The increase in lipid content during drying may be due to the action of temperature. The traditionally roasted samples for 10 min were more dehydrated than other samples, which resulted in a high concentration of lipids in these samples. The elevated lipid content obtained during processing indicates that marula oil is a suitable choice for the oils industry and culinary applications. They are also good for incorporation into cosmetic formulations.

The data demonstrated that the carbohydrate content of the sample ranged between 7.01% and 9.47%, with a notable variation between individual treatments. With regard to oven drying processing, the carbohydrate content exhibited an increase with elevated temperature, reaching a significant decline at 80 °C. A similar trend was observed with sun-drying processing. The sample that was sun-dried for three days exhibited a lower carbohydrate content than the sample that was sun-dried for one day. The traditional roasting process was observed to result in a reduction in carbohydrate content, with the roasted sample subjected to a 10-minute

roast exhibiting the lowest carbohydrate content. The observed variation during processing may be linked to the method applied. These findings align with those of Makinde et al. (2016) and Tenyang et al. (2017), who observed a decline in carbohydrate content during the roasting of sesame seeds. It is also possible that the reduction in carbohydrate content is due to the Maillard reaction occurring during the processing.

A reduction in crude fiber was observed during processing, with the raw marula kernel presenting the highest crude fiber content, and the oven-dried marula at 80 °C together with the traditional roasted marula for 10 minutes presenting the lowest values. These observations were also noted by Ezegbe et al. (2003) during the dry processing of Mucuna pruriens. The processed marula seeds, due to their high nutrient content, can be used in food industries as an ingredient for food formulation.

**3.2 Minerals composition**

Tables 2 and 3 present the mineral composition of raw, oven-dried, sun-dried, and roasted marula kernels consumed in Far-North Cameroon. As shown in Table 2, the marula kernel contains significant amounts of macroelements, with the highest concentration being phosphorus, followed by calcium, potassium, and magnesium. The other minerals are in low concentration, and Cu is the lowest microelement present in marula kernels (Table 3).

**Table 2:** Effect of processing methods on macroelement contents (mg/100g) of marula kernel

| Samples | Potassium | Phosphorus | Calcium | Magnesium |
|---|---|---|---|---|
| Raw | 983.87±1.05$^{f}$ | 1311.88±0.18$^{f}$ | 1144.13±1.18$^{g}$ | 581.79±0.16$^{g}$ |
| Oven-dried at 40 °C | 1150.61±5.05$^{e}$ | 1336.52±0.81$^{d}$ | 1392.13±0.68$^{e}$ | 599.80±0.08$^{e}$ |
| Oven-dried at 60 °C | 1186.32±0.98$^{d}$ | 1373.93±3.25$^{c}$ | 1432.25±1.95$^{d}$ | 608.49±1.16$^{d}$ |
| Oven-dried at 80 °C | 1208.35±1.19$^{c}$ | 1392.38±1.66$^{b}$ | 11448.03±1.03$^{c}$ | 626.59±1.01$^{b}$ |
| Solar-dried for 1 day | 1207.57±2.29$^{c}$ | 1314.75±0.69$^{e}$ | 1664.52±1.37$^{b}$ | 584.59±2.05$^{f}$ |
| Solar-dried for 3 days | 1242.34±5.05$^{b}$ | 1388.92±1.31$^{b}$ | 1696.25±1.35$^{a}$ | 6.7.65±1.06$^{d}$ |
| Roasted for 5 min | 1207.57±2.20$^{c}$ | 1369.44±1.06$^{c}$ | 1376.19±0.89$^{f}$ | 621.03±1.14$^{c}$ |
| Roasted for 10 min | 1288.20±1.35$^{a}$ | 1405.52±2.33$^{a}$ | 1136.23±1.03$^{h}$ | 658.95±0.93$^{a}$ |

Values are means ± standard error (n=3). Mean values in the same column with different superscript letters are significant differences (P<0.05)

