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# Ethnobotanical and Biochemical Data Bring no Evidence to Clarify the Biosystematics of *Irvingia gabonensis* and *I. wombolu* (Irvingiaceae): A Review

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**Abstract** *Irvingia gabonensis* and *I. wombolu* are two Irvingiaceae species with economic significance, because of their valuable kernels for West and Central Africans to thicken sauces. They are called sweet/edible – and bitter/inedible – fruited African bush mango trees (ABMTs), respectively, because of the taste of their mango – like fruit. The striking difference in fruit pulp taste clearly discriminates between *Irvingia gabonensis* and *I. wombolu* trees, which are morphologically very similar. Experts profoundly disagree on the taxonomic significance of differences among bush mango trees to allow classification of *Irvingia gabonensis* and *I. wombolu* as clearly different species. Therefore, the random species or variety consideration in researches indicates difficulty to define taxonomic units, which is vital for effective conservation and use of ABMT germplasm, because the source of tree – to tree variations is uncertain. This paper reviews ethnobotanical and biochemical data on ABMTs in order to evaluate their contribution to the biosystematics of *I. gabonensis* and *I. wombolu*. Thus, information on local uses (food and medicinal applications) and biochemical data of the kernel, pulp, leaves and bark are compared, and their implications for the distinction between *I. gabonensis* and *I. wombolu* are discussed. We evidenced a lack of comparative data related to ethnobotanical and many phytochemical aspects, mostly on the bark, leaves and roots. We hypothesised obvious misidentifications causing conflicting patterns, but no evidence of any phytochemical dissimilarity was found between *I. gabonensis* and *I. wombolu*. Kernel macronutrient composition, diversity, types and abundance of fatty acids in the kernel oil and the functional and therapeutic properties of this oil do not allow to discriminate between both species. Moreover, there is no correlation among patterns of lipophilic components profile, composition in fatty acids in the oil, geographical distribution of ABMTs. We interpreted these random patterns within ABMTs as tree – to – tree variations and this explains the vast co-occurrence of both taxa. However, consistent differences in fruit pulp taste across contrasting ecological conditions imply significant phytochemical differentiation between *I. gabonensis* and *I. wombolu*. This needs to be thoroughly re-evaluated and correlation with genetic data will clarify the taxonomic issue.

***Keywords:*** *biodiversity, biochemical species distinction, human nutrition, Irvingia spp, biosystematics, Sub-Saharan Africa*

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# 1. Introduction

African bush mango trees (ABMTs) widely occur in natural forests of West and Central Africa. They are very important fruit tree species that are intensively cultivated by local farmers due to the economic significance of the kernels they produce [1]. These slimy kernels are used by millions of Africans as sauce – thickening ingredient [2]. The kernels also produce edible oils usable in human nutrition and cosmetics [3,4]. The fruit pulp tastes sweet and is eaten, but extremely bitter and unpalatable fruits pulp also exist [5]. However, kernels with better organoleptic properties (highly slimy sauce with intensive aroma) come from the extremely bitter [6,7].

Species delimitation is central to biodiversity classification and conservation, while species definition concepts are numerous and controversial [8,9]. But, genetic isolation, which is a core idea in biological species definition, plays significant role in speciation processes and thus, is important to all species concepts [10]. A simplified species idea in taxonomy defines species as "a group of kinds of interbreeding natural populations that are reproductively isolated from other such groups" [9,11]. Here, the edibility of the bush mango pulp defines two reproductively isolated kinds of ABMTs that are, however, sympatric and botanically very similar [12,13]. Applicability of morphological species [14] eases taxa recognition and facilitates domestication and efficient use of biodiversity [15]. Difficulties to separate sweet – fruited ABMTs from the bitter ones, based on herbarium vouchers and living materials, is source of species problem within ABMTs. Sweet – and bitter – fruited ABMTs were considered [16,17]as two varieties within a unique *Irvingia gabonensis* species: *Irvingia gabonensis* (Aubry-LeComte ex O'Rorke) Baill. var. *gabonensis* and *I. gabonensis* var. *excelsa* Okafor, respectively. However, [5] revised the Irvingiaceae family and raised the sweet – and bitter – fruited ABMTs at species level, based on the correlation between the striking differences in fruit pulp taste with those in the fruits, seeds, and leaves: *Irvingia gabonensis* and *I. wombolu* Vermoesen, respectively. This opinion was later confirmed by significant genetic and phenological dissimilarities between these two kinds of trees [13,18]. However, the species consideration by [18] is still not totally acknowledged, since fruit taste and morphological diversity are often considered as random tree – to – tree variations within ABMTs [1]. The species' problem within ABMTs makes uncertain the definition of biological units for conservation and increases uncertainty in management and domestication programs [19]. For example, extinction of *I. wombolu* is taking place in the Volta Forest region (Ghana – Togo), because this kind of ABMT is considered by conservationists as wild *I. gabonensis* trees [13,20]. Consequently, it is difficult to: (i) develop efficient market led – domestication and cultivation systems; (ii) develop ABMTs – based food and pharmaceutical products at a wider scale; and (iii) suggest policies for the efficient conservation of ABMTs.

Biosystematics combines a wide range of biological criteria (ecology, morphology, phenology, genetics, phylogenetics, eco-physiology, etc.) to capture patterns of variations and classify organisms, based on the correlation between differences [21,22]. Comparative ethnobotanical data may provide hypotheses regarding differences in biochemical characteristics, to support plant taxonomic decision [23], because plant biochemistry, genetics and ecological circumstances are inextricably linked [24,25] (Pacheco-Hernández *et al.*, 2021). Therefore, [26] combined phytochemical and genetic data to clarify the delimitation of a number of bryophyte species and [27] identified significant genetic and morphological differences among folks classified potato materials.

This review evaluates the contribution of available ethnobotanical and biochemical data to the biosystematics of *I. gabonensis* and *I. wombolu*. Thus, information on bitter – and sweet – fruited trees was compared, to see how both differ in food and medicinal applications as revealed by ethnobotanical data, on one hand. On the other hand, the two types of ABMTs were compared for the biochemical properties of their kernel, fruit pulp, leaves and bark.

# 2. Methods

## 2.1. Ethnobotanical and Biochemical Data

We performed a literature search in the databases of World Agroforestry Centre, African Journal Online (AJOL), Scopus, PubMed and Web of Science. Only papers dealing with ethnobotany, macronutrients, fatty acids, phytochemicals, or functional properties of *I. gabonensis* and / or *I. wombolu* were analysed.

We recorded all types of uses with organs and types of ABMTs (*I. gabonensis* and / or *I. wombolu*) involved.

A database was built with different provenances (Congolian, upper Guinean and lower Guinean forest zones samples) of *I. gabonensis* and *I. wombolu* trees, for which data on kernel macronutrients content and fatty acids diversity plus concentration existed. Macronutrients included: proteins, lipids, minerals, ash, carbohydrates and moisture. We recorded fifteen identified fatty acids in this database: capric acid (C10:0), lauric acid (C12:0), myristic acid (C14:0), myristolic acid (C14:1), palmitic acid (C16:0), palmitolic acid (C16:1), stearic acid (C18:0), oleic acids (C18:1 and C18:1n9), linoleic acids (C18:2 and C18:2n-6), linolenic acid (C18:3), α-linolenic acid (C18:3n-3), arachidic acid (C20:0), docosanoic acid (C22:0) and erucic acid (C22:1). These data were supplemented with secondary plant metabolites contents.

Kernel oil physicochemical properties were also recorded: total saturated fatty acid, mono and polyunsaturated fatty acids contents, the oil saponification value (SV: mg KOH/g), its iodine value (IV: g $I_2$/100 g), peroxide value (meq $O_2$/kg) and acid value (mg KOH/g). Moreover, kernel oil physicochemical, functional and therapeutic properties were recorded as well as pulp, leaves, bark and root biochemical properties.

## 2.2. Data Analysis

The two taxa were compared based on the percentage of the types of uses for which: (i) the two kinds ABMTs are involved, (ii) either *I. gabonensis* or *I. wombolu* was cited, and (iii) it was difficult to confirm the kind of ABMT that was studied, respectively. Misidentification was concluded based on three factors: material description (fruit pulp taste), geographical location and period of material collection [5,13,18].

