# Food applications of *Irvingia gabonensis* (Aubry-Lecomte ex. O'Rorke) Baill., the "bush~~wild~~ mango": a review

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## Abstract

*Irvingia gabonensis*, also known as 'bush~~wild~~ mango', is a multipurpose fruit tree, native to tropical Africa. It is a priority indigenous fruit tree in western and central Africa since its wood is used for making utensils and fruits are mostly used as food and medicine. The objective of this work is to provide an updated review of the available knowledge about physicochemical characteristics of *I. gabonensis* fruit in order to evaluate its potential use in the food industry. The fruit mesocarp contains various phytochemicals and ascorbic acid concentration higher than some vitamin C rich fruits, then it is consumed fresh or dried, used to produce juice and wine, or as a flavourant. *I. gabonensis* fruit kernel is rich in oil (63%-69% crude fat), mainly composed of myristic and lauric acids. Its triacylglycerol composition and, resultantly, melting curve and polymorphism indicate an aptitude for diverse applications, as it is solid at room temperature. Forty-one phenolic compounds were identified in the seeds and derived extracts and supplements~~oil~~, being ellagic acid and its derivates the most present. This review enhances our knowledge about nutritional content and health benefits of *I. gabonensis* whole fruit, especially its pulp and seed, evidencing the need for safer and more efficient production of value-added products.

Keywords: bush mango, ogbono soup, dika nut, polyphenols, carotenoids

## 1. Introduction

*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill., also known as 'African mango tree', 'bush mango', 'sweet bush mango', ~~'wild mango',~~ 'dika nut', 'rainy season bush mango', 'dika bread tree', 'odika', 'manguier sauvage', 'chocolatier', or 'ogbono', is a multipurpose fruit tree native to tropical Africa, and more specifically to West and Central Africa (National Research Council 2006; Singh 2007). This traditional tree is common in dense evergreen rain forests but is also found near riverbanks (Atangana et al. 2001); it has been reported to be used as a source of timber and to make utensils, and also as food and medicine (Okoronkwo et al. 2014; Fungo et al. 2016; Ofundem et al. 2017).

The fruits are available from May to September with the peak harvesting period being June/July (Onimawo et al. 2003). The fruit is a broad, ellipsoid drupe with a thin epicarp, an edible fleshy mesocarp (pulp) (when ripe) and a hard, stony, nut encasing a soft, oil rich, dicotyledonous kernel wrapped inside a brown seed-coat (Ogunsina, Koya and Adeosun 2008[a]; Ogunsina, Koya and Adeosun 2008[b]; Ogunsina et al. 2012; Ogunsina, Olatunde and Adeleye 2014). This kernel, which is also referred to as seed, is widely used as food (Omoniyi et al. 2017). Thus, *I. gabonensis* is included in the FAO/INFOODS biodiversity list and is recognized by the International Centre for Research in Agroforestry as a priority indigenous fruit tree for West and Central Africa (Franzel, Jaenicke and Janssen 1996; Leakey et al. 2005; National Research Council 2006; Ruth Charrondière et al. 2013; Stadlmayr et al. 2013; Vihotogbé, van der Berg and Sosef 2013; Bvenura and Sivakumar 2017; Shaheen, Ahmad and Haroon 2017). Over the last 25 years work in Cameroon and Nigeria has been also focussed on the domestication of *I. gabonensis* to diversify cropping systems, generate income for subsistence farmers and to create a new paradigm for tropical agriculture based on the sustainable intensification of smallholder farming (Leakey, 2014; 2018; 2019; Leakey et al 2012). Due to this, ethnobotanical and economical researches focussed on *I. gabonensis*, have emerged in recent years (Ladipo, Fondoun and Ganga 1996; Ayuk et al. 1999; Leakey et al. 2000; Atangana et al. 2001; Leakey and Page 2006; Singh 2007; Vihotogbé, van der Berg and Sosef 2013); however, up until now, a comprehensive review summarising its applications and the functional properties of *I. gabonensis* products in the food industry is lacking. The aim of this review is thus to deepen the existing knowledge about the physicochemical characteristics of *I. gabonensis* pulp and kernels in order to verify their potential use in the food industry, especially in functional products.

## 2. Literature search

Literature published prior to 2019 were examined using various databases, such as ScienceDirect, Scopus, Scielo, Google Scholars, Research Gate, PubMed and Web of Science. As *I. gabonensis* presents a specific nomenclature in each region of Africa, it was necessary to use several terms for a complete search. "*Irvingia*", "*Irvingia gabonensis*", "*I. gabonensis*", "African Mango", "Bush Mango", ~~"Wild Mango",~~ "Ogbono", "Dika Fruit", "Dika Nut", "Dikanut", "Dika Kernel", "Dika Seed" and "Ogbono Seed" were the keywords used in the databases. Articles were also identified by a manual search of bibliographies from all the retrieved articles.

## 3. Pulp

The fresh fruits, that are similar to small mangoes, have a green-yellow colour and, since their taste varies between sweet and bitter, they are divided into two groups, the "eating type" and the "cooking type". The "eating type" comprises of the species *Irvingia gabonensis* which is fibrous, has a mesocarp characterized by a sweet taste and a yellow to orange colour while the "cooking type" is the *Irvingia wombolu* species whose seeds are widely processed across West Africa but the mesocarp is bitter and non-edible (Harris 1996).

### 3.1. Chemical composition

Nutritional and chemical composition of *I. gabonensis* fruit (pulp) are shown on Table 1. The pulp of *I. gabonensis* has an elevated moisture content, from 78.8% to 90.5%, and a soluble solid content of around 10%, which indicates that this fruit is suitable for juice production. The pH varies between 4.7 to 6.2 and acidity may be the reason behind the bitter taste of the pulp (Onimawo et al. 2003). The ash content is low (0.8 – 1.8 %) but potassium (1114 mg/100 g dry weight) and calcium (118 mg/100 g dry weight) contents are high in contrast to low sodium content (12 mg/100 g dry weight) (Olayiwola et al. 2013). The high variability on reported fat content of this fruit could be due to the differences in sample extraction amongst different studies.

Polyphenol composition is described in the following section (2.2), as it is related to *I. gabonensis* pulp functional properties.

**3.2. Functional Properties**

*I. gabonensis* fruits are well cited as anti-sickling products then useful for the treatment of sickle cell disorder or sickle cell anemia, an autosomal recessive genetic blood disorder with over-dominance characterized by red blood cells with abnormal, rigid, sickle shaped that afflicting the population living in Africa, South America and Asia (Amujoyegbe et al. 2016). Etebu (2013) compared the phytochemicals in *I. gabonensis* and *I. wombolu* documenting the presence of five groups of phytochemicals (alkaloids, flavonoids, saponins, tannins and glucosides) in mesocarp from both varieties. This finding is supported by other studies which investigated these components or other (Table 2). The fruit of *I. gabonensis* can be considered vitamin C rich (51-76 mg/100g) when compared with other fruits like orange (about 50 mg/100g), and common mango (*Mangifera indica* L.) (about 40 mg/100g) (USDA 2018). Also, the carotenoid and the phenolic content of *I. gabonensis* fruits are very high (Table 2).

