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Effects of drying methods on compositional characterization and functional characteristics of *Blighia sapida* aril oil☆

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Abstract – The composition of *Blighia sapida* fruits is reported to differ based on its origin, variety, and preservation technique. In this study, the effect of drying method on the composition as well as the antioxidant activity of oven-dried and sun-dried *B. sapida* aril flour and oil were examined using standard procedures. Sun-dried *B. sapida* aril flour had significantly higher protein and fat content compared to the oven-dried flour. In addition, sun-dried *B. sapida* aril flour contained a more diverse phytochemical profile compared to the oven-dried flour. However, oven-dried *B. sapida* aril oil (ODAO) showed a higher percentage of unsaturated fatty acids compared to oil from the sun-dried *B. sapida* flour (SDAO). On the other hand, SDAO showed significantly higher DPPH scavenging and nitric oxide inhibitory activities compared to ODAO. Based on these findings, sun-drying is recommended for both nutritional purposes and other health-promoting usage such as antioxidant, over oven-drying.

Keywords: *Blighia sapida* aril flour / *Blighia sapida* aril oil / food composition / fatty acid profile / antioxidants

Résumé – Effets des méthodes de séchage sur la caractérisation de la composition et les caractéristiques fonctionnelles de l'huile de *Blighia sapida aril*. La composition des fruits de *Blighia sapida* diffère selon leur origine, leur variété et leur technique de conservation. Dans cette étude, l'effet de la méthode de séchage sur la composition ainsi que l'activité antioxydante de la farine et de l'huile de *B. sapida aril* séchées au four et au soleil sont examinés selon des procédures standard. La farine de *B. sapida aril* séchée au soleil avait une teneur en protéines et en graisses nettement plus élevée que la farine séchée au four. Toutefois, la farine de *B. sapida aril* séchée au four présente un profil phytochimique plus diversifié que celle séchée au soleil. L'huile de *B. sapida aril* séchée au four (ODAO) présentait un pourcentage plus élevé d'acides gras insaturés que celle séchée au soleil (SDAO). En outre, l'ODAO a montré des activités de piégeage du DPPH et d'inhibition de l'oxyde nitrique significativement plus élevées que la SDAO. Sur la base de ces résultats, le séchage au soleil pourrait être plus adapté à des fins nutritionnelles, alors que pour d'autres usages favorables à la santé, tels que les antioxydants, le séchage au four semblerait plus approprié.

Mots clés : Farine de *Blighia sapida aril* / huile de *Blighia sapida aril* / composition des aliments / profil des acides gras / antioxydants

1 Introduction

The challenge of food security, coupled with increasing global population, has necessitated the search for additional sources of nutrients. Nigeria, and indeed, all of Africa, has a rich diversity of plant food sources which have been grossly underutilized. From time immemorial, fruits and vegetables have played significant roles in meeting the nutritional needs of animals and humans, thus improving global nutrition and wellness (Gul *et al.*, 2016). Plant fruits constitute a rich source of the macro and micronutrients required for animal growth and development (Saxena *et al.*, 2013). Thus, the exploration and evaluation of the nutritional potential of indigenous wild

☆ Contribution to the Topical Issue "Minor oils from atypical plant sources / Huiles mineures de sources végétales atypiques".

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fruits and vegetables will not only reduce hunger but also improve global nutrition and wellness.

Blighia sapida is an herbaceous perennial plant native to tropical West and Central Africa. It is a member of the Sapidaceae family. In Nigeria and Jamaica, where *B. sapida* fruit forms a major delicacy, it is commonly called ackee. Ackee apple is consumed not only for nutrition but also for disease prevention (Adarkwa-Yiadom, 2018; Lawal *et al.*, 2018). The potential of ackee apple to promote health and well-being has led to a recent increase in research on this grossly underused plant, especially in Nigeria and neighboring West African states where ackee is a staple food. In Jamaica, however, the ackee industry contributed a significant US $ 400 million in revenue in 2005 (Ekué *et al.*, 2011). Thus, ackee has great economic potential in countries like Nigeria, especially with the recent push to open the non-oil sector. Ackee fruit is consumed both fresh and cooked. In addition, products such as soap made from ackee provide substantial revenue to peasant farmers, especially women (Ekué *et al.*, 2010; Adeduntan *et al.*, 2016).

Immature ackee fruit can be somewhat toxic. Symptoms such as vomiting, drowsiness and even hyperglycemia have been reported due to acute toxic effects associated with the consumption of unripe ackee aril fruit (Manchester, 1974). In addition, there has been reported cases of coma and death occurring within 12 h in severe cases of immature ackee aril poisoning (Brown *et al.*, 1991). This is due to the presence of hypoglycin A, an unusual amino acid (Bowen-Forbes and Minott, 2011). However, as the ackee fruit matures, its hypoglycin A is converted to a less toxic hypoglycin B. In addition, proper harvesting and processing techniques, such as cooking of the mature fruit, have also been shown to reduce the hypoglycin level in the fruit by leaching hypoglycin A (Golden *et al.*, 1984; Blake *et al.*, 2006).

Antioxidants are substances that impede the oxidation of biomolecules either by extinguishing free radicals or chelating the metals (Arina and Harisun, 2019). Antioxidants protect against the deleterious effects of free radicals. They also neutralize the adverse effects of oxidative stress (Asadi *et al.*, 2017). Polyphenols found in both edible and non-edible plants have been found to have antioxidant activity (Hoba *et al.*, 2018). This is mainly due to their ability to scavenge and neutralize the various forms of free radicals. *B. sapida* aril has been demonstrated to have as much as 15% (w/w) oil content. Thus, *B. sapida* fruit could be properly classified as an oil-bearing fruit with a rich content of both saturated and unsaturated fatty acids (Hoba *et al.*, 2018).