Using the package *candisc* [28] of the R statistical software version 3.3. [29], a step-by-step canonical discriminant analysis (CDA) was applied on oil plus fatty acid data, to determine parameters which discriminate the two kinds of *Irvingia* trees. A principal component analysis (PCA) was performed on the discriminant factors in order to promote visibility of the CDA results. Principal component scores from the first two axes of the PCA were plotted in two-dimensional space, in order to promote visibility. Significance of discriminate factors was evaluated, by means of one sample *t* test. Here, we tested hypothesis that the mean single value of each one of the totally independent factors for *I. wombolu*, is taken from *I. gabonensis* population [30]. This test was applied because of the limited sample size for *I. wombolu*. For this same reason, the one sample *t* test was also applied to total saturated, mono-saturated and poly-saturated fatty acids concentration in order to evaluate whether the value for *I. wombolu* could supposedly be considered as sampled from an *I. gabonensis* population.

Third, [31] established that the ratio C14:0 / C12:0 is always higher and lower than 1 for *I. gabonensis* and *I. wombolu*, respectively. In order to test this hypothesis at a broader geographical scale, a binominal logistic regression was applied on this ratio calculated on the fatty acid database, to determine the probability of any kernel sample to be collected from *I. wombolu* while the ratio is higher than 1 [32].

Kernel oil physicochemical, functional and therapeutic properties and pulp, leaves, bark and root biochemical properties were too limited, so that only descriptive analyses were performed.

# 3. Results

## 3.1. Comparative Ethnobotanical Knowledge of *Irvingia* Species

In total, forty different uses engaging various parts of ABMTs were recorded (Table 1). *Irvingia gabonensis* and *I. wombolu* were co-cited in six indigenous uses related to their kernels, cooked in identical food technological procedures [5,20], and their woody materials (trunk, branches and shells) valued in rural buildings, domestic energy, traditional fishing system, cultural activities and as chewing-stick (Table 1). Therefore, 15% of uses were similarity, or either identic between *I. gabonensis* and *I. wombolu*.

The fruit pulp of *I. gabonensis* is sweet and consumed as food and medicament, while that of *I. wombolu* is extremely bitter and was not cited for such utilizations [33]. Sour and inedible fruit pulp taste was also mentioned for *I. wombolu* [34]. These two utilizations were those that clearly differentiated both taxa. Most importantly, there was no specific indigenous use for *I. wombolu* (Table 1).

In 17.5% of the indigenous uses, the kind of ABMT to which the use was assigned could not be clearly identified, because the authors addressed *Irvingia* spp or ABMTs, without indicating whether it was the sweet – or bitter – fruited trees that were investigated. Moreover, the majority (62.5%) of indigenous uses recorded was mentioned for *I. gabonensis*, while it is not clearly demonstrated that: (i) *I. wombolu* possesses no such properties, (ii) and it was not *I. wombolu* which was not investigated, since material identification. Therefore, 80% of ethnobotanical uncertainty exists between *I. gabonensis* and *I. wombolu*. This uncertainty is related to therapeutic properties and is due to the lack of consistent material identification and comparative studies and [4] doubted whether there is any significant biochemical dissimilarity between both kinds of ABMTs.

It was most likely that specific medicinal properties may have been ascribed to the wrong material, leading to wrong biological hypotheses tested in laboratory analyses.

## 3.2. Biochemical Characteristics on Bush Mangoes

### 3.2.1. Kernels Macronutrients and Fatty Acids

Macronutrient and fatty acid data were available for 42 trees: 34 and 8 *I. gabonensis* and *I wombolu* trees, respectively. Their kernel water content overlap: 2.1-12.8 and 6.7-11.9 for *I. gabonensis* and *I. wombolu*, respectively [35,36,37,38]. Crude fat content in the kernels also overlaps: 37.5-76% and 38.4-69.7% for *I. gabonensis* and for *I. wombolu*, respectively, as evidenced by [2,39,40]. Similarly, variation in crude protein content in the kernel is identical for *I. gabonensis* and *I. wombolu*: 6.9-9.2% and 7.4-9.7%, respectively [38.40,41,42]. This similarity in the kernels' crude fat (71.9 and 72.01 for *I. gabonensis* and *I. wombolu*, respectively) and protein content (8.65 and 8.66 for *I. gabonensis* and *I. wombolu*, respectively) is indeed clearly evidenced in a recent comparative study [43]. The overlap between *I. gabonensis* and *I. wombolu* is also observed for ash (1.5–11.1% against 2.5–10.33% for *I. gabonensis* and *I. wombolu*, respectively [37,38,42] and kernel carbohydrate content (7.4-39% and 26-41% for of *I. gabonensis* and *I. wombolu*, respectively: [35,38,44,45]). Therefore, the clear separation between these two *Irvingia* species, based on macronutrients data [46] was not demonstrated.

The kernels of both taxa mainly contain three types of saturated fatty acids: lauric, myristic and palmitic acids [31,47,48]. The CDA showed that all the variation was captured by the first canonical axis (99.5%). The canonical correlations with this axis (Table 2) are significant (df = 8, approximated F-statistics = 78.75, p-value = 0.002). The most discriminating parameters of the two species were C10:0, C12:0, C14:0 and C16:0, *I. gabonensis* having lower values of C10:0 and C12, but higher values of C14:0 and C16:0 while the opposite trend was observed for *I. wombolu*).

**Table 1. Traditional uses of *I. gabonensis* and *I. wombolu***

| Type of organ on ABMTs | State of the part and indication of the type of ABMTs | Type of ABMTs studied | Type of use | References |
|---|---|---|---|---|
| Fruits | Ripe sweet mesocarp | *Ig* | Fh: consumed as fresh fruit | [5,20,33] |
| | Mature unripe mesocarp | *Ig* | T: Consumed fresh to ease digestion of nitrogenous foods (mainly beans) | [20] |
| Leaf / fruit | Mature leaves or fruits | *Ig (Iw)* | Ch: Accelerate other fruits uniform ripening | [20] |
| Leaves | Decoction of fresh leaves | *Ig (Iw)* | T: Malaria and icterus treatment | [20] |
| | | *Ig (Iw)* | T: Reinforce bladder excitation during the night | [20] |
| | | *Ig (Iw)* | T: Analgesic effects | [20] |
| | Fresh and mature leaves | *Ig (Iw)* | Fa: Forage for animals | [33] |
| | Fresh leaves | *Ig (Iw)* | T: Specific child diseases | [20] |
| Endocarp | Mature, dried and ground | *Ig (Iw)* | T: Consumed the endocarp-based sauce with *Chromolaena odorata* (Asteraceae) to treat ulcers | [20] |
| | Mature, dried and ground endocarp-based sauce | *Ig--Iw* | T: Body pressure regulation | [33] |
| | Mature, dried and ground | *Ig+Iw* | Fh: Used as main condiment to thicken and flavour sauce | [33] |
| | Oil extracted from the endocarp | *Ig (Iw)* | T: Skin disease treatment | [20] |
| Seed shell | Dried shells of large seeds | *Ig+Iw* | Sc: To build traditional geomancy instrument | [20] |
| | Dried shells | *Ig+Iw* | E: Domestic energy | [20] |
| Wood | Fresh or dried | *Ig+Iw* | Tc: Rural and urban construction | [33,112] |
| | Dead or dried | *Ig+Iw* | E: firewood | [20,33,112] |
| | Fresh twigs | *Ig (Iw)* | T: Chewing-stick | [20,33] |
| | Branches / juvenile trunk | *Ig (Iw)* | Sc: Fetish service | [20] |
| | Mature and dried wood | *Ig (Iw)* | Sc: Material for fetish drum | [20] |
| | Mature and dried wood | *Ig (Iw)* | Sc: Incarnation of died twins | [20] |
| Bark | Dried and ground bark mixed with palm oil | *Ig (Iw)* | T: Diarrheal treatment | [33] |
| | | *Ig--Iw* | T: Shorten their breast-feeding period | [33] |
| | Unspecified | *Ig (Iw)* | T: Colic | [86] |
| | Bark decoction | *Ig (Iw)* | T: Analgesic properties: body pain relief | [86] |
| | Bark decoction | *Ig (Iw)* | T: Haemorrhoid | [20] |
| | Unspecified | *Ig--Iw* | T: Dysentery | [86] |
| | Fresh | *Ig--Iw* | T: Palm wine tasting | [33] |
| | Fresh or dried | *Ig (Iw)* | T: Female gynaecology | [20] |
| | Bark decoction | *Ig (Iw)* | T: Wounds treatment | [20] |
| | Bark decoction | *Ig (Iw)* | T: Human body temperature balancing | [20] |
| | Bark decoction | *Ig (Iw)* | T: Reinforcing babies' fontanel | [20] |
| | Bark decoction | *Ig (Iw)* | T: Mycosis treatment | [20] |
| | Bark decoction | *Ig (Iw)* | T: Dyspnoea treatment | [20] |
| | Dried and ground bark mixed with palm oil | *Ig--Iw* | T: Hernias | [33] |
| | Dried and ground bark mixed with palm oil | *Ig--Iw* | T: Yellow fever | [33] |
| | Dried and ground bark mixed with palm oil | *Ig--Iw* | T: Anti-poison | [33] |
| Root | Fresh root decoction | *Ig (Iw)* | T: Impotence treatment | [20] |
| Unspecified | Unspecified | *Ig (Iw)* | T: Geophagy treatment | [33] |
| Unspecified | Unspecified | *Ig (Iw)* | T: Oedema treatment | [113] |
| Entire juvenile | of 1.5 - 2 m high | *Ig+Iw* | Tc: Material to construct traditional in water fishing system | [20] |

*Ig*: *I. gabonensis*; Iw: *I. wombolu*; *Ig (Iw):* Only *Ig* was investigated and evidence that *Iw* is not used for this property is not demonstrated; *Ig+Iw*: both taxa ar154077.
QHFCGNB M;e known for these properties; *Ig--Iw*: it is not clear whether it is *Ig* or *Iw* that is known for these properties. Type of use: Fh: food for human; Fa: forage; T: therapeutic use; Sc: sociocultural use; E: use as domestic Energy; Tc: technological use; Ch: biochemical use.