Emejulu et al. (2014) studied the effect of *I. gabonensis* fruit juice on serum lipid profile of sodium fluoride-intoxicated rats by comparing with positive and negative control groups. They concluded that the level of HDL-cholesterol was higher in the *I. gabonensis* group than in the positive control group (20 mg/kg body weight of quercertin + 100 mg/kg body weight of alfpha-tocopherol) and the fruit juice of *I. gabonensis* was reported to have a lowering effect on LDL-cholesterol as compared to the other groups tested. The author attributed this action to the presence of alkaloids, saponins, flavonoids and polyphenols commonly known to reduce serum lipids in animals (Ezekwe and Obioha 2001). An ameliorative effect was observed in NaF-induced lipidemia in rats when fed with *I.*

*gabonensis* fruit juice, which may be due to its reportedly rich vitamin C content and plant polyphenols. *I. gabonensis* pulp is also used for diabetes treatment when coupled with *Ouratea turnarea* and *Citrus medica* (Kuete and Efferth 2011).

## 3.3. Traditional Processing and Products Obtained

As *I. gabonensis* kernels are more economically resourceful, the traditional post-harvesting operations aim to remove the kernel in its optimum conditions. In most cases, the interest in the seed results in the neglect of the potential of other parts of the fruit, including the pulp.

Fruit harvesting must be undertaken at an appropriate time, preventing the harvest of immature fruits, but also ensuring a good shelf life (Ladipo 1999). Besides harvesting, the gathering of fallen ripe has also been reported (Elah 2010; Nkwatoh et al. 2010). The fresh fruits of *I. gabonensis* have a shelf life of less than 2 days if picked when ripe and not more than 10 days if harvested at the mature green stage, due to high respiration rate, moisture loss and microbial attack (Aina 1990; Joseph and Aworh 1991; Joseph and Aworh 1992; Etebu 2013). Etebu (2013) isolated four genera of fungi (*Aspergillus, Penicillium, Rhizopus* and *Mucor*) from postharvest fruits of *I. gabonensis* and *I. wombolu*, concluding that *Rhizopus* and *Mucor* species were the most predominant genera of fungi associated with postharvest *Irvingia* fruits.

Aina (1990) described the physicochemical changes in *I. gabonensis* fruits during normal storage ripening and revealed that, with the ripening process, the fruit peel gets yellow and the sweetness of the pulp increases due to starch degradation. The sourness and the acidity decreases, the fruit turns softer, mainly due to pectin degradation, and, finally, the vitamin C content decreases as ascorbic acid is very susceptible to oxidative degradation. In order to extend the shelf-life of *I. gabonensis* fruits during storage, Joseph and Aworh (1991; 1992) studied the influence of some post-harvest treatments. Firstly, while comparing ripening at room temperature and refrigerated storage of the fruits, it was noticed that low temperatures induced cold injuries in *I. gabonensis* and that room-ripened fruits had better flesh colour and texture, although, they also had a higher moisture loss (Joseph and Aworh 1991). After these primary results, the authors conducted other experiments in order to determine the effects of dipping fruits in hot water and in different concentrations of benomyl, DHA-S, and $Na_2S_20_5$ at different temperatures, on the shelf life and quality. While untreated fruits had become brownish black and unmarketable by day 12, the fruits treated with hot 0.1% benomyl or 0.5% $Na_2S_20_5$ solutions followed by waxing had an attractive appearance and good quality until day 14. Dipping fruits in hot water (55 °C) or chemical solutions (0.1% benomyl, 0.5% DHA-S or 0-5% $Na_2S_20_5$) followed by waxing or packaging in boxes overwrapped with stretch PVC film, delayed ripening, controlled decay, minimised weight loss and extended the shelf life of the fruits under tropical ambient conditions, without adverse effects on visual and chemical qualities (Joseph and Aworh 1992).

*I. gabonensis* pulp is consumed to a considerable extent, normally eaten raw as a dessert or snack; however, large quantities are usually wasted (Akubor 1996). Juice, beverage, and jam manufacturing requires little processing and addresses the need to use the raw pulp, injured or not. Various authors cited bush mango as being more suitable for juice, wine, and jam production, compared to other known tropical fruits (Ejiofor 1994; Okolo 1994; Agbor 1994; Okafor, Okolo and Ejiofor 1996; Akubor 1996; Ainge and Brown 2001; Aworh 2015).

Laboratory trials have shown that jam can be produced from lesser known Nigerian fruits including *I. gabonensis* (Aina and Adesina 1991; Ainge and Brown 2001; Aworh 2014; Aworh 2015). Aworh (2014) produced jams from three indigenous fruits containing 50% of pulp. For the *I. gabonensis* jam recipe, 500 g of pulp was mashed and boiled with 638 g of sugar, 100 g of water, 6 g of citric acid and 5 g of calcium chloride in a steam-jacketed kettle. In a sensory evaluation of the wild fruit jams, *I. gabonensis* jam was the less preferred, especially in terms of flavour and consistency. The author concluded that although *I. gabonensis* jam is manufacturable, it may not be marketable for its low acceptance.

Akubor (1996) studied the suitability of *I. gabonensis* fruits for juice and wine production. The pulp was blended with water in a 1:5 proportion, then filtered in cheesecloth and cane sugar added in order to obtain 23 ºBrix. A yield of 75% was achieved and the obtained juice was compared to other tropical fruit juices obtained from banana, orange and cashew. *I. gabonensis* juice showed a lower protein content and a higher ascorbic acid content compared to the other tropical fruit juices.

For wine production, the *I. gabonensis* juice was fermented with *Saccharomyces cerevisiae* at 30 °C for 28 days. The wine produced had 8.12% (v/v) alcohol, 0.78% protein, 6.5 °Brix SS, and a pH 3.10. Consumer test showed that the obtained product was generally accepted and had no significant differences in colour, sweetness, mouthfeel, and general acceptability as compared to a German reference wine.

Besides beverage production, osmotic dehydration has also been cited as an excellent application of *I. gabonensis* fruits (Falade and Aworh 2004; Falade and Aworh 2005; Aworh 2015). With this process, a variety of new shelf-stable food products can be developed with few modifications in the fruits' colour, flavour, and texture characteristics. Osmose-dried products could reduce perishable fruit losses postharvest and ensure that seasonal fruit products are available throughout the year. The osmotic process is very suitable as a pre-treatment prior to air-drying of fruits, resulting in a fruit product with an intermediate moisture content (Falade and Aworh 2004; Falade and Aworh 2005; Aworh 2015).

Falade and Aworh (2004) studied the influence of osmotic pre-treatment on the adsorption isotherms of osmo-air dried *I. gabonensis* fruits. The treatments were performed at 27 ºC and 40 ºC, with sugar concentrations of 52 ºBrix, 60 ºBrix and 68 ºBrix, maintaining a fruit:syrup ratio of 1:4 w/w for 10 h. Afterwards the fruit slices were oven air-dried at 60 ºC for 72 h. The authors concluded that the adsorption isotherms of osmo-oven dried fruits followed a type III isotherm, which characterizes high sugar products like many other fruits. In the experiments, *I. gabonensis* isotherm was affected by fruit ripeness degree. In fact, the equilibrium moisture content of the fruit increased with higher degree of ripeness at the same water activity ($a_w$), concentration of the sucrose solution used for pre-treatment (the higher the sugar concentration, less water was absorbed at low and intermediate $a_w$ ranges), and equilibrium temperature (equilibrium moisture content decreased with increasing temperature, when $a_w < 0.8$).