Drying as a preservation technique is most often employed in the dehydration of food, thus reducing its susceptibility to microbial spoilage. This specific method of preservation has been shown to affect the quality of food, including its physicochemical and sensorial properties as well as microbiological attributes. The use of drying methods, such as sun drying and oven drying, in the dehydration of *B. sapida* arils has been reported by some authors (Akintayo *et al.*, 2002; Oyeleke *et al.*, 2013), and the effect of different drying methods on other agricultural products has been widely reported by several others. However, there exists a dearth of information on the effects of different drying techniques on the nutritional quality of dried *B. sapida* arils. The present study was therefore designed to provide information on the comparative effects of sun- and oven-drying methods in the preservation of *B. sapida* aril on the composition of its flour as well as the nutritional and antioxidant properties of its oil extract.

2 Materials and methods

2.1 Chemical and reagents

All chemicals and reagents were of analytical grade and were products of Sigma-Adrich (UK) unless otherwise stated.

2.2 Plant material

Fresh *B. sapida* fruits were harvested in the month of August from an ackee apple plant at Ikare Akoko, Ondo State, Nigeria. The arils were immediately removed from the pods, seeds and raphe of the fruits; washed with copious water and transported in dark cellophane bags to the laboratory for further analysis. The leaves and fruits of the plant sample were taken to the Department of Plant Science, University of Ilorin (Nigeria) for authentication.

The ackee apple arils were divided into two equal halves. A portion was dried in the sun for five consecutive days (120 h) at 33 °C (Ayanwale *et al.*, 2007) and labelled sun-dried apple aril (SDA). The second portion was dried in an oven (Gallenkamp OV-300, England) at 50 °C for 48 h.

2.3 Oil extraction

The sun-dried and oven-dried *B. sapida* arils were separately milled into fine powder using a kitchen blender and the powdered samples kept separately in an airtight dark container and kept at 4 °C until required for further analysis. A known sample (50 g) of each powder was extracted with n-hexane (1:5; flour:solvent) at 65–68 °C for 6 h using a Soxhlet apparatus (Karthikeyan *et al.*, 2017). The extracted oil was dried using a rotary evaporator and then stored in a dark air-tight container. The percentage oil yield was calculated using the equation below:

$$Percentageyield = \frac{W_1}{W_2} \times 100,$$

Where W_1 is the weight of the oil and W_2 the weight of the dried *B. sapida* flour sample.

2.4 Proximate composition

The proximate composition of the fresh and defatted oven-dried and sun-dried *B. sapida* aril flours was determined using AOAC methods (2005).

2.5 GC-MS analysis

Samples of both fresh and defatted *B. sapida* aril flour were each separately pulverized and mixed with GC-grade methanol (1:5 w/v). The mixture was placed in an orbital shaker and left at 25 ± 2 °C for 48 h. Thereafter, the mixture was filtered through a muslin cloth to obtain the crude extract which was concentrated using a rotary evaporator and stored at −4 °C

Table 1. Proximate composition analysis of both fresh and defatted oven-dried and sun-dried *B. sapida* aril flours.

Composition (%)	Oven-dried aril flour		Sun-dried aril flour	
	Fresh sample	Defatted sample	Fresh sample	Defatted sample
Crude protein	15.03 ± 1.13^{a}	19.50 ± 2.21^{b}	21.88 ± 1.58^{b}	26.40 ± 3.80^{c}
Crude fat	31.30 ± 3.53^{a}	–	38.00 ± 5.22^{b}	–
Crude fibre	5.53 ± 0.55^{a}	8.60 ± 0.55^{b}	5.22 ± 0.95^{a}	8.33 ± 1.11^{b}
Ash	8.12 ± 0.88^{b}	8.33 ± 1.22^{b}	6.03 ± 1.10^{a}	6.10 ± 0.53^{a}
Total carbohydrate	11.12 ± 2.33^{a}	11.73 ± 2.27^{a}	12.12 ± 1.35^{a}	12.33 ± 1.15^{a}

Results are means ± SD of three determinations. Values in the same row carrying different alphabets are significant ($p > 0.05$).

until required for further analysis. The methanol extract of both defatted flour for both sun-dried and over-dried *B. sapida* aril were each separately subjected to GC-MS analysis in order to identify its constituent bioactive metabolites. The detection was at 70 eV ionization energy and 60 kPa with helium as the carrier gas. The initial temperature of the oven was set at 100 °C for 2 min and ramp rate of 4 °C per min to 225 °C and then 1 °C per min to 245 °C followed by 40 to 280 °C with a 30 min hold. An injection volume of 2 μL was injected at 280 °C with a split ratio of 1:50. Detected spectra were identified from the NIST database using the ChemStation software. Following the extraction process prior to GC-MS analysis, the extract was derivatized with *N*,*O*-bis(trimethylsilyl) trifluoroacetamide (BSTFA) and trimethylchlorosilane (TMCS) reagents. The resulting trimethylsilyl derivatives were separated and quantified using GC-MS (Stalikas, 2007).

2.6 Fatty acid analysis

The fatty acid profile of the *B. sapida* aril oil was determined using gas chromatography as described by Oluba *et al.* (2008).

2.6.1 Physicochemical properties

The refractive index and specific gravity of the oil samples were determined using a refractometer and a universal hydrometer respectively. The iodine value was evaluated according to the procedure described by Strong and Kosh (1974). Acid and peroxide values were estimated following the methods of Li *et al.* (2007) and Yildiz *et al.* (2003), respectively while the saponification number was evaluated based on the method of Dileesh *et al.* (2013). The free fatty acid content of the oil samples was determined using the titrimetric method of Kardash and Tur (2005) using phenolphthalein as indicator.