**Table 2. Correlation of each parameter with the canonical axis**

| Fatty acid data | Correlation with the canonical axis |
|---|---|
| Oil yield | 0.48 |
| C10:0 | 0.95 |
| C12:0 | 0.96 |
| C14:0 | -0.89 |
| C16:0 | -0.85 |
| C18:0 | -0.55 |
| C18:1 | -0.10 |
| C18_2 | -0.53 |

**Table 3. Two PCA axis (percent of variance explained in brackets) with loadings for each of the four fatty acids**

| Fatty acid data | PCA 1 (78.68%) | PCA 2 (12.22%) |
|---|---|---|
| C10:0 | 0.86 | 0.42 |
| C12:0 | 0.94 | -0.05 |
| C14:0 | -0.92 | -0.14 |
| C16:0 | -0.82 | 0.54 |

The PCA performed on these four discriminating fatty acids data indicated that the first two axes together account for 90.9% of the total variation (Table 3). The first axis (78.68%) was positively correlated with capric and lauric acids and negatively correlated with myristic and palmitic acids, while the second (12.22%) explains no consistent variation, compared to the first axis. Thus, two main groups of trees can be distinguished (Figure 1): (i) the first group (G1) most *I. wombolu* trees plus the two Nigeria *I. gabonensis* samples, with higher concentration of capric and lauric acids in their fruit kernels and lower concentrations of myristic and palmitic acids, and (ii) the second group (G2) made of most *I. gabonensis* kernels plus two *I. wombolu* samples, with opposite trends, as refer to G1. Indeed, Leakey [49] indicated that concentration of those three major fatty acids (lauric, myristic and palmitic acids) is only provenance – dependent. Here, the PCA shows no such pattern. The groups are much more random than provenance-dependant.

The *t* test indicated that total oil content ($t$ = 0.98; P = 0.33) and stearic acid concentration ($t$ = 1; P = 0.22) in the kernels did not distinguish between *I. gabonensis* and *I. wombolu*. However, capric acid (C10:0; $t$ = -14.36, P<0.001), lauric acid (C12:0; $t$ = -11.28, P<0.001), myristic acid (C14:0; $t$ = 3.19, P=0.004) and palmitic acid (C16:0; $t$ = 8.36, P<0.001) significantly distinguished *I. gabonensis* from *I. wombolu*. Capric and lauric acids were significantly more concentrated in *I. wombolu* kernels, which contains less myristic and palmitic acids (Figure 1). This relationship between Capric, lauric myristic and palmitic acids is consistent throughout the Upper and Lower Guinean and Congolian forest regions [50,51].

Concentrations of saturated fatty acids in the kernel are similar for both taxa: 86.6–98.7% and 95.6–98%, respectively. These high concentrations of saturated fatty acids make of bad quality for cooking [52].

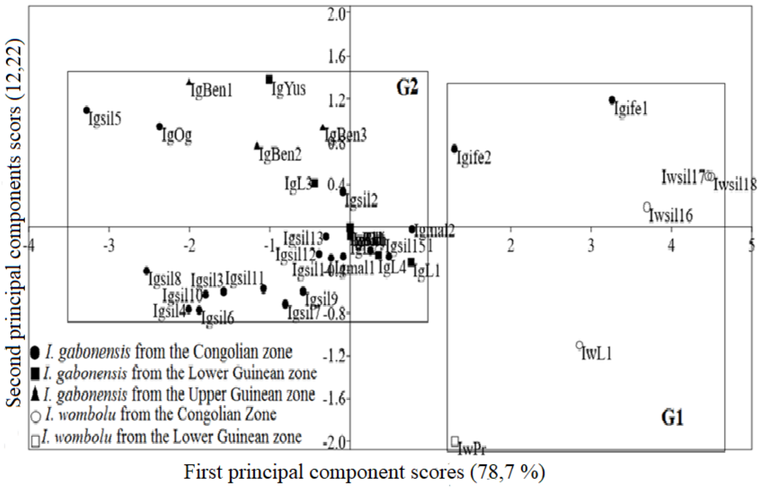


**Figure 1.** Result of the principal component analysis: identification of groups of ABMTs based on the most discriminative fatty acids in the kernels

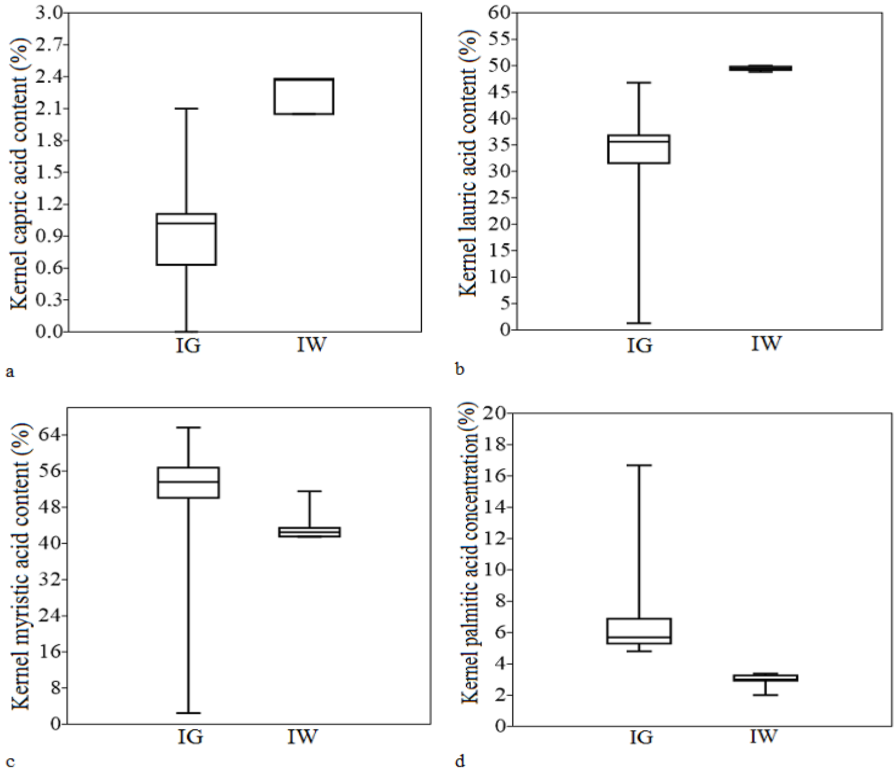


**Figure 2.** Results of *t* test: differences between *I. gabonensis* and *I. wombolu* regarding the significant fatty acids

**Table 4. R ratio calculated based on Silou et al. (2011) to consistently discriminate *I. gabonensis and I. wombolu***

| References | R values | Material supposed to be investigated | *IG (R>1)* | *IW (R<1)* |
|---|---|---|---|---|
| Dahouenon-Awissi et al. (2012) | 1.41-1.78 | *I. gabonensis* | X | |
| Zoué et al. (2013) | 0.52 | *I. gabonensis* | | X |
| Nangue et al. (2011) | 1.2 | *I. gabonensis* | X | |
| Matos et al. (2009) | 1.29-1.47 | *I. gabonensis* | X | |
| Loumouamou et al. (2012) | 0.86 | *I. wombolu* | | X |
| Silou et al. (2011) | 1.2 -2.8 | *I. gabonensis* | X | |
| | 0.8 -0.9 | *I. wombolu* | | X |

Legend: IG = *I. gabonensis*; IW = *I. wombolu;* the symbol X indicates the right classification of the studied material.