Dried fruits of *I. gabonensis* can also be used as a flavouring agent in other food products in order to diversify its usage. Mbaeyi and Anyanwu (2010) evaluated the use of these products as a yogurt flavourant. The dried and pliable fruits were milled, sieved through a 0.59 mm sieve, and added at 0.8%, 1.6%, 2.4%, 3.2%, 4.0%, and 4.8% in commercial full-fat cow yogurt. The best sensory results were obtained in the yogurt containing 0.8% of dried fruit with an overall acceptability statistically not different from commercial yogurt.



## 4. Seeds

The kernels are the main products of *I. gabonensis* and constitute an important part of West and Central Africa diet, mainly in rural communities, providing carbohydrate and protein. The seed consists of a hard shell, an outer brown testa (hull) and inside, the kernel, composed of two white cotyledons. The seeds of the fruits of *I. gabonensis*, can be eaten raw or roasted and are used in food preparations (National Research Council, 2006).

### 4.1. Chemical composition

The summary of the proximate composition of *I. gabonensis* kernels is provided in Table 3. According to literature, *I. gabonensis* seed has a high energetic value (595 – 729 kcal), due to high percentages of fat (10 – 71%), carbohydrates (3 - 52%) and protein (7-22%). With crude protein content ranging from 7 to 22%, *I. gabonensis* seeds have comparable or higher protein levels than the majority of the cereals comprising our daily diet (corn, sorghum, rice, etc), which generally does not exceed 13%. Fibre content was generally low in the studies reported, except by Onimawo et al. (2003), who observed an outlying value of 10.23%. This may be due to sample preparation but also ~~and/or plant origin~~the intraspecific variability that offers horticulturalists and agroforesters the opportunity to develop cultivars appropriate to different uses and industries (Leakey et al. 2012; Leakey 2017; 2019).

### 4.1.1. Kernel Oil Composition and physical properties

The analysis revealed that *I. gabonensis* is essentially a rich source of edible fat, with a mean percentage of 6~~1.56~~2%. Some oil-bearing products with such high percentage of oil are coconut, almond, pistachio, sunflower, walnut, and watermelon seeds which contain 62.3, 58.9, 53.5, 52.1, 64.5 and 52.6% of oil, respectively (Gopalan, Rama Sari and Balasubramanian 2014).

Physicochemical characteristics of *I. gabonensis* kernel oil are summarized in Table 4. This oilseed could also be a source of minerals with nutritional value such as iron, copper and zinc and therefore recommended for use in diets. The content in micronutrients such as trace elements (iron, copper and zinc) and microelements (potassium and sodium) of *I. gabonensis* kernel oil are summarized in Table 5.Acid value is used as an indicator for edibility of oil and suitability for use in the paint industry (Etong, Mustapha and Taleat 2014) . The acid value for samples of *I. gabonensis* oil found in literature (3.18 - 24.7 mg KOH/g) were considerably diverse, and most of them did not fall within the allowable limits for edible oils, 4.0 mg KOH/g fat for oil (Codex Alimentarius 2015). The free fatty acid values ranged from 0.30 to 4.70%, which can be considered low if compared with other vegetable oils (Omoniyi et al. 2017). Etong, Mustapha and Taleat (2014) reported that a low acid value with a correspondingly low level of free fatty acid, suggests the low level of hydrolytic and lipolytic activities in the oil, thus the seed oil studied could be a good source of raw materials for industries. The peroxide value (0.04 – 3.33 meq $O_2$/kg fat) was incredibly low, which indicates a low level of oxidative rancidity and also suggests a high antioxidant level in the oil (Etong, Mustapha and Taleat 2014). Etong, Mustapha and Taleat (2014) also stated that the relative low iodine number of the seed oil may be indicative of the presence of few unsaturated bonds and low susceptibility to oxidative rancidity. High saponification value (187.90 – 701.00 mg KOH/g) also indicates it has potential for industrial use (Omoniyi et al. 2017). Low unsaponifiable matter (0.12 – 1.70%) indicates that the oil is pure (Etong, Mustapha and Taleat 2014).

*I. gabonensis* seed kernel oil (Table 6) is mostly cited as a mystiric-lauric oil, with mystiric acid being the most abundant followed by lauric acid (Matos et al. 2009; Silou et al. 2011; Yamoneka et al. 2015; Lieb et al. 2018). According to Matos et al. (2009), *I. gabonensis* kernel oil is a technical fat because it resists thermo oxidative, hydrolytic, and enzymatic activities due to its fatty acid profile.

Nine free fatty acids were described in literature, only three of which are unsaturated. *I. gabonensis* kernel oil is mainly composed by saturated fatty acids (SFA) (approximately 95,46%) and, consequently, has a high oxidative stability, even at high temperatures (Yamoneka et al., 2015; Lieb et al., 2018).

Amongst triacylglicerols the most abundant are LaMM (31.1%), CMM/LaLaM (25.6%) and MMM/LaMP (12.9%) (Lieb et al. 2018). Similar results were reported by Meara and Patel (1950), Silou et al. (2011) and Yamoneka et al. (2015). The high proportions of saturated TAGs (approximately 83% tri- and 13% disaturated TAGs), and low proportions of unsaturated TAGs (1.5% di- and 2.6% triunsaturated TAGs), found in *I. gabonensis* kernel fat, could be further associated with the high saturation level of fatty acids previously described (Lieb et al., 2018).

Meara and Patel (1950) descried the impossibility of completely separating fully saturated glycerides from mono-oleoglycerides by crystallization, as well as an individual triglyceride fraction by exhaustive crystallization, in dika fat. The greater solubility of the lower molecular weight, fully saturated glycerides is more similar to those of the mono-oleoglycerides present than fully saturated components, which explains the problems in separating these fractions. Moreover, the authors noticed that triglycerides occurred in different fractions of the fat, indicating that those are the components primarily responsible for the " mutual solubility " effects, which precluded the achievement of sharp separations by exhaustive crystallization.

Additionally, unsaponifiable matter composition, as well as phospholipid fraction, have also been discussed. Phospholipid portion (PL) of *I. gabonensis* seed oil has a higher unsaturated fatty acid content when compared with crude seed oil (32.6-36.1% oleic acid, 24.7–29.6 % palmitic acid and 16.7–18.0 % stearic acid). HPLC analysis of the PL fraction showed that phosphatidylcholine was the most abundant class, making up to 70 % of the total PL content followed by phosphatidylinositol and phosphatidylethanolamine (Ifeduba et al., 2013).

Amidst phytosterols identified in *I. gabonensis* seed oil, 4-desmethylsterols were the most representative. More specifically, β-sitosterol and stigmasterol were the predominant components of the unsaponifiable fraction, followed by Δ5-avenasterol and the phytosterol precursor squalene (Silou et al., 2011; Lieb et al., 2018). Lieb et al. (2018) also identified minor 4-desmethylsterols in the seed oil, including cholesterol, 24-methylenecholesterol, campesterol, clerosterol, sitostanol, and Δ7-avenasterol.

Determination of tocochromanols in *I. gabonensis* fat generated contradictory results in literature. While Ifeduba et al. (2013) reported the prevalence of β-tocopherol, followed by α- and γ-tocopherol, Lieb et al. (2018), contrariwise, identified γ-tocopherol as the most abundant tocopherol homolog and trace amount of α-tocopherol. Despite the differences, both studies reported similar concentrations of tocopherols in *I. gabonensis* seed oil (4.5 - 4.6 mg/100 g).