**Table 3:** Effect of processing methods on microelement contents (mg/100g) of marula kernel

| Samples | Copper | Zinc | Iron |
|---|---|---|---|
| Raw | 0.15±0.01$^{ab}$ | 7.60±0.14$^{e}$ | 7.04±0.02$^{f}$ |
| Oven-dried at 40 °C | 0.16±0.09$^{ab}$ | 8.74±0.08$^{ab}$ | 7.36±0.06$^{ef}$ |
| Oven-dried at 60 °C | 0.14±0.01$^{ab}$ | 8.60±0.21$^{bc}$ | 7.90±0.01$^{d}$ |
| Oven-dried at 80 °C | 0.15±0.01$^{ab}$ | 9.25±0.07$^{a}$ | 8.53±0.20$^{bc}$ |
| Solar-dried for 1 day | 0.17±0.02$^{ab}$ | 7.92±0.05$^{de}$ | 7.50±0.16$^{e}$ |
| Solar-dried for 3 days | 0.13±0.01$^{ab}$ | 7.99±0.35$^{cde}$ | 8.64±0.09$^{b}$ |
| Roasted for 5 min | 0.17±0.02$^{ab}$ | 8.27±0.21$^{bcd}$ | 8.19±0.03$^{cd}$ |
| Roasted for 10 min | 0.18±0.01$^{ab}$ | 8.76±0.14$^{ab}$ | 9.44±0.11$^{a}$ |

Values are means ± standard error (n=3). Mean values in the same column with different superscript letters are significant differences (P<0.05)

These results are different from those observed by Muhammad et al. (2011) in Nigeria, who reported that in the raw marula kernel, Ca is present in a high proportion, followed in descending order by K, Mg, Na, and P. The Zn and Fe contents in the raw sample in this study are higher compared to those observed in the raw sample by Muhammad et al. in Nigeria (Muhammad et al., 2011). The observed variation could be attributed to genetic or environmental differences (Florkowski et al., 2009).

Processing significantly affects the mineral profile of the marula kernel. Calcium is an important element that is essential for the formation of strong bones and teeth. It may also aid in blood clotting (Gordon, 1999). As shown in Table 2, the different processing used in this study significantly (P<0.05) increases the mean Ca content in marula kernels. The increase is proportional to drying temperature, roasting, and sun drying time. After processing, the highest Ca content (1696.25 mg/100 g) was found in the sample dried in the sun for 3 days. The

results also showed that when the roasting time was increased by 10 minutes, a decrease in Ca content was observed. The variation in Ca content observed in the different samples may be related to the process used. An increase in Ca during processing may be due to the destruction of antinutrients present in the seeds that complexed with Ca. These findings align with those of Alakili et al. (2014), who observed a notable elevation in Fe content during the drying process of Moringa oleifera leaves. The same trend was observed by Tenyang et al. (2017) when evaluating the effect of roasting on the mineral content of sesame seeds. Alakali et al. (2014) also noted the increase in Ca content during drying of *Moringa oleifera* leaves. Consumption of processed Marula kernel can be beneficial to protect the health.

Magnesium has a very important role and function in life. It is the fourth most abundant mineral in the body and is very important for many processes in the body, including the regulation of muscle and nerve function, blood sugar levels, and blood pressure (Florentin et al., 2020). According to the present study, there are significant variations ($P<0.05$) between the Mg content of raw, oven-dried, sun-dried, and roasted Marula kernels. The mean value increased with drying temperature, sun, drying time, and roasting time. The sample roasted for 10 minutes had the highest Mg content (658.95 mg/100 g), while the lowest value was recorded for the raw sample. These variations could be attributed to the process applied and the removal of moisture during the treatment. This result is in agreement with that of Tenyang et al. (2017) in sesame seeds. The Mg content of the raw sample in this work is relatively higher than 436 mg/100 g, the value obtained by Magaia (2015) on Mozambique marula kernel seeds. The difference may be related to the environmental conditions.