The logistic regression performed on R=C14:0 / C12:0 confirms that this ratio is linked to differentiation between *I. gabonensis* from *I. wombolu* (Type 3 effect: Chi²=16.99, *P*<=0.005). However, the power of this ratio to consistently separate both taxa is weak (Wald Stat = $56*10^{-5}$, *P*=0.99). Reclassifying studied materials (the R ratio is lower than 1 for some *I. gabonensis* kernel samples, from the Upper and Lower Guinean Forest zones [48,53,54], while it is higher than one for *I. wombolu* in the Congolian zone [50], investigated by [31]. Most importantly, in the same ecological conditions of Enugu State in West Nigeria: R > 1 and R < 1 were simultaneously found within *I. gabonensis*, depending on the village [40] in the same ecological zone. Therefore, the variation of index is not linked to differences in the bush mango pulp taste, nor to any geographical distinction of provenances. This may better be considered as a simple tree-to-tree variation within ABMTs [2].

Significant differences in secondary plant metabolites content, such as phytosterols may exist between the kernel oils of *I. gabonensis* and *I. wombolu* [31]. Thus, beta sitosterol plus stigmasterol are abundant in the unsaponifiable fraction of *I. gabonensis*' kernel oil, while it is the abundance of isobutyl phthalate plus stigmasta-3,5-dien-7-one that characterizes *I. wombolu*. These differences in secondary metabolites synthesis in oils are genetically-governed, and determine ecological fitness, growth system and survival of plant [55]. However, replication is needed to eliminate ecological and domestication effects for consistent conclusion.

The kernels of all provenances of *I. gabonensis* display linoleic acid contents close to 1%, while that of *I. wombolu* show significantly lower values of 0-0.4% [31,50]. The difference with regard to the content of unsaturated fatty acids implies differences regarding ecological adaptation, and in particular growth under lower temperatures [56]. Unfortunately, results in West African samples contradict this conclusion. Therefore, the lack of differences in unsaturated fatty acid concentration explains the vast occurrence of *I. gabonensis* and *I. wombolu*.

### 3.2.2. Kernel Oil Physicochemical Properties

Important variation exists, regarding the physicochemical properties of the kernel oil (Table 5.1), for both taxa. Acid value overlaps and ranges between 2.6-25.18 MgKOH/g for *I. gabonen*sis and *I. wombolu* [57,58,59]. Similar variation was observed for peroxide and saponification values, refractive index, specific gravity, melting and smoke points [47,48,60]. The peroxide value in the kernels of *I. gabonensis* and *I. wombolu* overlap and range between 0.81 to 3.3 mg KOH/g, with no obvious difference between the two taxa. A similar situation is observed for the smoke point of 78–215 for both taxa. The refractive index and the specific gravity at 40°C range between 1.4 to 1.5 and 0.8 to 0.9, respectively for both taxa. In contrast significant differences in variation of iodine value were found: 2.54–3.5 and 4.2–32.43 for *I. wombolu* and *I. gabonensis*, respectively.

**Table 5.1. *Irvingia* species kernel oil properties**

| Species | References | Acid value Mg KOH/g | Iodine value | Peroxide value (meq $O_2$/kg) | Saponification value (mg KOH/g) | FFA (% lauric acid) | Refractive index | Specific gravity | Melting point | Smoke point |
|---|---|---|---|---|---|---|---|---|---|---|
| *IG* | [59] | 4.67 | 32.43 $I_2$/100g | 3.3 | 233.7 | - | 1.4 (40°C) | 0.8 (40°C) | | |
| | [58] | 12.94-25.18 (not precise) | 4.3-4.9 Not precise | 1.2-1.9 | 196.3-277.7 | 4.6-9 | - | - | - | - |
| | [51] | - | 7.3 Not precise | 1.2-7.0 | 204-225 | 0.9-2.3 | - | - | - | - |
| | [53] | 22.36 | 4.17/100g fat | 2.0 | 182.3 | - | 1.5 | 0.9 | 13°C | 78 |
| | [60] | - | 4.2 (not precise) | 2.0 | 219 | - | 1.4 (40°C) | 0.8 (40°C) | 39.6 | 213 |
| *IW* | [60] | - | 3.5 (not precise) | 1.9 | 212.7 | - | 1.4 (40°C) | 0.9 (40°C) | 39.9 | 215.3 |

IG = I. gabonensis; IW = I. wombolu.

**Table 5.2. Phytochemicals in *Irvingia* species pulp**

| | Species | References | Alkaloids | Flavonoids | Saponins | Tannins | Cardiac glycosides | Phlobatannin | Anthocyanin | Quinone |
|---|---|---|---|---|---|---|---|---|---|---|
| Aqueous extract | *IG* | [78] | + | ++ | + | + | + | - | - | - |
| | *IW* | [78] | ++ | ++ | +++ | ++ | + | - | - | - |
| Hydro-ethanolic extract | *IW* | [77] | + | - | - | + | + | + | + | + |
| | | | + | - | - | + | + | + | + | - |

+= low intensity, ++= moderate intensity? +++= high intensity*: IG = I. gabonensis; IW = I. wombolu.*

### 3.2.3. Kernel Mineral and Vitamin Content

Few studies addressed the mineral composition of only *I. gabonensis* kernels and there are not comparative data with *I. wombolu*.

The comparative data on of the in vitro-produced callus of *I. gabonensis* and *I. wombolu* demonstrated that callus was formed after three weeks for both taxa. Moreover, proteins, carbohydrates, lipids, moisture, fibres, ash, iron, zinc, bore, cupper, potassium, calcium, manganese, phosphorus and nitrogen contents in the callus present no significant difference between *I. gabonensis* and *I. wombolu* [61,62].

### 3.2.4. Kernel Functional Properties

Attempts to bind tablets using *I. gabonensis* defatted kernels demonstrated high brittleness plus friability values, with low disintegration and dissolution of the tablets. In contrast, gums from kernels of *I. wombolu* were successfully used to bind tramadol with short disintegration time [63]. Moreover, significantly higher thickening capacity was found for the defatted kernel of *I. wombolu*: 91% against 64% for *I. gabonensis* [43], while evaluation of viscosity and drawability of the defatted kernels from *I. gabonensis*, contrastingly shows on the one hand, that the relationship between these two characters is weak, due to important tree-to-tree variation (3- to 5-fold) within this taxon [2]. On the other hand, this study also demonstrated that protein and fat contents did not have any effect on the thickening properties of *I. gabonensis* kernels. Unfortunately, this study did not include *I. wombolu* to allow direct comparison.

### 3.2.5. Therapeutic Properties of *Irvingia* Kernels

The consumption of kernel-based diets by diabetics (unknown doses and frequencies) may decrease blood glucose and increase activity of $Na^+$, $K^+$-ATPase, $Mg^{2+}$-ATPase and $Ca^{2+}$-ATPase [64].

Precisely, 4g/day of *I. gabonensis* kernel during 4 weeks in type II diabetics and streptozotocin-induced diabetic treatment may significantly decrease plasma lipids, blood glucose, total cholesterol, triglycerides, HDl cholesterol, LVL + VLDL cholesterol and lower erythrocytes ATPases level with reduction of body weight and stabilization of activities of glycolytic enzymes pyruvate kinase, lactate dehydrogenase and glucose-6-phosphatase [64,65,66,67]. Moreover, 3.15g of *I. gabonensis* kernel extracts administered three times a day during 4 weeks significantly decreased body weight and systolic blood pressure with many other positive specific effects [68].

A standardized extract with 7% albumin from *I. gabonensis* kernels and extract a *Cissus quadrangularis* with 2.5% ketosteroids (Vitaceae) was applied to successfully control obesity [69,70]. Here, the type of kernel (entire or defatted), type of extract (organic or aqueous) and doses remain unknown. It was also demonstrated that the kernel of *I. gabonensis* had anti-hypertensive, anti-lipidemic, anti-inflammatory, anti-nociceptive nephro-protective and hepatoprotective properties [71].

However, evidences of negative effects of the same diets exist: increased blood glucose and severe troubles in reproduction system: arrested spermatogenesis, degenerated germinal epithelium, absent interstitial cells, hardened basal cells and empty seminiferous tubules [71]. Moreover, consumption of kernel extracts contrastingly increases of HDL-cholesterol [64,65]. Unfortunately, there is no such data on *I. wombolu.*

### 3.2.6. Biochemistry of *Irvingia* Pulp

The fruit pulp of *I. gabonensis* contains 0.8g/100g, 0.4g/100g, 1.09g/100g and 1.06g/100g of ash, crude fiber, crude proteins, and crude fat, respectively. It is also rich in calcium (262.3 mg/100g), total reduced sugar (459.7 mg/100ml), and ascorbic acid (67 mg/100ml) [72,73]. Low concentration carotenoids (2.25mg/100g) was reported in the ripened fruit [74]. These surprisingly low concentrations of carotenoids call for thorough re-evaluation, because carotenoids determine fruit pulp colour [75] which varies from yellowish to pink for *I. gabonensis* [76]. Again, *Irvingia wombolu* has not been evaluated for these characters.