Due to *I. gabonensis* extraordinary proportions of saturated fatty acids and TAGs, it presents a high content of solid fats (SFC) at room temperature, even in tropical countries. Its SFC melting profile remains nearly unchanged up to 20°C and is completely melted at around 40°C. After a tempering at 26°C for 40h, *I. gabonensis* SFC melting profile was not affected, indicating that it probably crystallizes directly in a stable form (Yamoneka et al., 2013). Thermograms of *I. gabonensis* fat melting, obtained by differential scanning calorimetry (DSC), also indicate initial melting around 20 – 25°C, a fast drop during melting interval with a single maximum peak at 39 – 40°C and its termination at 42 – 45°C (Yamoneka et al., 2013; Silou et al., 2011; Lieb et al., 2018). As for its polymorphic behavior, *I. gabonensis* seed oil tends to form $\beta'_1$-form crystals even after tempering and storage, contrarily to cocoa butter, which presents more stability in β-form. This distinctive polymorphism indicates that tempering would not be necessary to induce conformation stability in *I. gabonensis* seed oil manufacturing (Yamoneka et al., 2013).

Polyphenol composition is described in the following section (3.2), as it is related to I. gabonensis seed functional properties.

**4.2. Functional Properties**

*In-vivo* and *in-vitro* assays have already been developed to functionally characterize the seed. Data comprising of the antioxidant capacity, total phenol (TPC), total flavonoid (TFC), total anthocyanin (TAC) and total tannin (TTC) contents, as well as total carotenoid (TCC) and ascorbic acid contents, are described in Table 7.

The presence of steroids, flavonoids, alkaloids, cardiac glycosides, volatile oils, terpenoids, tannins and saponins in *I. gabonensis* kernel extract has been revealed on phytochemical screening by Obianime and Uche (2010).

Giami, Okonkwo and Akusu (1994) studied the influence of heat treatment in the composition of *I. gabonensis* seed flour and stated that increase in temperature occasioned an undesired loss in ascorbic acid, total carotenoid and total polyphenol contents.

*I. gabonensis* seed phytochemical constituents were also compared with mango (*Mangifera indica*) kernels and with a mix of both species (Arogba and Omede 2012; Arogba 2014). According to DPPH, lipid peroxidation and FRAP assays, mango kernels had a higher antioxidant activity than *I. gabonensis* kernels, contrary to nitric oxide assay results. However, *I. gabonensis* kernel results were similar or higher than mango kernel for ascorbic acid content. Total phenol, flavonoid and tannin contents were also higher in *Mangifera indica* samples, whereas, *I. gabonensis* kernels presented a much higher anthocyanin content. The author showed in these studies that processed kernels of mango (*Mangifera indica*) and *I. gabonensis* contain significant amounts of gallotannins with high antioxidant capacity even with statistically ($p < 0.05$) higher activity than some other known naturally-occurring phenolic antioxidants (Arogba and Omede 2012; Arogba 2014).

*I. gabonensis* kernel was also compared to 13 Cameroonian herbs/spices. It presented the highest FRAP-free antioxidant capacity followed by *Thymus vulgaris* and ranked third in FRAP total antioxidant but had one of the lowest results in Folin total antioxidant assay (Agbor et al. 2005).

Besides spectrophotometry quantification, it is essential to determine the chemical composition and marker compounds in *I. gabonensis* seed oil for fully comprehend its functionality. Sun and Chen (2012) identified forty-one phenolic compounds in *I. gabonensis* seeds, using an ultra high-performance liquid chromatography high-resolution mass spectrometry (UHPLC-HRMS) method. Major constituents in the PDA and total ion chromatograms were identified as ellagic acid and ellagic acid derivates (di-O-methyl ellagic acid, tri-O-methyl ellagic acid, monomethyl-ellagic acid, di-O-methyl-ellagic acid hexoside, methyl ellagic acid-O-deoxyhexose, di-O-methyl ellagic acid-O-pentoside, di-O-methyl-ellagic acid deoxyhexoside and methyl-ellagic acid-O-rhamnosyl-rhamnoside). Ellagitannins (di-HHDP-hexose and unknown ellagitannins) and flavonoids (kaempferol 3-O-glucoside, quercetin 3-O-rhamnoside, rhamnetin/isorhamnetin with one hexose group and one rhamnosyl-rhamnose and O-methylated flavon) were also identified in minor proportions (Sun and Chen, 2013).

Obianime and Uche (2010) studied the effects of *I. gabonensis* seed phytoconstituents in an *in vivo* study, which described the influence of aqueous extract of *I. gabonensis* kernels on biochemical parameters of adult male guinea pigs. The animals were divided into groups in order to perform time-dependent and dose-dependent studies. Groups 1-5 were administered a fixed dose of *I. gabonensis* extract (400 mg/kg/day) over a period of 7, 14, 21, 28 days, respectively. Groups 6-10 were administered different doses of the extract (50-400 mg/kg/day) for 96 hours. Results showed that the aqueous extract of *I. gabonensis* kernels caused a dose and time-dependent decrease in urea, uric acid, creatine, total cholesterol, protein, alkaline acid, and prostatic phosphatases. Pre-treatment with *I. gabonensis* was also able to inhibit the increase in most biochemical parameter levels caused by cadmium administration. The highest reduction effect was obtained with uric acid at 400 mg/kg of *I. gabonensis* extract while the least effect was observed in total cholesterol (Obianime and Uche, 2010).

*I. gabonensis* seed extracts were also evaluated for obesity management (Ngondi, Oben and Minka 2005). The subjects ingested three capsules, three times daily, each containing 350 mg of *I. gabonensis* seed extract (active formulation) or oat bran (placebo), for one month. After 4 weeks, the mean body weight of the *I. gabonensis* group had decreased by 5.26% and that of the placebo group by 1.32%. By the second week, the systolic blood pressure was significantly reduced by the active extract. Obese patients under *I. gabonensis* treatment also had a reduction of 39.21% in total cholesterol, 44.9% in triglycerides, 45.58% in LDL and 32.36% in blood glucose level, as well as an increase of 46.85% in HDL-cholesterol.

Dosumu et al. (2012) studied more specifically the antimicrobial effect of three Nigerian condiments, including *I. gabonensis* dried seed extracts. Clinical isolates of bacteria strains (*Staphylococcus aureus, Escherichia coli, Bacillus subtilis, Pseudomonas aeruginosa, Klebsiella pneumonae, Salmonella typhi*) and fungi (*Candida albicans, Aspergillus niger, Rhizopus stolon, Penicillum notatum, Tricophyton rubrum, Epidermophyton floccosum*) were used in the study. Overall, *I. gabonensis* extract had lower antimicrobial activity than the other Nigerian condiments tested. All condiments tested were more effective against fungi than against bacteria. *I. gabonensis* seed extracts obtained with ethyl acetate (200 mg/ml) and methanol (200 mg/ml) presented considerable fungal inhibition when compared to the positive control (Tioconazole,10 μg/ml).