Phosphorus is a macro element that is needed in small amounts in the body. It is essential for development, disease prevention, and well-being. Its absence can have serious consequences. From the results presented in Table 2, all treatments showed a significant effect in increasing the P content in Marula kernel seeds. The lowest P content was observed in the raw sample, while the highest value was found in the sample roasted for 10 minutes. Similar results were found by Obembe et al. (2021) in oven-dried pumpkin leaves. An increase in P content during processing could be attributed to moisture loss, which concentrates and releases these minerals (Mehlomakulu et al., 2020).

Potassium content for raw and processed samples ranged from 983.87 mg/100g to 1288 mg/100g. The K content of the raw sample obtained in this study is higher than the value of 622 mg/100 g found by Magaia (2015) on Mozambique marula kernel seeds. The variation can be attributed to genetics. The traditional marula kernel roasted for 10 minutes was found to have the highest K value (1288.20 mg/100 g). The increase in K content during processing is in line with the findings of Djikeng et al. (2018), who demonstrated that heating processes improve the mineral content of seeds.

With regard to the trace elements (Table 3), the results of this study indicate that the raw sample exhibited the lowest concentration of copper (Cu) and the highest concentration of zinc (Zn) and iron (Fe). The various drying techniques had no notable impact ($P>0.05$) on the copper content of marula kernels. The concentration of copper in the unprocessed sample exceeds the range of 0.3-0.49 mg/100 g, which is comparable to the values observed in sweet potatoes (45). Copper is essential for the synthesis of hemoglobin and the maintenance of blood vessels. As illustrated in Table 3, the iron content of the marula kernel was influenced by the various methods employed. The content ranges between 7.04 and 9.44 mg/100g. The observed increase in Fe content in this study is proportional to the increase in temperature for oven-dried samples and the time for sun-dried samples. These relationships are also proportional to the time of roasting. The roasted sample that was roasted for 10 minutes exhibited the highest Fe content. The general increase in Fe content during processing can be attributed to the concentration factor resulting from the removal of moisture. Tenyang et al. (2017) observed a similar trend when evaluating the impact of roasting and oven drying on the mineral composition of sesame seeds. The marula kernel is a relatively good source of iron. Zinc is one of the essential trace elements which increases the affinity of hemoglobin for oxygen, participates in the transport of vitamin A, plays a role in taste perception, and interacts with a number of hormones (Mpho et al., 2022). The body requires zinc for optimal growth and development during the stages of pregnancy, infancy, and childhood. As evidenced in Table 3, all processing methods resulted in a statistically significant ($P < 0.05$) alteration in the zinc content of marula kernels. The Zn content of the raw sample (7.60 mg/100 g) was higher than that reported by Muhammad et al. (2011) for *Sclerocarya birrea* seeds kernels in Nigeria (3.29 mg/100 g). During the treatment period, a similar trend was observed with regard to the iron content of the samples. The oven-dried sample at 80 °C exhibited the highest zinc value, followed by the traditional roasted sample that had been roasted for 10 minutes. The considerable increase noted in the roasted sample that had been roasted for 10 minutes could be attributed to

excessive desiccation, which resulted in an elevated dry matter content and mineral content due to the enriched concentration effect that occurred as a consequence of the drying process.

The removal of moisture during processing has been demonstrated to enhance the digestibility of kernels, elevate the concentration of nutrients, and render the Zn content more bioavailable. These seeds can be employed as an ingredient in food formulations for industrial use.

### 3.3 Lipid quality of dried and roasted marula kernel

#### 3.3.1 Free fatty acid

The hydrolysis of triglycerides via enzymatic (lipases) and chemical pathways results in the production of free fatty acids (FFAs). The measurement of FFA is a crucial aspect of the analytical process. The formation of an FFA chain as a result of hydrolysis may result in a sensorial characterization (Ogutche and Yimaz, 2017). The utilization of oil for industrial or human nutritional purposes is significantly influenced by its FFA value. Table 4 illustrates the FFA (expressed as a percentage of oleic acid) of raw, oven-dried, sun-dried, and roasted marula kernels. The FFA of the marula kernel oil samples ranged from 0.61% to 2.22% oleic acid.