2.7 Total phenolic content determination

Total phenol content of the oil samples was determined as reported by Waterhouse (2002) and its content was calculated and recorded as gallic acid equivalent (GAE).

2.8 Antioxidant analysis

2.8.1 DPPH scavenging activity

The DPPH scavenging activity of the oil sample was carried out following the procedures of Bersuder *et al.* (1998) as described by Oluba *et al.* (2020). The DPPH scavenging capacity was estimated according to the equation:

$$\%\,Inhibition = \frac{A_{control} - A_{sample}}{A_{control}} \times 100,$$

- $A_{control}$ = Absorbance of the ethanolic DPPH solution;
- A_{sample} = Absorbance of oil sample or vitamin C in ethanolic DPPH solution.

The sample concentration required to scavenge 50% DPPH radical was evaluated from the vitamin C standard curve.

2.8.2 Nitric oxide scavenging activity

The oil samples were evaluated for their potential to scavenge nitric oxide according to the procedure detailed by Makhija *et al.* (2011). The procedure is based on the generation of nitric oxide radical (NO^{*}) due to the decomposition of sodium nitroprusside in aqueous solution at pH 7.2. The NO^{*} then reacts with oxygen to form nitrite and nitrate whose concentration is determined using Griess's reagent (2008).

2.8.3 Lipid peroxidation

The scavenging activity of the oil samples against lipid peroxides (herein measured as thiobarbituric acid reactive species, TBARS) generated by ferric sulphate in egg yolk homogenate was assayed using the method described by Okoh *et al.* (2014). Briefly, 0.1 mL of varying concentration (0.05 to 0.5 mL) of the oil sample or vitamin C dissolved in DMSO as the case may be, was added to 0.5 mL of egg yolk homogenate (10%) and the resulting mixture made up to 1.0 mL. Lipid peroxidation was then induced by the addition of 0.5 mL ferric sulphate (0.07 M). The mixture was incubated for 30 min and 1.5 mL each of 10% acetic acid (pH 3.5) and 0.08% 2-thiobarbituric acid (in 1.1% sodium dodecyl sulphate and 20% trichloroacetic acid) was added. The reaction mixture was vortexed for 5 min, heated at 65 °C for one hour and then allowed to cool. To the cooled solution, 0.5 mL of n-butanol was added and the resulting mixture centrifuged at 3000 rpm for 10 min. The absorbance of the upper organic layer was read at 532 nm.

2.9 Statistical analysis

Results are reported as mean ± SD and statistically analyzed using One-Way Analysis of Variance (ANOVA)

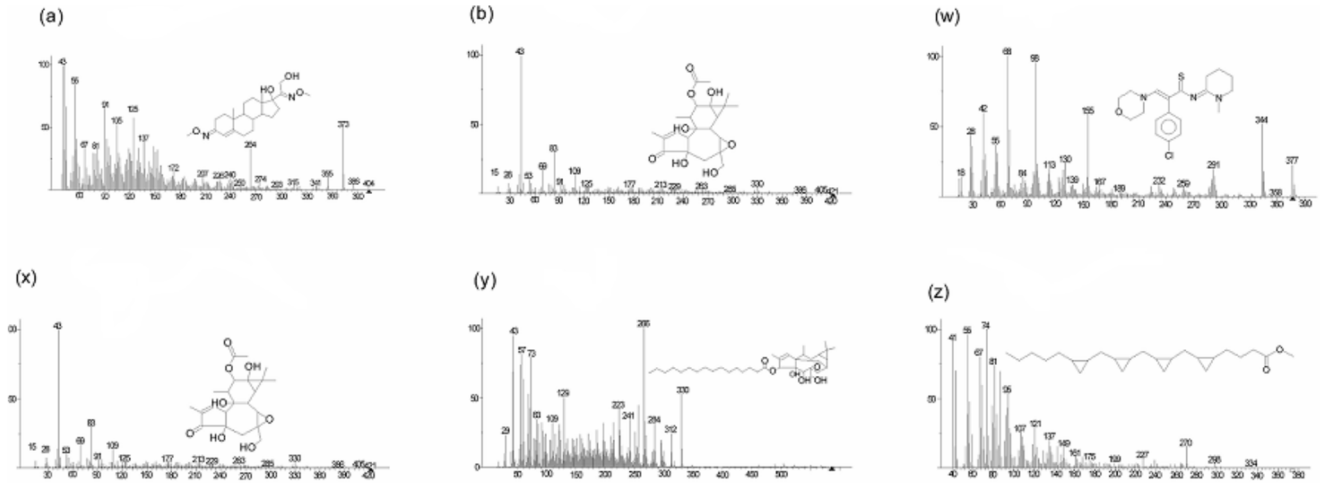

Fig. 1a. Pahytochemical contituents of fresh oven-dried (a and b) and sun-dried (w, x, y and z) *B. sapida* aril flour as determined using GC-MS analysis. Note: a: Pregn-4-ene-3,20-dione,17,21-dihydroxy-, bis(O-methyloxime); b: 4H-Cyclopropa[5',6']benz[1',2':7,8] azuleno[5,6-b]oxiren-4-one, 8-(acetyloxy)-1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a-dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)-; w: N-Methylpiperidin-2-yliden-3-morpholino-2-(4-chlorphenyl)-thioacrylamide; x: 4H-Cyclopropa[5',6']benz[1',2':7,8]azuleno[5,6-b]oxiren-4-one,8 (acetyloxy)1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a-dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)-; y: Hexadecanoic acid, 1a,2,5,5a,6,9,10, 10a-octahydro-5,5a-dihydroxy-4-(hydroxymethyl)-1,1,7,9-tetramethyl-11-oxo-1H-2,8a-methanocyclopenta[a]cyclopropa[e]cyclodecen-6-yl ester, [1aR-(1aα,2α,5β,5aβ,6β,8aα,9α,10aα)]-; z: Cyclopropanebutanoic acid, 2-[[2-[[2-[(2-pentylcyclopropyl)methyl]cyclopropyl]methyl] cyclopropyl]methyl]-, methyl ester.