Based on a screening, several phytochemical compounds were identified in the fruit pulp of *I. gabonensis* and *I. wombolu* [77,78] (Table 5.2). In general, *I. wombolu* has higher alkaloids, saponins and tannins' concentration according to [78]. However, lower concentrations of these phytochemical compounds or their total absence were contrastingly observed in the pulp of *I. wombolu* [77]. The pulp of *I. wombolu* contained 97.77±17.22 µg/g of total polyphenol compounds [79] with phlobatannin, anthocyanin and quinones, which were specific to this taxon [77]. However, [77] did not detect phlobatannins and quinones in the pulp *I. wombolu*, and [78] missed anthocyanins that of *I. gabonensis*.

Here, the diversity and concentration of biochemical compounds of the fruit pulp present conflicting results and we could not conclude, any similarity / dissimilarity between *I. gabonensis I. wombolu*.

### 3.2.7. Biochemistry of *Irvingia* Leaves

Concentrations of tannins, saponins, alkaloids, phenols, phlobatannins and anthraquinones were revealed through a screening of leaves of *I. gabonensis* [80,81]. These studies also demonstrated that extracts of leaves of *I. gabonensis* significantly decreases gastrointestinal motility and increases gastric mucous secretion. Moreover, the extract inhibits gastric ulceration, decreases gastric acidity and shows significant anti-diarrheic properties [80,82]. There is no research on the leaves from *I. wombolu*.

### 3.2.8. Biochemistry of *Irvingia* Trees' Bark

Terpenoids (3-friedelanone, betulinic, oleanicand hardwickiic acids) and ellagic acid derivatives (methyl gallate and 3-β- acetoxyursolic acids) were isolated from bark extracts of *I. gabonensis* [83,84]. Alkaloids, tannins, phlobatannins, saponins, flavonoids, anthraquinones, phenols and cardiac glycosides were abundantly found in the bark of *I. gabonensis* [85]. These are important antioxidants, valuable in the treatment of cancerous tumours. [86] demonstrated that the bark of *I. gabonensis* possesses analgesic properties. Antibacterial and antifungal activities of the bark of this taxon are used in traditional medicine as was successfully demonstrated by [83]. However, contrasting results were reported by [81] who observed no antimicrobial effects. [84] presented in-vivo hepatoprotective and antioxidant activities of the bark extracts from *I. gabonensis* on the liver. Other studies demonstrated that significant loss of body weight, reduced subcutaneous fat and blood glucose plus HDL-cholesterol, increased liver enzymes activities were also noticed after the administration of the bark extracts [87,88] Here again, we question these data since [84] demonstrated hepatic degeneration. This calls for standardization (types of extracts, doses and frequency of consumption) to demonstrate the real effect of bioactive molecules against microorganisms and the limits of their use. A recent comparative analysis demonstrates significant differences between the two taxa, regarding phytochemical in the bark. However, this study is geographically limited and these differences are note easily perceptible. We postulate that these differences are not consistent, is in the case of macronutrients.

#### 3.2.9. Properties of *Irvingia* Roots

In West and Central Africa, the roots of *I. gabonensis* are traditionally used for a variety of purposes [13,33]. But there is a lack of laboratory works to reveal the phytochemical substances that are responsible for these properties. High concentrations of tannins, saponins, alkaloids and anthraquinones are found in the root of *I. gabonensis* and it was demonstrated that 5mg/ml ethyl acetate extracts of it was highly active against various bacteria and fungus species [81]. No data is available for roots of *I. wombolu*.

## 4. Discussion

### 4.1. Material Identification and Research Methods

This review shows a great diversity of ethnobotanical knowledge and a wide range of phytochemical properties of ABMTs. Thus, the bark, fruits, leaves, and roots of ABMTs contain substances with multiple anti-infective potential to control some complex multiple pathogens-induced and difficult to treat diseases [89]. However, three major concerns emerge from ethnobotanical and phytochemical data available on ABMTs.

First, a clear distinction between *I. gabonensis* and *I. wombolu* with comparative study are not often undertaken, because the two taxa are morphologically similar [40,67,90,91,92,93,94] and misidentification is suspected in many studies. For example, a sour taste appreciated in African diets [95], was mentioned for the fruit pulp of *I. wombolu* [34,96] and even used to distinguish *I. wombolu* from the sweet-tasting *I. gabonensis* [97], while such a taste has never been perceived by consumers. Thus, botanical misidentification is a serious issue to be addressed in future research, since knowledge of the correct botanical and taxonomic position of plants is essential for a proper understanding of their ethnobotany, medical use, and conservation [98]. The pulp of bush mangoes always tastes either sweet or bitter. The unclear material identification takes roots in wrong ethnobotanical data collection strategies, because the endogenous biosystematics [27] that leads to folk classification, on which hinges the better capture the existing variation.

Second, serious contradictions emerge from the biological data: increase and decrease of blood glucose, positive and negative impacts on human reproductive system, specificity of some phytochemicals which are totally missed in either *I. gabonensis* or in *I. wombolu* [77,78], absence of correlation among differences in iodine values, saturated fatty acids and secondary metabolites contents, etc. This absence of correlation supports the vast co-occurrence of *I. gabonensis* and *I. wombolu* in many ecological regions. Thus, [99] to simply reject the conclusions of [68,69,70]. We suspected three primary causes that may lead to such a situation: (i) unreliable laboratory methods, (ii) absence of ecological variability in materials analysed, and (iii) completely random tree-to-tree variation within ABMTs. This variation of biochemical data can also be caused by different processing methods [51,100,101,102], nature of kernels (defatted or entire), and type of kernels used (from bitter or sweet fruits). Therefore, the contradictions are method-dependant and the ranges observed for all macronutrients and phytochemicals in this review are wider than differences claimed by [99] to postulate any taxonomical significance between *I. gabonensis* and *I. wombolu*. Here again, the failure of ethnobotanical techniques to formulate correct biological hypotheses-based [103] becomes danger in which all the causes of the contradictory biological data are rooted. [27] indicates the importance of traditional biological knowledge to classify and geographically localize plant species. Consequently, ethnobotanical observations are also a taxonomic tool that provides background information for morphological, ecological, genetics and biochemical investigations.

Third, phytochemical analyses are often conducted on kernels acquired on local markets [38,48,104]. It is known that kernels from both taxa are often mixed for commercialization [105] and no standard is available to accurately distinguish *I. gabonensis* from *I. wombolu*, based on the kernels alone. [79] bought pulp of *I. wombolu* in local markets for phytochemical evaluation. There is no indication of extremely bitter fruits marketing, because kernels are always extracted at the collection place or at home. Thus, it is more likely that [79] have studied *I. gabonensis*. Engaging genetically conflicting and morphologically similar materials, acquired on local markets, into biochemical analyses raises a third major concern, which is their nature (fresh or dried or pre-processed into flour or cake) in varying conservation conditions, affecting their biochemical composition [106]. Therefore, the side effects of the kernel-based sauce consumption [99] and the conflicting biochemical data may have multiple causes that need to be clarified.

### 4.2. Macronutrients and Phytochemical-based Difference between *I. gabonensis* and *I. wombolu*

There is no clear distinction between *I. gabonensis* and *I. wombolu* based on their macronutrient's composition. Thus, fruit pulp edibility might be an organoleptic variation that makes *I. gabonensis* of higher economic value and explain the vast data available on this taxon, and its priority status in traditional domestication and cultivation systems [107].

The diversity, and concentration of fatty acids do not consistently separate *I. gabonensis* and *I. wombolu*. Likewise, the ration $C_{14}$ / $C_{12}$ fatty acids does not discriminate *I. gabonensis* from *I. wombolu* and other lipophilic components profiles need to be thoroughly reassessed. In addition to low botanical identity and vast co-occurrence of *I. gabonensis* and *I. wombolu* similar macronutrient and fatty acid characteristics evidence no taxonomic difference between these two taxa.