## 4.3. Traditional Processing and Products Obtained

The first step in processing *I. gabonensis* kernels is separating the seeds from the mesocarp, using three principal methods for this operation: "Fresh Cracking"; "Wet Cracking" and "Dry Cracking". The "Fresh Cracking" method was reported by Ayuk et al. (1999) and Nkwatoh et al. (2010), in which the whole ripe fruit (pulp and seed) is split in half, through its natural longitudinal line of weakness, with a cutlass or sharp knife. On the other hand, for the other methods, *I. gabonensis* fruits are piled up in heaps and left to fermentate before seed extraction, which facilitates this operation. After fermentation, the seeds can be sun-dried ("Dry Cracking") or directly split ("Wet Cracking"), using truncheons or hard stones as helping tools (Ejiofor, Onwubuke and Okafor 1987; Ladipo, Fondoun and Ganga 1996; Ladipo 1999; Ogunsina, Koya and Adeosun 2008[a]). As soon as the seeds are cracked, the kernels wrapped in a dark brown testa are exposed and extracted with a knife (Ladipo 1999). The nut cracking process is, therefore, complicated and the dried kernel-in-shell is brittle, resulting in a large percentage of cotyledons being crushed during the process, thereby reducing the market value of the kernels (Ogunsina, Koya and Adeosun 2008[a]; Ogunsina, Koya and Adeosun 2008[b]).

Ogunsina, Koya and Adeosun (2008[a] and 2008[b]) investigated fracture behaviour of *I. gabonensis* seed in order to provide baseline data for designing an appropriate nutcracker. The physical analysis revealed that minimum toughness was required for nutshell fracture with the small size nuts loaded along the transverse axis. Furthermore, a machine, whose fracture mechanism was based on the deformation characteristics of dried *I. gabonensis* seeds under uni-axial compression, was fabricated. The experimental machine gave 100% cracking efficiency but with 24% kernel breakage in cracking sun-dried *I. gabonensis* seeds with 6.6% moisture content (w.b.). The machine provided a viable and effective technique for safe *I. gabonensis* kernel extraction. Orhevba et al. (2013) also studied physical and mechanical parameters of *I. gabonensis* seed cracking and the influence of moisture content (13.75% and 8.74%). The two moisture content levels were observed to be the range between which *I. gabonensis* kernels can be extracted with least percentage of crushing. Further decrease in the moisture content will make the kernel brittle, while a higher moisture level will make the kernel to stick to the shell, therefore, resulting in crushing during cracking. A motorized machine that is capable of multiple cracking of dika nuts was designed, fabricated and tested by Ogundahunsi, Ogunsina and Ibrahim (2016). The device utilizes the impact of a sliding hammer block falling from a height to crack a tray of 20 nuts; cracking and splitting them, liberating the embedded kernels as split cotyledons. The highest cracking efficiency and throughput values (72% and 12.86 kg/h, respectively) were obtained for big roasted nuts. The method of pre-treatment and dika nut sizes were found to affect the cracking efficiency and throughput of the motorized dika nut cracking machine. After being removed, the kernels are dried for 2 to 7 days, in the sun or on bamboo drying racks over the fireplace (Tchoundjeu, Atangana and Degrande 2005), in order to remove all moisture (Onimawo et al. 2003; Nkwatoh et al. 2010). This procedure guarantees the quality of the product during storage, by preventing it from discolouring and from fungal degradation (Ladipo 1999; Ainge and Brown 2001).

Fermentation helps to increase the protein and nitrogen-free extractives of the seeds, as well as to reduce the fat content, which is an advantage if the kernels are consumed integrally (Ekpe, Umoh and Eka 2007; Ekundayo, Oladipupo and Ekundayo 2013). Otherwise, if seeds proceed to further processing, the fat loss may be undesired.

At this point, the kernels can be marketed or subjected to further processing. The cotyledons, without the hull, are pounded with a mortar and pestle (Ekpe, Umoh and Eka 2007). The kernels can also be milled with a grinding machine (Onimawo et al. 2003), which is a more industrial option (Festus and Ibor 2014). The mash, called 'cake', is then moulded manually into convenient sizes and shapes, placed in bags or leaves and smoke dried for a few days over a fireplace (Ekpe, Umoh and Eka 2007; Caspa et al. 2015).

*I. gabonensis* cake can become too slimy over time because of its high fat content; therefore, for an extended shelf-life, ~~deffating~~defatting is needed (Ainge and Brown 2001; Festus and Ibor 2014). This operation yields, besides crude fat, defatted cake as a product, which, according to Ejiofor, Onwubuke and Okafor (1987), is still acceptable in terms of its colour, taste, texture, and drawability after 9 months of storage under ambient conditions, and is more viscous, with greater emulsifying properties than regular flour. The normal flour and defatted flour from *I. gabonensis* kernels are used as ingredients for the popular Ogbono or draw soup which imparts unique flavour, drawability, and thickening properties to the stew (Agbor 1994; Leakey and Newton 1994, Vivien and Faure 1996), and also as ‘dika bread' after being baked (Leakey et al. 2005). Leakey et al. (2005) also identified that the food thickening properties of dika nuts were due to two independent and unrelated traits – drawability and viscosity. They also reported considerable tree-to-tree variation in both these traits as well as in protein and oil levels as previously highlighted by Atangana et al. (2001) and Anegbeh et al. (2003) even between trees from the same site, offering opportunities for genetic selection for these traits in new cultivars developed by farmers (Leakey, 2014) and improving the existing farmer domestication of these traditionally-important foods (Leakey et al., 2004). Ogbono soup is one of the cheapest, easiest, and fastest Nigerian soups to prepare (Oktay and Sadıkoglu 2018). Onabanjo and Oguntona (2003) described the following recipe as the most representative of this dish: *I. gabonensis* nuts, bitter (*Vernonia amygdalina*) leaves and okra~~o~~ (~~*Hibiscus esculentus*~~*Abelmoschus esculentus* (L.) Moench.) cooked with dried fish, crayfish, ground pepper, pepper, palm oil, bouillon cubes, salt, and water. The influence of *I. gabonensis* seed flour fat content and time of storage on the sensory characteristics of the Ogbono soup was evaluated. Sensory parameters of sliminess (viscosity), taste, aroma, colour, and overall acceptability showed that soups prepared from partially defatted *I. gabonensis* seed flour samples (especially the samples with 9% and 12% fat) were more acceptable to the panellists than soups prepared from full-fat *I. gabonensis* seed flour (Idowu et al. 2013). The preference test carried out by Idowu et al. (2013) during the 12-week period of storage also showed that sliminess, colour, taste, aroma, and overall acceptability of Ogbono soups prepared from defatted *I. gabonensis* seed flour (12% and 9% fat) samples packaged in low- and high-density polyethylene films were all acceptable to the panellists. However, the full-fat flour had its sensory parameters significantly decreased in a period of 4 weeks (Akusu and Kiin-Kabari 2013; Idowu et al. 2013).