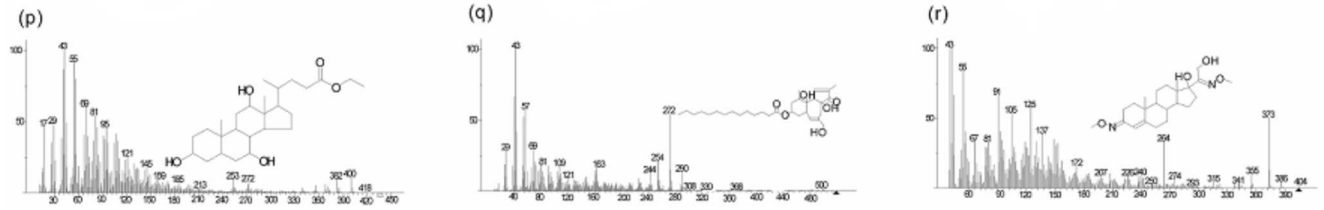

Fig. 1b. Pbhytochemical constitutents of defatted oven-dried (p) and sun-dried (q and r) *B. sapida* aril flour as determined using GC-MS analysis. Note: p: Ethyl iso-allocholate; q: Tetradecanoic acid, 3,3a,4,6a,7,8,9,10,10a,10b-decahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-2,10-dimethyl-3-oxobenz[e]azulen-8-yl ester, [3aR-(3aα,6aα,8α,10β,10aβ,10bβ)]-; r: Pregn-4-ene-3,20-dione, 17,21-dihydroxy-, bis(O-methyloxime).

followed by Turkey's multiple comparisons. Confidence value was set at 95%.

3 Results

3.1 Proximate composition

In terms of the effect of the drying method on crude protein level, the oven-dried flour had significantly ($p > 0.05$) lower protein content compared to the sun-dried flour. However, considering the impact of defatting on *B. sapida* aril, the defatted flour at both drying instances had significantly ($p > 0.05$) higher crude protein content compared to the flour. The oven-dried aril flour also contained significantly ($p > 0.05$) lower fat compared to the sun-dried aril flour. The amount of crude fibre obtained in the defatted flours (for both oven-dried and sun-dried) was significantly ($p > 0.05$) higher compared to the fresh oven-dried aril flour (Tab. 1).

3.2 Phytochemicals composition

GC-MS analysis of the fresh *B. sapida* aril revealed the presence of pregn-4-ene-3,20-dione,17,21-dihydroxy-, bis(O-methyloxime) and 4H-Cyclopropa[5',6']benz[1',2':7,8]azuleno[5,6-b]oxiren-4-one,8-(acetyloxy)-1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a-dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)- in the oven-dried flour while the sun-dried flour contained N-Methylpiperidin-2-yliden-3-morpholino-2-(4-chlorphenyl)-thioacrylamide, 4H-Cyclopropa[5',6']benz[1',2':7,8]azuleno[5,6-b] oxiren-4-one,8 (acetyloxy)1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a-dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)-, Hexadecanoic acid, 1a,2,5,5a,6,9, 10,10a-octahydro-5,5a-dihydroxy-4-(hydroxymethyl)-1,1,7,9-tetramethyl-11-oxo-1H-2,8a-methanocyclopenta[a]cyclopropa[e]cyclodecen-6-yl ester, [1aR-(1aα,2α,5β,5aβ,6β,8aα,9α,10aα)]- and cyclo-

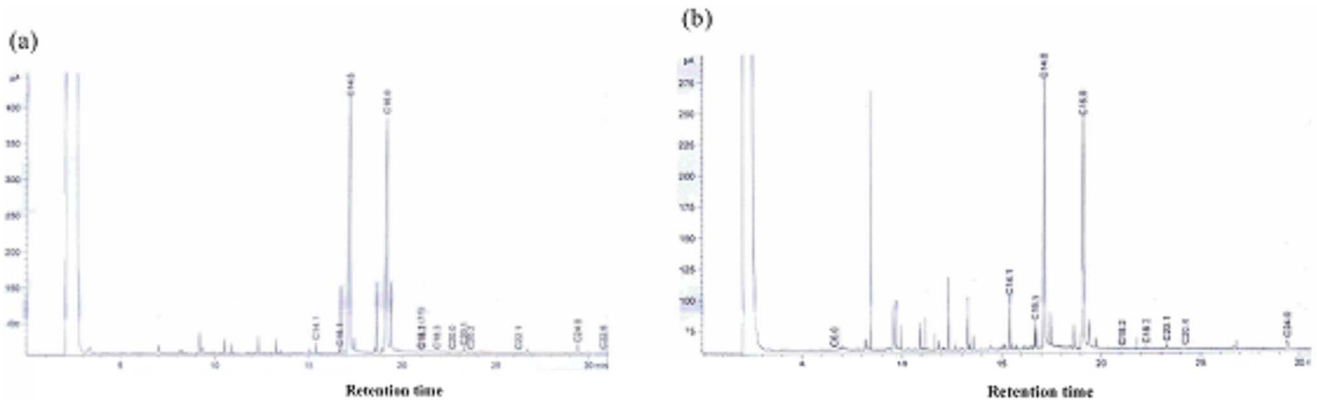

Fig. 2. Fatty acid composition of (a) oven-dried and (b) sun-dried *B. sapida* aril oil.