There is no geographical pattern within fatty acid data, demonstrating that differences in their biosynthesis is not environment mediated. Therefore, the lack of significant fatty acid difference between *I. gabonensis* and *I. wombolu* remains either laboratory technique-dependent or synonym taxonomic similarity. Differences of lauric, capric, palmitic and myristic acids concentration should be reassessed on a broader geographical scale for any consistent taxonomic conclusion.

Here, limited phytochemicals data (alkaloids, saponins and tannins) are conflicting, and lack of consistency, while they help clarify taxonomical decision in plant species [108].

Total absence of sweetness plus hight and low bitte plus Fruit pulp and bitterness are specific to *I. gabonensis* and *I. wombolu*, respectively, regardless the ecological conditions of their growth. This character represents the main difference between the two taxa (Harris 1996), which may be ecologically different. Fruit taste is a genetically coded character [109,110] and could be used to define subspecies / varieties / cultivars, but the environmental impact on its expression could be revealed significant [111].

## 5. Conclusion

This review shows the extensive ethnobotanical and phytochemical data available for *I. gabonensis* and *I. wombolu*. It also demonstrates, the difficulty to correlate ethnobotanical data and macronutrient plus fatty acids and phytochemical properties to fruit taste, in order conclude any taxonomic distinction between *I. gabonensis* and *I. wombolu*. Moreover, functional and therapeutic properties of the kernel oils, which are plant biochemical expressions, do not discriminate both taxa. The random macronutrient and biochemical characteristics within ABMTs may imply genetic similarity between *I. gabonensis* and *I. wombolu*.

The overlap of phytochemical properties between closely related species is not unusual and given the extent of tree-to-tree variation within *Irvingia gabonensis*, it is possible that variation in taste, biochemistry and morphology may not be taxonomically significant. However, this should not obscure a range-wide DNA analysis of the tree-to-tree variations within ABMTs, regarding pulp taste and many other morphological and phytochemical traits.

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## References

[1] Tsobeng, A., Muchugi, A., Alercia, A., Chege, J., Degrande, A., Hendre, P., Kangethe, S., Jamnadass, R., Cerutti, A.L., Cognetti, de Martiis, S. and Lopez, F., "Key descriptors for Irvingia spp. (bush mango)." *World Agroforestry*, Nairobi, Kenya and the *Food and Agriculture Organization* of the United Nations, Rome, Italy 2021.

[2] Leakey, R.R.B., Greenwell, P., Hall, M.N., Atangana, A.R., Usoro, C., Anegbeh, P.O., Fondoun, J-M. and Tchoundjeu, Z., "Domestication of *Irvingia gabonensis*: 4. Tree-to-tree variation in food-thickening properties and in fat and protein contents of dika nut." *Food chemistry*, 90:365-378. May 2005.

[3] Oyen, L.P.A., "*Irvingia wombolu* Vermoesen." *PROTA 14:* Wageningen, the Netherlands. November 2007.

[4] Tchoundjeu, Z. and Atangana, A.R. *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. In: van der Vossen, H.A.M. and Mkamilo, G., *PROTA 14:* Wageningen. Netherlands. November 2007.

[5] Harris, D.J., "A revision of the Irvingiaceae in Africa." *Bulletin du Jardin Botanique National de Belgique*, 65(1-2):143-196. May 1996.

[6] Jamnadass, R.H., Dawson, I.K., Franzel, S. Leakey, R.R.B., Mithöfer, D., Akinnifesi, F.K. and Tchoundjeu, Z., "Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review." *International Forestry Review*, 13(3):338-354. February 2011.

[7] Adeseko, C.J., Sanni, D.M. and Lawal, O.T., "Biochemical studies of enzyme-induced browning of African bush mango (*Irvingia gabonensis*) fruit pulp." *Preparative Biochemistry and Biotechnology*, 52(7):835-844. November 2021.

[8] Zhao, Y., Yi, Z., Warren, A. and Song, W.B., "Species delimitation for the molecular taxonomy and ecology of the widely distributed microbial eukaryote genus Euplotes (*Alveolata ciliophora*)." *Proceedings of the Royal Society B: Biological Sciences*, 285: 1-9. February 2018.

[9] Hausdorf, B., "Progress toward a general species concept." *Evolution*, 924-931. April 2011.

[10] Barker, G.C., Larson, T., Graham, I.A., Lynn, J.R. and King, G.J., "Novel Insights into Seed Fatty Acid Synthesis and Modification Pathways from Genetic Diversity and Quantitative Trait Loci Analysis of the *Brassica* C Genome." *Plant Physiology*, 144:1827-1842. August 2007.

[11] De Queiroz, K. "Species concepts and species delimitation." *Systematics Biology*, 56(6): 879-886. December 2007.

[12] Lowe, A.J.A., Gillies, C.M., Wilson, J. and Dawson, I.K., "Conservation genetics of bush mango from Central / West Africa: Implications from random amplified polymorphic DNA analysis." *Molecular Ecology* 9:831-841. January 2000.

[13] Vihotogbé, R., Berg van Den, R.G., Sinsin, B. Frans, F. and Sosef, M.S.M. Does phenology distinguish bitter and sweet African bush mango trees (*Irvingia* spp., Irvingiaceae)? *Trees - Structure and Function*, 28: 1777-1791. August 2014.

[14] Solbrig, O.T. and Solbrig, D.J. "Introduction to population Biology and Evolution". *Addison-Wesley Publishing*, January 1979.

[15] Gepts, P., "Crop Domestication as a Long-term Selection Experiment." *Plant Breeding Review*, 24(2):1-23. November 2010.

[16] Okafor, J.C., "Varietal delimitation in *Irvingia gabonensis* (Irvingiaceae)." *Bulletin du Jardin Botanique de Belgique*, 45: 211-221. February 1975.

[17] Asaah, E.K., Tchoundjeu, Z. and Atangana, A.R., "Cultivation and conservation status of Irvingia wombolu in humid lowland forest of Cameroon." *Food Agriculture and Environment*, 1(3-4): 251-256. January 2003.

[18] Ude, G.N., Dimkpa, C.O., Anegbeh, P.O., Shaibu, A.A., Tenkouano, A., Pillay, M. and Tchoundjeu, Z., "Analysis of genetic diversity in accessions of *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill." *African Journal of Biotechnology*, 5(3): 219-223. February 2006.

[19] Golding, J.S. and Timberlake, J. How taxonomists can bridge the gap between taxonomy and conservation science. Conservation Biology 17(4):1177-1178. October, 2003.

[20] Vihotogbé, R., Glèlè Kakaï, R., van Andel, T., Berg van Den, R.G., Sinsin, B. and Sosef, M.S.M. "Impacts of the diversity of traditional uses and potential economic value on food tree species conservation status: case study of African bush mango trees (Irvingiaceae) in the Dahomey Gap (West Africa)". *Plant Ecology and Evolution* 147(1):109.125. March, 2014.

[21] George, A.L. and Mayden, R.L., "Species concept and the endangered species act: how a valid biological definition of species enhances the legal protection of biodiversity." *Natural Resources Journal,* 45: 369-407. March 2000.

[22] de Queiroz, K., "Ernst Mayr and the modern concept of species. Arthur M. Sackler Colloquium of the National Academy of Sciences, ''Systematics and the Origin of Species" *The National Academy of Sciences of the USA.* April 2005.

[23] Badalamenti, N. Sottile, F. and Bruno, M., "Ethnobotany, phytochemistry, biological, and nutritional properties of genus Crepis - a review." Plants, 11,519, February 2022.

[24] Collisson, A., Yang, L., Dykes, L., Murray, S. and Awika, J., "Influence of genetic background on anthocyanin and copigment composition and behavior during thermoalkaline processing of maize." *Journal of Agriculture and Food Chemistry*, 03(22): 5528-5538. May 2015.

[25] Pacheco-Hernández, Y., Villa-Ruano, N., Lozoya-Gloria, E., Barrales-Cortés, C.A., Jiménez-Montejo, F.E., Cruz-López, M.d.C. "Influence of Environmental Factors on the Genetic and Chemical Diversity of Brickellia veronicifolia Populations Growing in Fragmented Shrublands from Mexico." Plants, 10, 325. February 2021.

[26] Heinrichs, J., Groth, H., Lindner, M., Feldberg, K. and Rycroft, D.S., "Molecular, morphological, and phytochemical evidence for a broad species concept of *Plagiochila bifaria* (Hepaticae)." *Bryologist.* 107(1), 28-40. Spring 2004.

[27] de Haan, S., Bonierbale, M., Ghislain, M., Núñez, J. and Trujillo, G., "Indigenous biosystematics of Andean potatoes: folk taxonomy, descriptors, and nomenclature." *Acta Horticulturae,* 745, 89-134. June, 2007.