The defatted cake can also be extruded and moulded into Ogbono cubes, which are sold as a convenient cooking ingredient, used as thickeners in Ogbono soup (Okafor, Okolo and Ejiofor 1996; Ejiofor and Okafor 1997). Bamidele, Ojedokun and Fasogbon (2015) and Kiin-Kabari and Akusu (2017) developed and analysed a "ready-to-cook" powder mix (*I. gabonensis* seed powder, crayfish, stock fish, Ugwu, mixture of locust bean, onion mix, seasoning, and Cameroon powder) for Ogbono soup. Five formulations of instant Ogbono premix were evaluated by Bamidele, Ojedokun and Fasogbon (2015) (proximate composition, functional properties, micronutrients and sensory analysis). Moisture, protein and carbohydrate contents increased as *I. gabonensis* seed powder percentage decreased in formulations, inversely to fat content. Sensory evaluation showed that the samples with higher percentage of *I. gabonensis* seed powder rated the highest on overall acceptability based on the fact that they showed the real attribute of Ogbono soup that people like which is attributed to the quantity of *I. gabonensis* kernel powder added to the sample (Bamidele, Ojedokun and Fasogbon 2015). These results are similar to that obtained by Kiin-Kabari and Akusu (2017), which tested formulations of *I. gabonensis* seed (Ogbono) and melon (Egusi) seeds soup premix. They concluded that consumers who do not like very thick soups and low drawability would prefer the formulation with 40:60 Ogbono/Egusi ratio, while consumers who prefer thick soups but low drawability will go for the formulation of 100% "Egusi".

Although oil is the major constituent of the seed, according to Nwokocha and Williams (2014), the defatted seed flour essentially consists of polysaccharides with lower than 5% of non-polysaccharide constituents. Nwokocha and Williams (2014) extracted *I. gabonensis* seed gum from its defatted flour by removing soluble sugars and organic pigments with 95% ethanol, followed by dispersion in distilled water (2% w/w), stirring (6 h), and double centrifugation (2500 rpm for 2h) at 25 ºC. On the other hand, Ndjouenkelu et al. (1996) heated the diluted flour (10 g/250 mL) under reflux and then centrifuged the mixture (2000×g for 30 min), repeating the process with the supernatant (2 times), then precipitated the crude polysaccharide with 85% ethanol and purified the extract by protein removal. Both studies concluded that *I. gabonensis* seed gum has polyelectrolyte properties, as it is an arabinogalactan but also contains a small proportion of neutral sugars and uronic acids (Ndjouenkelu et al. 1996; Nwokocha and Williams 2014). It showed non-Newtonian behaviour at concentrations from 0.2 to 3.0%, having mostly viscous response at concentrations less than 1.0% and elastic response at higher concentrations (Nwokocha and Williams, 2014).

Ogaji, Nan and Hoag (2012) developed a largely physical method for simultaneous extraction of the lipid and polymeric portions of *I. gabonensis*, which was simple, safer, and less expensive than the traditional use of *n*-hexane to extract the lipids. This method was also able to efficiently remove impurities from the gum fraction. The physicochemical properties of the extractives were evaluated, and the results showed similarities in the extractives obtained by this method and those obtained by conventional methods.

Uzomah and Ahiligwo (1999) studied the rheological properties of achi (*Brachystegea eurycoma*) and Ogbono (*I. gabonensis*) seed gums and their potential use as stabilizers in ice cream production. Ogbono seed gum (OSG) cream obtained similar results for quality parameters (maximum overrun, viscosity, shape factor, and meltdown) as the control sample. However, OSG imparted some viscosity to the mixture which resulted in a poor ability to trap and hold air and a poor tendency to resist melting, all of which are characteristics of a satisfactory ice cream. That being said, *I. gabonensis* seed gum was found to be unsuitable as an ice cream stabilizer (Uzomah and Ahiligwo 1999).

It was found that the fat extracted from the kernels can be used for food applications, such as food additive, flavour ingredient, coating fresh citrus fruits and in the manufacture of margarine, oil creams, cooking oil, and defoaming agent. It is also suitable for soap, cosmetics, pharmaceutical products and lather shaving cream (Ejiofor, Onwubuke and Okafor 1987; Ogunsina et al. 2012; Zouè et al. 2013; Okoronkwo et al. 2014; Etong, Mustapha and Taleat 2014; Omoniyi et al. 2017).

Matos et al. (2009) characterized margarine made from *I. gabonensis* kernels from two different origins, with and without lecithin. The major fatty acids found in these margarines were oleic acid (35.5%-37%), palmitic acid (18.5%-19.5%) and lauric acid (13.1%-15.1%). The margarines were more unsaturated than the original oil and could be regarded as an oleic acid source. The ratio between linoleic acid (7.07%) and linolenic acid (0.63%) was lower than 2%, showing it can be used for frying food.

*I. gabonenis* seed oil has also been studied as a possible biodiesel source (Bello et al. 2011; Adekunle et al. 2016). It was observed that the kernel fat has similar properties to diesel fuel and superior cold flow properties and flash point, which makes it a suitable alternative fuel for diesel engines (Bello et al. 2011). Adekunle et al. (2016) also concluded that the degumming process improves the physicochemical and biodiesel properties of *I. gabonensis* seed fat, as well as other vegetable oils.

## 5. Other parts

Bark and leaves from *I. gabonensis* have been traditionally used in Nigeria, Cameroon, and other countries where the fruit is available. Proximate composition of stem bark, leaf, and root bark from *I. gabonensis* reveals them to be nutritionally rich (Table 8).

*I. gabonensis* leaves have been reported to be used as a self-care plant for icterus treatment, by Benin habitants (Allabi et al. 2011). The appropriation of *I. gabonensis* leaves may be associated with high levels of phytochemicals. Ezeabara and Ezeani (2016) reported that *I. gabonensis* leaves contained 2.44% alkaloids, 1.07% flavonoids, and 2.37% anthraquinone, which can be considered high compared to other parts from the same plant. Awah et al. (2012) compared the free radical scavenging activity and phenolic contents from Nigerian medicinal plants and revealed that *I. gabonensis* had high results when compared to the other samples. However, *I. gabonensis* extract presented relative toxicity to humans in the WST-1-based cytotoxicity and cell viability assays (Awah et al. 2012). This toxicity might be related to the high hydrogen cyanide content of 3.45% (Ezeabara and Ezeani 2016). *I. gabonensis* stem and root barks, instead, do not present relevant levels of hydrogen cyanide, 1.87% and 1.66%, respectively (Ezeabara and Ezeani 2016). Two research studies involving farmers and collectors in Cameroon revealed that *I. gabonensis* stem bark is popular as a traditional medicine. It is reported to treat hernia, yellow fever, dysentery, diarrhoea, malaria, to relieve abdominal pain in women, and as antidote for poisons (Ayuk et al. 1999; Zihiri et al. 2005; Caspa et al. 2015).

These effects must be associated with the phytochemicals present in the stem bark. Ezeabara and Ezeani (2016) noted that *I. gabonensis* bark was the most valuable part of the plant, in terms of functional constituents. It consists of the highest percentages of alkaloids (2.78%), flavonoids (1.17%), tannins (1.05%), saponins (0.91%), sterols (0.25%), phenols (0.18%) and anthraquinones

(3.17%), compared to the leaf, root bark and raw seed from the same species (Ezeabara and Ezeani 2016).

Zihiri et al. (2005) tested the antiplasmodial activity of ethanol extracts of West African plants, including *I. gabonensis*, and concluded that stem bark extract (10 mg/ml) had a weak antiplasmodial activity against *Plasmodium falciparum* with $IC_{50}$ value of 21.6 µg/ml. However, in a study investigating the analgesic effect, the water extract of the stem bark of *I. gabonensis*, when administered to male mice, was found to protect the mice from pain stimuli (Okolo et al. 1995). Another *in vivo* assay evaluated long-term effects of *I. gabonensis* and other two plants, also known to be hypoglycaemic, on the oxidative status of normal rabbits (Omonkhua and Onoagbe 2012). Oxidative status was determined by measuring activities of superoxide dismutase (SOD) and catalase (CAT), and the concentration of malondialdehyde (MDA). *I. gabonensis* extract had positive effects on increasing serum and tissue antioxidant enzymes, particularly in the pancreas, and on decreasing liver MDA levels (Omonkhua and Onoagbe 2012).