**Table 4:** Changes in acid, iodine, peroxide, p-Anisidine, and TBARS values of marula kernel oil during different processing methods

| Samples | Acid value (% oleic acid) | Iodine value (g $I_2$/100g of oil) | Peroxide values (meq $O_2$/kg of oil) | p-Anisidine value | TBARS value (mg MDA/kg of oil) |
|---|---|---|---|---|---|
| Raw | 0.61±0.04$^{e}$ | 96.61±2.04$^{a}$ | 3.11±0.16$^{e}$ | 3.27±0.11$^{f}$ | 0.81±0.01$^{f}$ |
| Oven-dried at 40 °C | 1.18±0.10$^{d}$ | 92.68±1.30$^{ab}$ | 3.44±0.06$^{de}$ | 4.01±0.04$^{de}$ | 0.88±0.00$^{f}$ |
| Oven-dried at 60 °C | 1.51±0.04$^{c}$ | 88.50±0.84$^{bc}$ | 4.76±0.00$^{bc}$ | 4.55±0.07$^{cd}$ | 1.92±0.17$^{d}$ |
| Oven-dried at 80 °C | 2.22±0.03$^{a}$ | 85.16±1.18$^{c}$ | 5.95±0.69$^{ab}$ | 5.26±0.00$^{bc}$ | 2.99±0.03$^{b}$ |
| Solar-dried for 1 day | 1.04±0.01$^{d}$ | 90.66±0.015$^{b}$ | 4.65±0.16$^{bcd}$ | 4.66±0.16$^{cd}$ | 1.37±0.24$^{e}$ |
| Solar-dried for 3 days | 1.70±0.08$^{c}$ | 84.82±1.94$^{c}$ | 6.99±0.59$^{a}$ | 6.74±0.71$^{a}$ | 3.54±0.02$^{a}$ |
| Roasted for 5 min | 1.65±0.06$^{c}$ | 83.91±2.24$^{c}$ | 4.08±0.11$^{cde}$ | 5.29±0.12$^{bc}$ | 1.79±0.12$^{e}$ |
| Roasted for 10 min | 1.98±0.07$^{b}$ | 78.66±0.87$^{d}$ | 5.15±0.50$^{bc}$ | 5.89±0.04$^{ab}$ | 2.65±0.06$^{c}$ |

Values are means ± standard error (n=3). Mean values in the same column with different superscript letters are significant differences (P<0.05). TBARS: thiobarbituric reactive substances.

The FFA content in the raw marula kernel oil (0.61% oleic acid) was found to be lower than the 20.7% oleic acid value reported by Ejilah et al. (2012) in Nigeria from marula oil and the 3.6% oleic acid value reported by Zharare and Dhlamini (2012) in marula oil from Zimbabwe. The observed variation may be attributed to the species and environmental conditions. A gradual increase in FFA content was noted during processing, with oven-dried samples exhibiting a higher free fatty acid value. No significant difference (P > 0.05) was observed between the oven-dried sample processed at 40°C for 40 hours and the sun-dried sample dried for one day. The observed increase in FFA during processing indicated that triglyceride hydrolysis occurred during the treatments. During the processes of oven drying and roasting, the FFA value of the sample is found to be proportional to both the dry temperature and the roasting time. The observed increase in FFA during these processes can be attributed to the elevated temperatures, which facilitate the thermal hydrolysis of triglycerides. Abou-Ghariba et al. (2000) demonstrated that lipid hydrolysis in food is a significant chemical reaction that occurs during roasting at elevated temperatures. The free fatty acids occurring in hydrolysis are rapidly oxidized. In addition to endogenous enzyme activities (lipases and phospholipases), microbial activity also contributes to the increase in FFA during sun drying. Piggot and Tucker (1990) demonstrated that the majority of lipid hydrolysis occurring during storage is a consequence of bacterial catabolic processes. The formation of FFA itself during processing does not result in nutritional losses. However, lipid hydrolysis has been demonstrated to increase lipid oxidation. When oil has a low amount of FFA, this indicates that their storage can be prolonged. All the values obtained in this study are within the range specified by Codex Alimentarius (1999) (≤2.5% oleic acid). Consequently, it can be concluded that the oil is suitable for human consumption and can be used in cosmetic formulations due to its prolonged shelf life.