[28] R-Core-Team., R. "A language and environment for statistical computing." *R Foundation for Statistical Computing* Vienna 2016.

[29] Friendly, M., Fox, J., Candisc: "Visualizing Generalized Canonical Discriminant and Canonical Correlation Analysis (Version R package version 0.7-2)." *R Foundation for Statistical Computing* Vienna 2016.

[30] Crawford, J.R., Garthwaite, P.H. and Howell, D.C., "On comparing a single case with a control sample: an alternative perspective." *Neuropsychologia*, 2690-2695. November 2009.

[31] Silou, T., Loumouamou, B.W., Nsikabaka, S., Kinnkela, T., Nzikou, M., Chalard, P. and Figueredo, G., "Contribution to the varietal delimitation of *Irvingia gabonensis* and *Irvingia wombulu* chemical composition variability of fats extracted from kernels." *Journal of Food Technology*. 9(1):36-42. January 2011.

[32] Hyeoun-Ae, P., "An introduction to logistic regression: from basic concepts to interpretation with particular attention to nursing domain." *Journal of Korean Academy of Nursing*, 43(2):154-164. May 2013.

[33] Aigne, L., Brown, N., "Bush Mango (*Irvingia gabonensis* and *I. wombolu*). In: Clark LE, Sunderland TCH (eds) Key non-timber forest products of central Africa: state of the knowledge." *SD Publication Series, USAID, USA*, pp 15-35. May 2004.

[34] Edagbo, D.E., Ighere, D.A. and Michael, C., "Influence of the Mistletoe (*Tapinanthus bangwensis*) on the Conservation Status and Productivity of *Irvingia gabonensis* in Moor Plantation Area of Ibadan, Nigeria." *Greener Journal of Agricultural Sciences.* 3(10):743-747. October 2013.

[35] Ejiofor, M.A.N., Onwubuke, S.N. and Okafor, J.C., "Developing improved methods of processing and utilization of kernels of *Irvingia gabonensis* (var. *gabonensis* and var. *excelsa*)." *International Tree Crops J.* 4(4), 283-290. April 1987.

[36] Ibekwe, A.C., "Comparative study of the food and nutrient value of three provenances of *Irvingia gabonensis* and *Irvingia wombolu*." Bachelor thesis, *Federal University of Agriculture, Abeokuta*. February 2003.

[37] Aremu, M.O., Opaluwa, O.D., Bamidele, T.O., Nweze, C.C., Ohale, I.M. and Ocheg, M.O. "Comparative evaluation of nutritive value of Okro (Abelmoschusesculentus) and bush mango (*Irvingia gabonensis*) fruits grown in Nasarawa State, Nigeria." *Food Science and Quality Management*, 27:64-70. August 2014.

[38] Bamidele, O.P., Ojedokun, O.S. and Fasogbon, B.M., "Physicochemical properties of instant Ogbono (*Irvingia gabonensis*) mix powder". *Food Science and Nutrition,* 3(4): 313-318. March 2015.

[39] Ndjouenkou, R., Akingbala, J.O. and Oguntimein, G.B., "Emulsifying properties of three African food hydrocolloids: okra (*Hibiscus esculentus*), dika nut (*Irvingia gabonensis*), and khan (Belschmiedia sp.)." *Plant Foods for Human Nutrition*, 51:245-255. October 1997.

[40] Ifeduba, E.E., Awachie, M.N., Sabir, J.S.M. and Akoh, C.C., "Fatty acid composition of *Irvingia gabonensis* and *Treculia africana* seed lipids and phospholipids." *Journal of the American Oil Chemists' Society,* 90:517-528. April 2013.

[41] Sahoré, D.A., Gnopo, N.A. and Tetchi, A.F., "Study of physicochemical properties of some traditional vegetables in Ivory Coast: Seeds of *Beilschmiedia mannii* (Lauraceae), seeds of *Irvingia gabonensis* (Irvingiaceae) and *Volvariella volvaceae." Food and Nutrition Sciences* 3: 14-17. January 2012.

[42] Ikhatua, M.I., Egharevba, R.K.A. and Asaa, L.N., "Microbial spoilage of Irvingia kernels in Benin City, Nigeria." *Archives of Applied Science Research*, 2(5):168-176. February 2010.

[43] Festus, C. and Ibor, M.N., "The effect of defatting on the sliminess and shelf-life of Ugiri Cotyledons." *Archives of Applied Science Research*, 6(6):1-6. March 2014.

[44] Ikhatua, M.I. and Falodun, A., "The essential oil components of Irvingia gabonensis and Irvingia wombolu from Southern Nigeria." *Canadian Journal of Pure Applied Sciences*, 6(2):1955-1959. June 2012.

[45] Kengni, E., Mbofung, C.M.F., Tchouanguep, M.F. and Tchoundjeu, Z., "The nutritional role of indigenous foods in mitigating the HIV/AIDS Crisis in West and Central Africa. *International Forestry Review*, 6(2): 149-160. June 2004.

[46] Ezeabara, C. and Somtochukwu, E., "Comparative Study of Phytochemical and Nutrient Contents of Various Parts of *Irvingia gabonensis* (Aubry-Lecomte ex O' Rorke) Baill. and *Irvingia wombolu* Vermoesen. *Environmental Science*, 2(2): 10-14. October 2016.

[47] Yusuf, O.S., Ezeja, M.I. and Ugwudike, P.O., "The physiochemical properties and fatty acid profile of oil extracted from *Irvingia gabonensis* seeds." *International Journal of Biochemistry and Biotechnology*, 2(2): 273-275. February, 2013.

[48] Etong, D.I., Mustapha, A.O. and Taleat, A.A., "Physicochemical properties and fatty acid composition of dikanut (Irvingia gabonensis) seed oil." *Research Journal of Chemical Sciences*, 4(12):70-74. January 2014.

[49] Leakey, R.R.B. "Potential for novel food products from agroforestry trees: A review." *Food Chemistry*, 66: 1-14. January 1999.

[50] Loumouamou, B., "Contribution à la valorisation des oléagineux du genre Irvingia du bassin du Congo. Composition chimique et potentialités technologiques des amandes." *Thèse de Doctorat de l'Université Marien Ngouabi, Brazzaville*, 123p. March 2012.

[51] Dahouenon-Ahoussi, E., Djenontin, T.S., Codjia, D.R.M., Tchobo, F.P., Alitonou, A.G., Dangou, J., Avlessi, F. and Sohounhloue, D.C.K., "Morphologie des fruits et quelques caractéristiques physiques et chimiques de l'huile et des tourteaux de *Irvingia gabonensis* (*Irvingia*ceae)." *International Journal of Biological and Chemical Science*s, 6(5) :2263-2273. October 2012.

[52] Dubois, V., Breton, S., Linder, M., Fanni, J. and Parmentier, M., "Proposition de classement des sources végétales d'acides gras en fonction de leur profil nutritionnel." *Oilseeds and Fats, Crops and Lipids*, 15(1): 56-75. January 2008.

[53] Yusuf, O.S., Ezeja, M.I. and Ugwudike, P.O., "The physiochemical properties and fatty acid profile of oil extracted from *Irvingia gabonensis* seeds." *International Journal of Biochemistry and Biotechnology* 2(2): 273-275. February 2012.

[54] Zoué, L.T., Bédikou, M.E., Faulet, B.F., Gonnety, J.T. and Niamké, S.L. "Characterization of a highly saturated *Irvingia gabonensis* seed kernel oil with unusual linoleic acid content." *Food Science and Technology International*, 19(1): 79-87. February 2013.

[55] Jurić, S., Sopko Stracenski, K., Król-Kilińska, Ž., Žutić, I., Uher, SF., Đermić, E., Pintarić, S.T. and Vinceković, M., "The enhancement of plant secondary metabolites content in Lactuca sativa L. by encapsulated bioactive agents." Scientific Reporters 10(3737): 1-12. February 2020.

[56] Schulze ED, Beck E, Müller-Hohenstein K. “Plant ecology.” Springer.702 pp. January 2006.

[57] Akanni, M.S., Adekunle, A.S. and Oluyemi, E.A., “Physicochemical properties of some non-conventional oil seeds.” *Journal of Food Technology.* 3(2): 177-181. January 2005.

[58] Matos, L., Nzikou, J.M., Matouba, E., Pandzou-yembe, V.N., Guembot Mapepoulou, T., Linder, M. and Desobry, S., “Studies of *Irvingia gabonensis* seed kernels: oil technological applications.” *Parkistan Journal of Nutrition,* 8(2):151-157. February 2009.