## 6. Conclusion

As shown in this work, *I. gabonensis* is a good source of nutrients and phytochemicals and its seeds are already widely consumed and processed traditionally. This review enhances our knowledge about the use of other parts of the fruit, especially the pulp, and about improving the existing methods for a safer and more efficient production of value-added products.

*I. gabonensis* pulp is suitable for juice and wine production, can be also consumed osmose-dried or raw and used as flavourant in the development of other products. It is a vitamin C rich fruit (51-76 mg/100g) having higher ascorbic acid content than mango or orange. Carotenoids, phenolic compounds, and other phytochemical constituents have also been determined, as well as the hypolipidemic effect of *I. gabonensis* juice administration *in vivo*.

*I. gabonensis* kernel proximate composition revealed its high fat content, as well as a relevant carbohydrate content. *I. gabonensis* kernel oil is considered a “technical” fat because it resists thermo oxidative, hydrolytic, and enzymatic activities due to its fatty acid profile. *I. gabonensis* seed oil has a unique melting profile and polymorphism, which characterizes it as a possible ingredient for diverse industries, ~~inasmuch~~ as it remains solid in room temperature (even in tropical countries) and does not require tempering, as it naturally crystalizes in an stable ~~form (~~$\beta'_1$-form~~)~~. The presence of steroids, flavonoids, alkaloids, cardiac glycosides, volatile oils, terpenoids, tannins and saponins in *I. gabonensis* kernel extract has been revealed on phytochemical screening and its hepatoprotective, nephroprotective, hypolipidemic effects and its influence on body weight have been confirmed. Potential anti-carcinogenic, anti-lipidemic, analgesic and anti-inflammatory effects of the kernel have been highlighted.

Various methods are employed to process the seed. However, all of them have safety issues, when it comes to cracking operation. Various researchers indicated that fermented seeds with specific moisture content, with the appropriate equipment, are easier to crack and kernel loss is reduced. Main products from traditional processing are the sun-dried kernels and the 'cake' which is used as a thickener in 'ogbono soup', a conventional African food. It was described, that with a more sophisticated process, the fat could be extracted from the kernel powder generating a defatted *I. gabonensis* cake. This product can be used as a thickener, stabilizer and as a kind of gum. Not only the defatted flour is potentially manufacturable, but also the crude seed oil, which could be exploited as a potential substitute for fats largely employed, such as cocoa butter and palm oil.

Furthermore, the production of *I. gabonensis* value-added products could reduce food loss, as this would allow the whole fruit to be used. This will also encourage the consumption of wild fruits and support plant biodiversity. This new approach could ameliorate the diet of rural communities as the *I. gabonensis* fruits are a good source of nutrients and phytochemicals. Commercialization of *I. gabonensis* derived products can also increase the income of the rural communities.

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Table 1: Proximate composition of *Irvingia gabonensis* ripe raw pulp

| | FAO, 1968 | Onimawo et al., 2003 | Stadlmayr et al., 2013 | Aina, 1990 | Joseph and Aworh, 1991 | Mbaeyi and Anyanwu, 2010 |
|---|---|---|---|---|---|---|
| **Moisture (%)** | 81.4 | 80.0 | 78.8 | 80.5 | 80.0 | 90.5 |
| **Ash (%)** | 1.8 | 0.8 | 0.8 | - | - | 1.4 |
| **Fibre (%)** | 0.4 | 0.4 | 0.4 | - | - | 4.9 |
| **Fat (%)** | 0.2 | 1.1 | 1.1 | - | - | 2.2 |
| **Protein (%)** | 0.9 | 1.1 | 1.1 | - | - | 4.4 |
| **Carbohydrate (%)** | 15.7 | 16.7 | 17.8 | - | - | 4.6 |
| **Total Acidity (%)** | - | 0.1 | - | 0.3 | 0.1 | - |
| **pH** | - | 5.8 | - | 4.7 | 5.0 | 6.2 |
| **Soluble solids (%)** | - | 10.0 | - | 10.5 | 14.0 | 9.5 |

Table 2: Phytochemical content (mg/100 g fresh fruit) of *I. gabonensis* ripe raw pulp

| | | Reference |
|---|---|---|
| **Ascorbic and dehydroascorbic acids** | 51.00-76.07 | FAO, 1968; Onimawo et al., 2003; Stadlmayr et al., 2013; Aina, 1990; Joseph and Aworh, 1991; Olayiwola et al., 2013; Achinewhu, 1983 |
| **Carotenoids** | 1.26 – 2.21 | Olayiwola et al., 2013; Aina, 1990 |
| **Tannin** | 54.9 | Aina, 1990 |
| **Phenolics** | 382.20 | Olayiwola et al., 2013 |
| **Vitamin A** | 280.18* | Mbaeyi and Anyanwu, 2010 |

* Retinol equivalent

Table 3: Proximate composition of *Irvingia gabonensis* kernel

| | Reference | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Idowu et al., 2013 | Onyeike and Acheru, 2002 | Elah, 2010 | Okoronkwo et al, 2014 | Ibezim, 2015 | Matos et al., 2009 | Ekpe et al., 2007 | Ogunsina et al., 2012 | Joseph, 1995 | Onimawo et al., 2003 | Dosumu et al., 2012 | Ezeabara and Ezeani, 2016 | Giami et al., 1994 | Eka, 1980 | Ejiofor et al., 1987 |
| **Energy (kcal)** | 684.5 | 688.00 | - | - | - | 729,36 | - | - | - | - | 595.05 | - | 682 | - | - |
| **Moisture Content (%)** | 4.26 | 5.93 | 2.55 | 3,21 | 8,28 | 0,02 | 5,20 | 2,55 | - | 3,36 | 3.75 | 11,54 | 4,1 | 2,10 | 11,90 |
| **Protein (%)** | 8.10 | 8.71 | 8.90 | 7,47 | 8,81 | 8,52 | 7,60 | 8,90 | 8,70 | 7,76 | 21.52 | 17,43 | 10,9 | 8,60 | 9,24 |
| **Fat (%)** | 67.69 | 62.80 | 68.37 | 68,81 | 69,34 | 68,24 | 66,60 | 68,37 | 66,50 | 65,46 | 55.09 | 9,81 | 64,2 | 70,80 | 51,32 |
| **Fiber (%)** | 5.88 | - | - | 4,38 | 1,25 | - | 1,90 | - | - | 10,23 | - | 4,18 | 3,4 | 1,40 | 0,86 |
| **Ash (%)** | 3.35 | 0.63 | 2.32 | 8,71 | 4,52 | 2,93 | 9,50 | 2,32 | - | 2,26 | 16.35 | 4,66 | 2,2 | 6,80 | 2,46 |
| **Carbohydrate (%)** | 10.72 | 21.93 | 18.67 | - | 11,39 | 20,28 | - | 18,67 | - | 10,93 | 3.29 | 52,40 | 15,2 | 14,10 | 26,02 |