propanebutanoic acid, 2-[[2-[[2-[(2-pentylcyclopropyl)methyl] cyclopropyl]methyl]cyclopropyl]methyl]-, methyl ester. 4H-Cyclopropa[5',6']benz[1',2':7,8]azuleno[5,6-b]oxiren-4-one,8-(acetyloxy)-1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a-dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)- was observed as a common component in both fresh oven- and sun-dried *B. sapida* aril flour (Fig. 1a). The defatted *B. sapida* aril flour showed the presence of ethyl iso-allocholate in the oven-dried sample while the sun-dried sample revealed the presence of tetradecanoic acid, 3,3a,4,6a,7,8,9,10,10a,10b-decahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-2,10-dimethyl-3-oxo-benz[e]azulen-8-yl ester, [3aR-(3aα,6aα,8α,10β,10aβ,10bβ)]- and pregn-4-ene-3, 20-dione, 17,21-dihydroxy-, bis (O-methyloxime) (Fig. 1b). These diverse chemicals belong to different chemical groups ranging from steroids, phytosterols, polyphenolics, terpenes, fatty esters, alkaloids etc. For instance, Ethyliso-allocholate is a triterpene; Pregn-4-ene-3,20-dione, 17,21-dihydroxy-, bis(O-methyloxime) is a steroid etc. The phytochemical components of the respective samples are indicated in Table 2.

3.3 Oil yield and fatty acid composition

The calculated yields of oil were 31.3 and 38.0% for the oven-dried and sun-dried *B. sapida* aril flours, respectively. Analysis of the fatty acid composition of the oven-dried *B. sapida* aril oil showed 64.60% saturated fatty acid, 33.95% monounsaturated fatty acid and 1.45% polyunsaturated fatty acid. The major saturated fatty acid component is palmitic acid (22.51 mg/L), myristic acid (16.74 mg/L) and lignoceric acid (1.98 mg/L) (Fig. 2a). Fatty acid profile of the sun-dried *B. sapida* oil showed 89.65% saturated fatty acid, 9.13% monounsaturated fatty acid, and 1.23% polyunsaturated fatty acid. The major saturated fatty acids are palmitic acid (52.22 mg/L), myristic acid (37.71 mg/L), lignoceric acid (3.07 mg/L), and arachidic acid (1.80×10^{-1} mg/L). The monounsaturated fatty acids present are myristoleic acid (7.74 mg/L), gondoic acid (1.03 mg/L), palmitoleic acid (3.44×10^{-1} mg/L), erucic acid (2.41×10^{-1} mg/L) and oleic acid (1.28×10^{-1} mg/L) while the following polyunsaturated acids were present docosahexaenoic acid (7.67×10^{-1} mg/L), linolenic acid (1.79×10^{-1} mg/L), 20:2 (1.74×10^{-1} mg/L) and linoleic acid (1.55×10^{-1} mg/L) (Fig. 2b).

3.4 Physicochemical characteristics

The physicochemical characteristics of the oven-dried and sun-dried *B. sapida* aril oil were similar except for the free fatty acid and total phenolic contents that were significantly ($p > 0.05$) lower in the oven-dried oil sample compared to the sun-dried oil sample (Tab. 3). The two oil samples were yellow in colour with refractive index of 1.21 ± 0.02 and 1.23 ± 0.02 for oven-dried and sun-dried *B. sapida* oils respectively.

3.5 Antioxidant activity

Both the sun-dried and oven-dried aril oil displayed significant DPPH scavenging activity (Fig. 3a), lipid peroxide inhibitory activity (Fig. 3b) and nitric oxide scavenging activity (Fig. 3c). The oven-dried aril oil showed a lower significant ($p < 0.05$) DPPH scavenging and nitric oxide inhibitory activities compared to the sun-dried aril oil. The scavenging effects on both DPPH and nitric oxide radical were dose-dependent. The sun-dried aril oil and oven-dried aril oil displayed similar lipid peroxide scavenging activity especially at higher concentration (Fig. 3b). Overall, vitamin C demonstrated superior scavenging potential against DPPH, nitric oxide and lipid peroxide radicals compared to both oven-dried aril oil and sun-dried aril oil.

4 Discussion

The study on the composition of plants and plant products forms the basis for successful technological processing and applications of such plants (Saenz, 2000). The previous study on the proximate composition analyses of *B. sapida* arils from Toukountouna (Northwest Benin) showed that it contains 46% of crude fat, 47% of crude fibers and 3% of crude proteins (Dossou *et al.*, 2004). The analysis of raw *B. sapida* arils from Mexico revealed 57.6% of moisture, 8.8% of crude protein, 18.8% of crude fat, 3.5% of crude fiber, 9.6% of total carbohydrates and 1.9% of ash (Morton, 1987). The crude protein values as reported for both oven-dried and sun-dried *B. sapida* flour in this study were higher than that reported by

Table 2. GC-MS data analysis of the phytochemical components of both fresh and defatted oven-dried and sun-dried *B. sapida* aril.