#### 3.3.2 Iodine value (IV)

Marula kernel oil is characterized by a high concentration of unsaturated fatty acids. During the processing stage, the unsaturated fatty acids were susceptible to oxidation. The double bonds are susceptible to attack by

free radicals, which results in the production of oxidized products (Tenyang et al., 2017). IV is used to calculate the total number of unsaturations in the oils. This is an important parameter to illustrate the quality of edible oil. The iodine measurement is obtained by determining the quantity of grams of iodine that bind to 100 grams of fat. A higher iodine value number indicates a greater number of double bonds in the sample, necessitating greater care to slow down oxidation. Table 4 illustrates the distinctions between the unprocessed and the processed samples. The present study revealed that all processing methods resulted in a reduction in the iodine value of marula kernel oil. The iodine value of the raw sample in this study was 96.61 g/100 g, a value that is lower than that reported by Ejilah et al. (2012) for marula oil in Nigeria (100.34 g/100 g) and also lower than that reported by Tenyang et al. (2017) for sesame seed oil (107.7 $gI_2$/100 g of oil). Orhevba et al. (2013) observed a lower iodine concentration (75-77 g/100 g) in neem seed kernel oil. Such variation may be linked to species, variety, and/or environmental conditions. All samples exhibited a decrease in IV when subjected to distinct processing techniques. The lowest value (78.66 g/100g) was observed in the traditional roasted sample subjected to 10 minutes of oven drying at 80 °C. As the temperature increased during oven drying, the iodine value decreased, and the lowest value was recorded in the sample roasted at 80 °C for 30 minutes. No statistically significant difference was observed between the oven-dried sample at 80 °C, the sun-dried sample for three days, and the traditional roasted sample for five minutes. The observed decline in IV during processing is consistent with the findings of Tenyang et al. (2017). The decrease in IV may be attributed to the alterations in fatty acid composition that occur during the drying and roasting processes. A reduction in the iodine value (IV) is indicative of lipid oxidation. The values obtained in this study fall within the range of 80-106 gI2/100g of oil specified by the FAO/WHO (2009) for edible oil. The raw, oven-dry at 40 °C, and solar-dry samples for one day exhibited a higher iodine value, indicating that their oils may be suitable for use in the manufacture of vegetable oil-based foods and cosmetic products.

### 3.3.3 Peroxide value

During the early stages of lipid oxidation, PV is an important indicator for evaluating peroxides and hydroperoxides. Therefore, it's used to evaluate the level of primary oxidation products in the oil, which are formed when unsaturated fatty acids in oils react with oxygen (Zhang et al., 2010). The peroxide value serves as an indicator of the extent of deterioration of the oil in question. As illustrated in Table 4, the peroxide value of all treated marula kernel oils exhibited variability based on the processing methods employed, with values ranging between 3.11 and 6.99 meq O2/kg. The lowest value was observed in a raw sample, while the highest was recorded in a sun-dried sample that had been exposed to sunlight for three days. This PV value for the raw sample was lower than 4.58 meq O2/kg, which is the value reported by Ejilah et al. (2012) for marula seed oil in Nigeria, but higher than the 2.25 meq/kg value observed in cottonseed oils (Papoola and Yangomodou, 2006). The difference may be linked to species, environmental conditions, and genetics. An increase in drying temperature, drying time, and methods caused an increase in PV. No significant difference ($P>0.05$) was observed in PV between oven-dried samples at 60 °C, oven-dried samples at 80 °C, and sun-dried samples for one day. For pistachio oil that underwent drying at high temperature, Sana-Moreno et al. (2015) have reported a high peroxide value. The increase of PV during treatment may be due to the exposition of marula kernel in high temperature and free air, which potentially provoke the lipid oxidation with the formation of hydroperoxides, molecules that result in free radicals attacking the unsaturated fatty acids (Nkpa et al., 1990). The Codex Alimentarius (2005) specifies a maximum PV of 15 meq$O_2$/kg for cold-pressed oils. The oils extracted from the treated samples exhibited PV values below 15 meqO2/kg, with the exception of the samples that had been sun-dried for three days and oven-dried at 80 °C. The remaining samples demonstrated favorable qualities, with PV values around 5 meq O2/kg. The oil with low PV has low rancidity products and also can have a strong presence of anti-oxidants, which is very useful for human consumption and for industry formulation.