1 Table 4: Physicochemical parameters of *I. gabonensis* kernel oil

2

| | Reference | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Onyeike and Acheru, 2002 | Joseph, 1995 | Ogunsina et al., 2012 | Okoronkwo et al., 2014 | Matos et al., 2009 | Zoué et al., 2013 | Etong et al., 2014 | Ifeduba et al., 2013 |
| **Chemical Parameters** | | | | | | | | |
| **Oil yeld (%)** | 62.80 | 66.5 | 68.37 | 68.81 | 62.67 | 69.76 | 22.50 | 64.85 |
| **Acid value (mg KOH/g)** | 24.7 | - | - | 3.18 | 12.94 | 4.67 | 9.40 | - |
| **Saponification value (mg KOH/g)** | 701 | 219.2 | 256.5 | 230.95 | 199.50 | 233.75 | 187.90 | 243.90 |
| **Peroxide value (meq $O_2$/kg fat)** | 0.04 | 1.98 | 0.5 | 2.67 | 1.9 | 3.33 | 1.80 | - |
| **Iodine value (mg $I_2$/ 100g fat)** | 21.5 | 4.2 | 8.2g | 13.40 | 4.3 | 32.43g | 4.50 | 4.00 |
| **Free fatty acids (%)** | 1.19 | 0.30 | 2.72 | 1.59 | 4.61 | 2.33 | 4.70 | - |
| **Unsaponifiable matter (%)** | 1.70 | 0.12 | - | - | - | 1.50 | 1.50 | - |
| **Physical Parameters** | | | | | | | | |
| **State at room temperature** | Semi liquid | - | Solid | - | - | - | Solid | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Specific gravity** | 0.89 | 0.85 | - | - | - | - | 0.88 | - |
| **Smoke point (°C)** | - | 213.0 | - | 147.57 | - | - | 78 | - |
| **Cloud point (°C)** | - | 35.0 | - | 41.83 | - | - | - | - |
| **Flash point (°C)** | - | - | - | 335.33 | - | - | - | - |
| **Fire point (°C)** | - | - | - | 340.67 | - | - | - | - |
| **Setting point (°C)** | 26.3 | - | - | - | - | - | 25.30 | - |
| **Melting/freezing point (°C)** | 56.0 | 39.5 | - | 32.47 | - | - | 13 | - |
| **Colour** | Golden yellow | - | White | - | - | - | Grey yellow | - |

1 Table 5: Micronutrient content (mg/100 g) of *I. gabonensis* kernel

2

| | Reference | | |
|---|---|---|---|
| | Onyeike and Acheru, 2002 | Ayivor et al., 2011 | Dosumu et al., 2012 |
| **Iron** | 0.315 | 19.374 | 10.101 |
| **Copper** | 0.139 | 5.722 | 2.346 |
| **Zinc** | 0.285 | 5.786 | 4.386 |
| **Potassium** | 15.600 | 0.723 | 612.55 |
| **Sodium** | 2.020 | 4.383 | 59.99 |

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Table 6: Mean values (%) of the fatty acid profile of *I. gabonensis* kernel oil

| | Reference | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Matos et al., 2009 | Nangue et al., 2011 | Silou et al., 2011 | Ogunsina et al., 2012 | Zoué et al., 2013 | Etong et al., 2014 | Yamoneka et al., 2015 | Lieb et al., 2018 | Ifeduba et al., 2013 |
| **Capric acid (C 10:0)** | 1.34 | 1.54 | 0.82 | - | 0.25 | - | 1.2 | 1.3 | 1.9 |
| **Lauric acid (C 12:0)** | 39.37 | 40.70 | 33.18 | 27.63 | 39.35 | 39.40 | 37.11 | 37.6 | 43.3 |
| **Myristic acid (C 14:0)** | 50.92 | 49.05 | 55.74 | 61.68 | 20.54 | 20.50 | 49.83 | 51.3 | 45,15 |
| **Palmitic acid (C 16:0)** | 4.97 | 5.06 | 5.85 | 7.49 | 10.39 | 10.30 | 5.51 | 5.4 | 5.05 |
| **Stearic acid (C 18:0)** | 0.73 | 2.38 | 0.76 | 0.81 | 11.46 | 11.40 | 0.89 | 1.0 | 0.95 |
| **Oleic acid (C 18:1)** | 1.97 | 0.49 | 1.35 | 2.12 | 6.99 | 6.90 | 4.31 | 2.3 | 2.95 |
| **Linoleic acid (C 18:2)** | 0.48 | - | 0.44 | 0.27 | 0.01 | 6.40 | 1.09 | - | 0.7 |
| **Linolenic acid (C 18:3)** | 0.00 | - | - | - | 6.44 | - | - | - | - |
| **Arachidic acid (C 20:0)** | - | - | - | - | 4.52 | - | | - | - |
| **Saturated fatty acid** | 97.33 | 98.73 | - | 97.61 | 86.56 | - | 94.54 | 97.1 | 96.35 |
| **Monosaturated fatty acid** | 1.97 | - | - | 2.21 | 6.99 | - | 4.31 | 2.6 | 2.95 |
| **Polyunsaturated fatty acid** | 0.48 | 0.49 | - | 0.27 | 6.45 | - | 1.09 | 0.4 | 0.7 |
| **n-6/n-3 ratio** | - | - | - | - | 1.55 | - | - | - | - |

4



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Table 7: Phytochemical constituents and antioxidant capacity of *I. gabonensis* kernel

| | Value | Reference |
|---|---|---|
| **DPPH antiradical assay** | 177.22% ($IC_{50}$) | Arogba and Omede, 2012 |
| **FRAP* assay** | 431.58 mg of catechin equiv/g | Agbor et al., 2005 |
| | 65.43 mM $Fe^{+2}$ ($IC_{50}$) | Arogba, 2014 |
| **Lipid peroxidation assay** | 375.38% ($IC_{50}$) | Arogba, 2014 |
| **Nitric oxide assay** | 106.12% ($IC_{50}$) | Arogba, 2014 |
| **TPC*** | 2.6 mg/100g | Giami et al., 1994 |
| | 10.74 mg/g | Agbor et al., 2005 |
| | 1.15 mg/g dw | Arogba, 2014 |
| **TFC*** | 077 mg QUE/g dw | Arogba, 2014 |
| **TAC*** | 0.67 ng cyanidin chloride/g dw | Arogba, 2014 |
| **TTC*** | 1.25 mg catechin/g dw | Arogba, 2014 |
| **TCC*** | 3.6 mg/100g | Giami et al., 1994 |
| **Ascorbic acid** | 6.2 mg/100g | Giami et al., 1994 |

*(FRAP - Ferric reducing antioxidant power; TPC – Total Phenolic Compounds; TFC – Total Flavonoid Compounds; TAC – Total Anthocyanin Compounds; TTC – Total Tannin Compounds; TCC – Total Carotenoid content)

Table 8: Proximate composition (%) of *I. gabonensis* stem bark, leaf and root bark (Ezeabara and Ezeani 2016)

| | Stem bark | Leaf | Root bark |
|---|---|---|---|
| **Moisture** | 9.43 | 10.83 | 8.91 |
| **Dry matter** | 90.58 | 89.17 | 91.09 |
| **Ash** | 7.72 | 9.61 | 6.58 |
| **Fibre** | 11.38 | 15.34 | 8.69 |
| **Fat** | 2.78 | 1.86 | 1.45 |
| **Protein** | 5.28 | 14.78 | 5.92 |
| **Carbohydrates** | 63.43 | 47.58 | 68.44 |