Sample	Molecular formula	Molecular weight (g)	Exact mass (g)	Probability (%)	CAS number	NIST number	Name
Fresh oven-dried flour	$C_{23}H_{36}N_2O_4$	404	404.267508	30.9	55557-09-0	17078	Pregn-4-ene-3,20-dione, 17,21-dihydroxy-, bis(O-methyloxime)
	$C_{22}H_{30}O_8$	422	422.194067	19.6	77646-23-2	67592	4H-Cyclopropa[5',6']benz[1',2':7,8] azuleno[5,6-b]oxiren-4-one, 8-(acetyloxy)-1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a −dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)
	$C_{22}H_{30}O_8$	422	422.194067	19.6	77646-23-2	67592	4H-Cyclopropa[5',6']benz[1',2':7,8] azuleno[5,6-b]oxiren-4-one, 8-(acetyloxy)-1,1a,1b,1c,2a,3,3a,6a,6b,7,8,8a −dodecahydro-3a,6b,8a-trihydroxy-2a-(hydroxymethyl)-1,1,5,7-tetramethyl-, (1aα,1bβ,1cβ,2aβ,3aβ,6aα,6bα,7α,8β, 8aα)
Fresh sun-dried flour	$C_{36}H_{58}O_6$	586	586.42334	22.5	52557-26-3	67658	Hexadecanoic acid, 1a,2,5,5a,6,9,10,10a-octahydro-5,5a-dihydroxy-4-(hydroxymethyl)-1,1,7,9-tetramethyl-11 −oxo-1H-2,8a-methanocyclopenta[a] cyclopropa[e]cyclodecen-6-yl ester, [1aR-(1aα,2α,5β,5aβ,6β,8aα,9α,10aα)]
	$C_{25}H_{42}O_2$	374	374.318481	57.9	56051-53-7	28143	Cyclopropanebutanoic acid, 2-[[2-[[2-[(2-pentylcyclopropyl)methyl] cyclopropyl]methyl]cyclopropyl] methyl]-, methyl ester
	$C_{19}H_{24}ClN_3OS$	377	377.13286	26.2	155243-50-8	286965	N-Methylpiperidin-2-yliden-3-morpholino-2-(4-chlorphenyl)-thioacrylamide
Defatted oven-dried flour	$C_{26}H_{44}O_5$	436	436.318874	31.4		43053	Ethyl iso-allocholate
	$C_{31}H_{50}O_6$	518	518.36074	37.2	77058-95-8	67590	Tetradecanoic acid, 3,3a,4,6a,7,8,9,10,10a,10b-decahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-2,10 −dimethyl-3-oxobenz[e]azulen-8-yl ester, [3aR-(3aα,6aα,8α,10β,10aβ,10bβ)]
Defatted sun-dried flour	$C_{23}H_{36}N_2O_4$	404	404.267508	10.3	55557-09-0	17078	Pregn-4-ene-3,20-dione, 17,21-dihydroxy-, bis(O-methyloxime)

Dossou *et al.* (2004) and Morton (1987). In the same vein, results from the present study gave a crude fat level of 38.0% (for sun-dried flour) which was lower than the reported values by Dossou *et al.* (2004) and Morton (1987). This goes to show that the proximate composition of *B. sapida* flour could possibly vary from place to place. In addition, the present study demonstrated that the sun-dried *B. sapida* flour had considerably higher contents of protein and oil compared to oven- dried flour. Thus, in addition to the influence of geographical location in determining the percentage crude protein and fat in *B. sapida* flour, the choice of drying method also plays a significant role. Judging by results of this study, sun drying might be the preferred drying method of choice in obtaining higher protein and oil quantities from *B. sapida* flour. Defatting has been shown to improve the nutritional and functional attributes of oilseed flour (Akinyede and Amoo, 2009; Ndie *et al.*, 2010). A report by Ndie *et al.* (2010) showed that defatted African walnut flour had higher protein content compared with the non-defatted flour. Results from this study showed that the crude protein contents of *B. sapida* aril flour were significantly increased after defatting. The crude protein content obtained for the defatted oven-dried and sun-dried *B. sapida* aril flours in this study compared favorably with that of many known legume flours, including cowpea (24.1%),

Table 3. Physicochemical characteristics of oven-dried and sun-dried *B. sapida* aril oil.

Physicochemical parameter	ODAO	SDAO
Colour	Yellow	Yellow
Refractive index	1.21 ± 0.02^a	1.23 ± 0.02^a
Specific gravity (gL^{-1})	0.91 ± 0.02^a	0.90 ± 0.01^a
Peroxide value (mg reactive O_2g^{-1})	9.55 ± 0.35^a	9.83 ± 0.30^a
Acid value ($mgKOHg^{-1}$)	3.31 ± 0.15^a	3.57 ± 0.19^a
Saponification value ($mgKOHg^{-1}$)	191.50 ± 7.23^a	196.35 ± 5.32^a
Iodine value (mgI_2g^{-1})	90.33 ± 3.33^a	92.39 ± 2.80^a
Free fatty acid (%)	0.21 ± 0.01^a	0.35 ± 0.00^b
Total phenolic content ($mgGAEg^{-1}$)	2.57 ± 0.35^a	3.86 ± 0.30^b

Results are means ± SD of three determinations. Values in the same row carrying different alphabets are significant ($p > 0.05$). Note: SDAO: sun-dried aril oil; ODAO: oven-dried aril oil; vit C: vitamin C; GAE: gallic acid equivalent.

egusi melon (23.4%), pigeon pea (19.9–24.0%), and chicken pea (23.7%) (Ojieh *et al.*, 2007; Maninder *et al.*, 2007; Anderson-Foster *et al.*, 2012; Sreerama *et al.*, 2012). The crude protein content of defatted *B. sapida* aril flour as reported in the present study is sufficient to meet the minimum dietary protein recommendation of the Food and Agriculture Organization (FAO/WHO, 2002).