### 3.3.4 p-Anisidine value (p-AV)

The p-AV value is employed for the assessment of secondary oxidation products (aldehydes and ketones) that arise from the degradation of fatty acid hydroperoxides, which are generated during the initial oxidation phase. The presence of these secondary oxidation products alters the quality of the oil (Majchrzak et al., 2005). As illustrated in Table 4, the p-AV of the treated sample exhibits a pattern comparable to that observed in the peroxide value. The p-AV of the samples exhibited a range of 3.27 to 6.74. The raw sample exhibited the lowest p-AV, while the sun-dried sample that had been subjected to drying for a period of three days demonstrated the highest p-AV. The p-AV of the raw sample was found to be lower than that of sunflower oil (4.52) and peanut (4.22), as reported by Gan et al. (2005). The p-AV of oven-dried samples exhibited a proportional relationship

with the drying temperature and the day of drying. The Increase in p-AV noted in this study agrees with those noted by Tenyang et al. (2017) in sesame seeds during different processing. The results are also in accordance with the findings of Womeni et al. (2010), who reached the same conclusion during the drying processes of palm kernel. The increase in p-AV during processing is linked to lipid oxidation. Marula kernel oils contain an unsaturated fatty acid. During the different drying methods, these unsaturated fatty acids undergo autooxidation, resulting in the formation of unstable peroxides that eventually break down, mainly into volatile products. These products include aldehydes, ketones, alcohols, acids, hydrocarbons, furanones, and lactones (Grosch et al., 1982). The volatile compounds formed have a variety of unpleasant odors and are responsible for flavor problems in the food industry. One nutritional effect of oxidation is to reduce the essential fatty acid content of edible fats.

one nutritional. The MDA produced during oxidation are very dangerous and can be responsible for cancer. The P-AV found in the present study fell within the range of 6.17-8.59 reported by Gan et al. (2005) for edible oils.