Phytochemicals also referred to as plant secondary metabolites play significant roles in the free radical scavenging activities of plants and animals. The antioxidant properties of plants secondary metabolites are attributed to the activity of the phytochemicals they contain (Saxena *et al.*, 2013; Lawal *et al.*, 2018). The GC-MS fingerprints of both fresh and defatted *B. sapida* aril flour revealed the presence diverse phytochemicals including triterpenes, sesquiterpenes, steroids, quinones, alkaloids, polyphenols, glycosides and phytosterols in accordance with previous studies by Antwi *et al.* (2009), Onuekwusi *et al.* (2014), Balogun and Fetuga (1988). Pregn-4-ene-3,20-dione, 17,21-dihydroxy-, bis(O-methyloxime) has been reported to exhibit anti-inflammatory activity as well as been used in hormone replacement therapy (Hameed *et al.*, 2018), Tetradecanoic acid, 3,3a,4,6a,7,8,9,10,10a,10b-decahydro-3a,10a-dihydroxy-5-(hydroxymethyl)-2,10 -dimethyl-3-oxo-benz[e]azulen-8-yl ester, [3aR-(3aα,6aα,8α,10β,10aβ,10bβ)] has also been documented to show anti-inflammatory activity (Mohammed *et al.*, 2016). Cyclopropanebutanoic acid, 2-[[2-[[2-[(2-pentylcyclopropyl) methyl]cyclopropyl]methyl]cyclopropyl]methyl]-, methyl ester identified in the methanolic leaf extract of *Cinnamomum iners* was demonstrated to show strong antioxidant activity against reactive oxygen species (Udayaprakash *et al.*, 2015). According to a report by Malathi and Ramaiah (2017), Ethyl iso-allocholate isolated from rice was demonstrated to exhibit antimicrobial acitivity against E. coli through the inhibition of dihydropteroate synthase.

Phenolic compounds, due to their electron releasing and hydrogen donating potentials, are responsible for the antioxidant activity of edible fruits and vegetables. The result obtained from the phytochemical screening of both fresh and defatted *B. sapida* aril flour showed the presence of phenolic compounds. Polyphenols, carotenoids and nitrogen containing

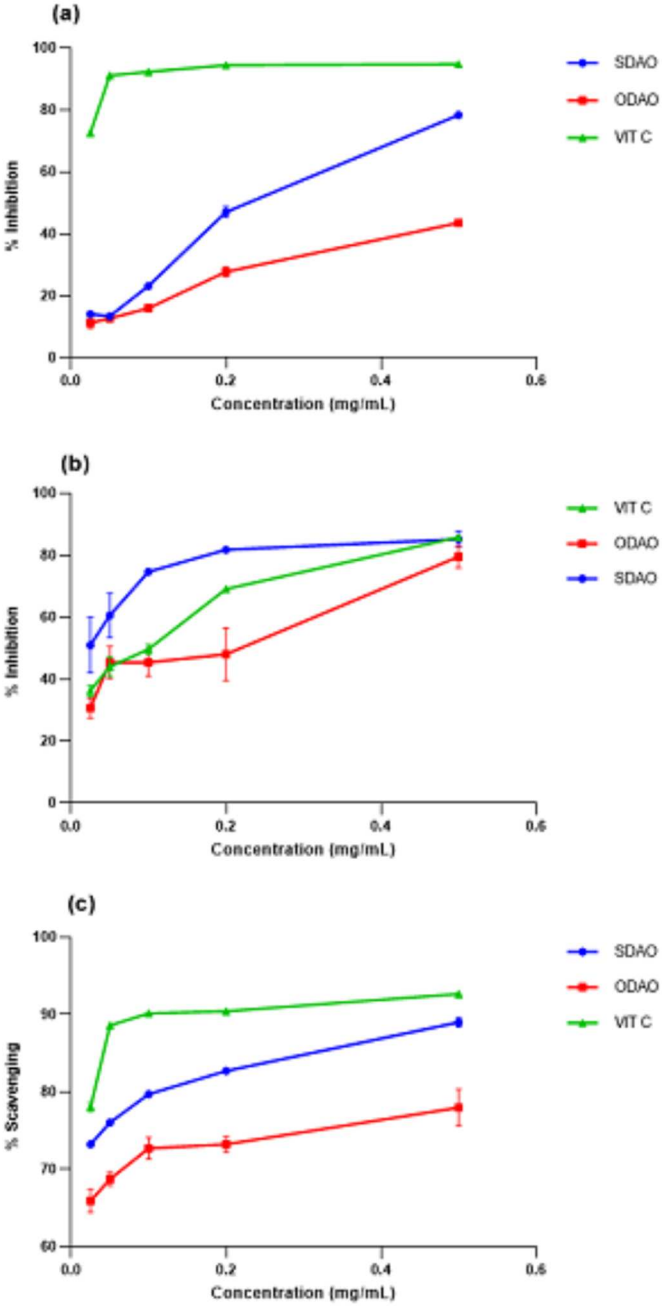

Fig. 3. DPPH scavenging activity (a) lipid peroxide inhibitory activity (b) and nitric oxide scavenging activity (c) of sun-dried and oven-dried *B. sapida* aril oil in comparison to vitamin C. Results are means ± SD of three determinations. Note: SDAO: sun-dried aril oil; ODAO: oven-dried aril oil; vit C: vitamin C.

compounds are classical examples of substances with antioxidant activities (Asiamah 2018; Musa *et al.*, 2019). The high level of unsaturation in phenolic compounds makes them the preferred oxidation substrates for free radicals thus protecting intracellular molecules against oxidation. The phenolics component of *B. sapida* aril could thus account for its ability to scavenge free radicals in DPPH, nitric oxide and lipid peroxides as demonstrated in this study. In addition, the oven-dried and sun-dried aril oils contained as much as

35.40 and 10.36% unsaturated fatty acids, respectively, which could serve as potential electron donors. Data from this study showed that the sun-dried *B. sapida* flour showed the presence of a more diverse range of phenolic compounds compared to the oven-dried flour. However, oil obtained from the oven-dried flour showed a higher degree of unsaturation in terms of its fatty acid content than oil from the sun-dried flour. These observations could naturally translate to the sun-dried *B. sapida* oil exhibiting higher antioxidant ability than oil from the oven-dried *B. sapida* flour as was observed in the present study. The fatty acid profiles obtained from both oven-dried and sun-dried *B. sapida* aril oil in the study identified palmitic acid as the major fatty acids. This is in agreement with the report of Odutuga *et al.* (1992) who had earlier shown that palmitic acid was the major fatty acid in *B. sapida* aril from Jamaica. However, other studies have shown that the major fatty acid in *B. sapida* aril is oleic acid (Tsado *et al.*, 2018; Grande-Tovar *et al.*, 2019). The differences in geographic location as well as processing methods could account for the different results.

In agreement with previous reports the oil obtained from both oven-dried and sun-dried *B. sapida* aril in this study is yellow in colour (Djenontin *et al.*, 2009). The refractive index of 1.21 obtained for oven-dried *B. sapida* oil in this study is low compared to the value (1.46) obtained for *B. sapida* aril from Niger state, Nigeria. Refractive index of oil has been established to be a good predictor of oil susceptibility to rancidity. Oils with low refractive indices are less prone to oxidative rancidity (Godswill *et al.*, 2018). Data on specific gravity obtained in the present study indicated that *B. sapida* aril oil is less dense compared to water. Oils generally have specific gravity of less than one. Reports from a study have demonstrated that *B. sapida* aril oil is less dense than oils from canola, cottonseed, and sesame (Dossou, 2014). The iodine values obtained for both sun-dried and oven-dried *B. sapida* aril in this study is similar to the reported value for palm oil but lower than that of groundnut oil, soybean oil and egusi melon (Oluba *et al.*, 2008). The low iodine value reported for *B. sapida* aril oil in this study shows that it's a non-drying oil. The iodine value of oils gives a measure of their degree of unsaturation as well as their susceptibility to oxidative rancidity (Oyeleke *et al.*, 2013; Adepoju *et al.*, 2013). The acid values of 3.31 and 3.57 $mgKOHg^{-1}$ obtained for oven-dried and sun-dried *B. sapida* aril oil, respectively in this study is low compared to the reported value for corn oil and peanut oil which are majorly utilized for pharmaceutical products. Thus, *B. sapida* aril oil could find possible application in the pharmaceutical industries. Its low acid value also showes that it is safe for consumption (Howele *et al.*, 2010). The saponification values of oven-dried and sun-dried *B. sapida* aril oil obtained in this study compare relatively to that of most plant oils used in soap making (Oluba *et al.*, 2008; Anderson-Foster *et al.*, 2012). This justified its suitability in soap making in countries like Nigeria and Benin (Ekué *et al.*, 2010). Overall, the physicochemical characteristics results obtained for both oven-dried and sun-dried *B. sapida* aril oil in this study is higher than the values reported by Aloko *et al.* (2017).

The higher total phenolic content of the oil sample obtained from sun-dried *B. sapida* flour could possibly account for the observed higher capacity of the oils to scavenge DPPH radical when compared to oil from the oven-dried *B. sapida* flour. Phenolics have established free radical scavenging activity hence capable of minimizing oxidative degradation of biomolecules (Kang *et al.*, 2005; Amoateng *et al.*, 2010). According to the recommendation of Scalbert and Williamson (2000) the consumption of 1000 mgGAE/day of antioxidants is desirable thus the daily intake of 100 g of *B. sapida* oil is sufficient to meet this nutritional requirement. The stem back extract of *B. sapida* was recently demonstrated to show DPPH scavenging as well as iron chelating activities (Ojo *et al.*, 2018). According to Oloyede *et al.* (2013), *B. sapida* aril polyphenolics was demonstrated to scavenge and detoxify free radicals thus impeding lipid and protein oxidation. In addition, the ethyl acetate extracts of *B. sapida* pod and seed were demonstrated to exhibit strong DPPH antioxidant activities (Parkinson, 2007).

5 Conclusion

Data obtained from this study showed that the chemical composition of *Blighia sapida* aril is greatly influenced both by geographical location and preservation method. Our data showed that sun-dried *B. sapida* flour contained higher crude protein and crude fat than oven-dried flour. In addition, the sun-dried *B. sapida* aril flour contained more diverse phytochemicals compared to the oven-dried aril flour. More so, oil from the sun-dried aril had significantly higher total phenolics content and thus displayed better antioxidant activity compared to the oven-dried aril oil. However, *in vitro* antioxidant assays do not always translate to antioxidant properties, therefore, to further ascertain this claim, *in vivo* studies are necessary. Therefore, the method of choice for drying will be greatly influenced by the intended application of either the flour or the oil. Based on results obtained from this study, sun-drying is recommended for both nutritional purposes and health-promoting usage such as antioxidant, over oven-drying.

Abbreviations

BSAF	Blighia sapida aril flour
ODAO	Oven dried aril oil
SDAO	Sun-dried aril oil
GC-MS	Gas chromatography-mass spectrometry
DPPH	2,2-diphenyl-1-picrylhydrazyl
NO	Nitric oxide

Conflicts of interest. The authors declare no conflicts of interest.

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