### 3.3.5 TBA value

The oxidation of unsaturated fatty acids is initiated by the abstraction of a hydrogen atom from a carbon atom adjacent to the unsaturated bond. The reaction continues with the propagation step, which is characterized by the decomposition of unstable peroxide and ultimately results in the production of a stable oxidation product in the termination step. Malonaldehyde (MDA), a secondary product of lipid oxidation, is the most toxic. MDA is the most commonly used indicator of lipid oxidation. It is produced during the breakdown of unsaturated fatty acids during processing (Reitznerova et al., 2017). The Thiobarbituric reactive substances (TBARS) assay is one of the most popular methods used to determine lipid oxidation. Marula kernel oil is a source of polyunsaturated fatty acids. This conclusion is corroborated by the data presented in Table 4 regarding iodine value. The numerous double bonds present in marula kernel oil render it susceptible to oxidation. Table 4 presents the TBARS value of the raw, oven-dried, sun-dried, and roasted marula kernel. The TBARS value of all treated samples exhibited variation. Oven-dried samples, except the one at 40 °C, demonstrated a significant increase ($P < 0.05$) in MDA content in marula kernel oil. This trend was similarly observed in marula kernel oil after drying in the sun and after roasting. The lowest TBARS value (0.81 mg MDA/kg of oil) was found in the raw and oven-dried samples at 40 °C, while the highest value (3.54 mg MDA/kg of oil) was found in the sun-dried sample for 3 days. The marula kernel oil was observed to be more susceptible to lipid oxidation when exposed to sunlight. The increase in MDA during processing indicates that lipid oxidation occurred in the samples due to the presence of a higher concentration of unsaturated fatty acids in the marula kernel oil. These results are in line with those reported by Tenyang et al. (2017) when studying the effect of roasting on lipid oxidation of sesame seeds. The lower MDA in the oven-dried sample at 40 °C, indicated a low secondary oxidation product. One of the most significant quality parameters influenced by lipid oxidation is the sensory quality of food products. The chronic ingestion of lipid oxidation products, such as MDA, has been linked to an elevated risk of developing numerous chronic non-transmittable diseases (Benita et al., 2018). MDA has been demonstrated to induce alterations in blood LDL lipoproteins, which in turn give rise to the formation of atherosclerotic plaques and, subsequently, atherosclerosis and coronary artery disease (Benita et al., 2018). Additionally, MDA has been identified as a mutagen and carcinogen, with high ingestion levels posing a significant public health risk. With the exception of the oven-dried sample at 80 °C, the sun-dried sample that had been dried for three days, and the traditional roasted sample that had been roasted for ten minutes, all the other samples fell below the limit for oxidation acceptability of 2.5 mg MDA/kg of oil, as previously established (Zhang et al., 2019). Munekata et al. (2020) observed that the presence of rancid flavor could be discerned at a TBARS value exceeding 0.6 mg MDA/kg of oil. Consequently, the oil in question is unsuitable for use in the cosmetic industry.

## 4. CONCLUSION

This study evaluated the effect of different drying methods (oven drying, sun drying, and traditional roasting) on the nutritional value and lipid oxidation of marula kernels grown in the Far North of Cameroon. Raw marula kernels contain significant amounts of proteins, lipids, and ash. They also have a high content of Ca, P, K, Fe, and Zn. Different drying methods had a significant ($P<0.05$) effect on the nutritional composition and lipid oxidation of marula seeds. Oven drying, sun drying, and traditional roasting increased the ash, protein, and lipid content of marula seeds while decreasing the moisture content. K, P, Ca, Zn, and Fe increased with drying, with the highest values observed after traditional roasting for 10 minutes. Marula kernel oil quality indices were

significantly affected during processing (P<0.05). FFA, PV, p-AV, and TBARS increased during processing, while IV decreased. Traditional sun drying for 3 days, oven drying at 80 °C, and traditional roasting for 10 minutes were found to have the greatest effect on the lipid qualities of marula kernel oils. The best method of drying marula kernels in terms of lipid qualities was oven-drying at 40 °C. Marula kernel can be used in human nutrition and the food industry due to its high nutritional value. The good qualities of oils for raw, oven-dried at 40 °C for 10 min and that solar-dried sample for 1 day make them very important for cosmetic formulation. The government should encourage the domestication of the marula plant and promote its local use. The cosmetic industries should implement these oils in their product formulations. Each drying technique has positive and negative aspects and particular characteristics that may affect the quality of the final product. Further research should be done on the optimisation methods for drying marula kernel that improved the quality of seeds.

**AUTHORSHIP CONTRIBUTION STATEMENT.** TENYANG, N.: Conceptualization, Formal analysis, Data curation, writing original draft, Data curation, Investigation, Writing-review & editing, Supervision. TAWAI, A.J.: Investigation, Formal analysis, Writing original draft, Methodology. HAMAN, B.Z.: Investigation; Methodology. TABANTY, Z.G.: Investigation; Methodology. MAMAT, A.: Methodology, DOUKA, G.: Investigation; Methodology.

**ETHICAL STATEMENT.** Not applicable

**DECLARATION OF COMPETING INTEREST.** The authors declare that no conflict of interest could have influenced the work. The research presented here is unique and hasn't been submitted to or published anywhere else.

**FUNDING STATEMENT.** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**DATA AVAILABILITY.** Data will be made available on request

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