[59] Zoué, L.T., Bédikou, M.E., Faulet, B.F., Gonnety, J.T. and Niamké, S.L. “Characterization of a highly saturated *Irvingia gabonensis* seed kernel oil with unusual linoleic acid content.” *Food Science and Technology International* 19(1):79-87. January 2013.

[60] Joseph, J.K., “Physico-chemical attributes of wild mango (*Irvingia gabonensis*) seeds.” *Bioresource Technology,* 53(2):179-181. April 1995.

[61] Etukudo, M.M., Hamilton-Amachree, A. and Roberts-Eneni, M.I. “A study on mineral and proximate compositions of callus segments of *Irvingia wombolu* mildbr using in vitro technique.” *European International Journal of Science and Technology,* 4(6):38-46. August 2015.

[62] Etukudo, M.M. llesanmi, O.B. and Stephen, A., “In vitro nutrient composition of callus Irvingia gabonensis (Aubrey-Lecomte Ex O’ Rorke, baill).” *International Journal of Recent Trends in Science and Technology,* 15(2):245-250. June 2015.

[63] Onyishi, V.I. and Chime, A.S. “Physicochemical characterization of *Irvingia wombolu* gum in tramadol encapsulated granules.” *African Journal of Pharmacy and Pharmacology* 7(42):2788-2793.November 2013.

[64] Adamson, I., Okafor, C. and Abu-Bakare, A., “Erythrocyte membrane ATPases in diabetes: effect of dikanut (*Irvingia gabonensis*). *Enzyme* 36(3):212-215. January 1986.

[65] Omoruyi, F.O. and Adamson, I. “Effect of Dika nut (Irvingia gabonensis) and cellulose on plasma Lipid in streptozotocin induced diabetic rat. Nutrition Research; 14: 537-544. April 1994.

[66] Ozolua, R.I., Omogbai, E.K.I. and Ebeigbe, A.B. “Altered vascular reactivity in isolated aortic rings from potassium-adapted Wistar rats.” International Journal of Pharmacology, 2: 193-200. May, 2006.

[67] Hossain, M.S., Sokeng, S., Shoeb, M., Hasan, K., Mosihuzzaman, M., Nahar, N., Ali, L. and Rokeya, B., “Hypoglycemic effect of *Irvingia gabonensis* (Aubry-Lecomte Ex.O’rorke), Baill in type 2 diabetic long-Evans rats.” *Dhaka University Journal of Pharmaceutical Sciences,* 11(1):19-24. November 2012.

[68] Ngondi, J.L., Oben, J.E. and Minka, S.R. “The effect of *Irvingia gabonensis* seeds on body weight and bloodlipids of obese subjects in Cameroon.” *Lipids in Health and Disease*4: 12. May 2005.

[69] Oben, J.E., Ngondi, J.L., Momo, C.N., Agbor, G.A. and Makamto-Sobgui, C.S. “The use of a *Cissus quadrangularis / Irvingia gabonensis* combination in the management of weight loss: a double-blind placebo-controlled study.” *Lipids in Health and Disease* 7(12):1-7. March 2008.

[70] Ngondi, J.L., Etoundi, B.C, Nyangono, C.B., Mbofung, C.M-F. and Oben, J.E. “IGOB131, a novel seed extract of the West African plant *Irvingia gabonensis*, significantly reduces body weight and improves metabolic parameters in overweight humans in a randomized double-blind placebo-controlled investigation”. *Lipids in Health and Disease* 8(7):1-7. March 2009.

[71] Obianime, A.W. and Uche, F.I. “The phytoconstituents and the comparative effects of aqueous extract of *Irvingia gabonensis* seeds and proviron on the biochemical parameters of male guinea pigs.” *Asian Pacific Journal of Tropical Medicine* 3(2):101-104. February 2010.

[72] Achinewhu, S.C. “Ascorbic acid content of some Nigerian local fruits and vegetables.” *Qualitas Plant Plant Foods Human Nutrition* 33:261-266. December 1983.

[73] Onimawo, I.A., Oteno, F., Orokpo, G. and Akubor, P.I. Physicochemical and nutrient evaluation of African bush mango (*Irvingia gabonensis*) seeds and pulp. *Plants foods for Human Nutrition* 58:1-6. September 2003.

[74] Aina, J.O. 1990. “Physico-chemical changes in African mango (*Irvingia gabonensis*) during normal storage ripening.” *Food chemistry* 37:205-212. May 1990.

[75] Hock-Eng, K., Nagendra, P., Kin-Weng, K., Yueming, J. and Amin, I. “Carotenoids and their isomers: color pigments in fruits and vegetables.” *Molecules 16:*1710-1738. February 2011.

[76] Vihotogbé, R., Berg van Den, R.G. and Sosef, M.S.M. “Morphological characterization of African bush mango trees (*Irvingia* species) in the Dahomey Gap (West Africa).” *Genetic Resource and Crop Evolution* 60:1597-1614. February 2013.

[77] Matsinkou, R.S., Ngondi, J.L., Kuate, D., Mbofung, C. and Oben, J.E., “Antioxidant and anti-hyperglycemic potential of pulp extracts of *Irvingia wombolu* fruits.” *Biology and Medicine* 4(1): 10-19. January-March 2012.

[78] Etebu, E. “Differences in fruit size, postharvest pathology and phytochemicals between *Irvingia gabonensis* and *Irvingia wombulu.” Sustainable Agriculture Research,* 2(1):52-61. October 2012.

[79] Oviasogie, P.O., Okoro, D. and Ndiokwere, C.L., “Determination of total phenolic amount of some edible fruits and vegetables.” *African Journal of Biotechnology,* 8(12):2819-2820. June 2009.

[80] Abdulrahman, F., Inyang, I.S., Abbah, J., Binda, L., Amos, S. and Gamaniel, K., “Effect of aqueous leaf extract of *Irvingia gabonensis* in gastrointestinal tract in rodents.” *Indian Journal of experimental Biology,* 42:787-791. August 2004.

[81] Fadaré, D.A. and Ajaiyeoba, F.O. “Phytochemical and antimicrobial activities of the wild mango *Irvingia gabonensis* extracts and fractions.” *African Journal of medicine and Medical Sciences,* 37(2): 119-124. June 2008

[82] Raji, Y., Ogunwande, I.A., Adesola, J.M. and Bolarinwa, A.F. “Anti-diarrhegenic and anti-ulcer properties of *Irvingia gabonensis* in rats.” *Pharmaceutical Biology,* 39(5):340-345. September 2008.

[83] Kuete, V., Wabo, G.F., Ngameni, B., Mbaveng, A.T., Metuno, R., Etoa, F-X., Ngadjui, B.T. Beng, V.P. Meyer, J.J.M. and Lall, N. “Antimicrobial activity of the methanolic extract, fractions and compounds from the stem bark of *Irvingia gabonensis* (Ixonanthaceae).” *Journal of Ethnopharmacology,* 114(1): 54-60. August 2007.

[84] Donfack, J.H., Wabo, G.F., Ngameni, B., Nguegin Tsofack, F., Tchoukoua, A., Ambassa, P., Abia, W., Tchana, A.N., Giardinia, S., Buonocore, D., Vita Finzi, P., Vidari, G., Marzatico, F., Ngadjui, B.T. and Moundipa, P.F., “In vitro hepatoprotective and antioxidant activities of the crude extract and isolated compounds from *Irvingia gabonensis.” Asian Journal of Traditional Medicines* 5(3): 79-88. May 2010.

[85] Ojo, O.A., Ajiboye, B.O., Oyinloye, B.E. and Ojo, A.B., “Prophylactic Effects of Ethanolic Extract of Irvingia gabonensis Stem Bark against Cadmium-Induced Toxicity in Albino Rats.” *Advances in Pharmaceutics,* 2014- ID 894610. September 2014.

[86] Okolo, C.O., Johnson, P.B., Abdurahman, E.M., Abdu Aguye, I. and Hussaini, I.M., “Analgesic effect of *I. gabonensis* stern bark extract.” *Journal of Ethnopharmacology* 45(2): 125-129. February1995

[87] Omonkhua, A.A. and Onoagbe, I.O., “Effects of long-term oral administration of aqueous extracts of *Irvingia gabonensis* bark on blood glucose and liver profile of normal rabbits.” *Journal of Medicinal Plants Research,* 6(13):2581-2589. November 2012.

[88] Omonkhua, A.A., Onoagbe, I.O., Fajimeye, I.A., Adekola, M.B. and Imoru, Z.A., “Long-term anti-diabetic and anti-hyperlipidaemic effects of aqueous stem bark extract of *Irvingia gabonensis* in streptozotocin-induced diabetic rats.” *International Journal of Nigerian Society for Experimental Biology,* 26(1):1-8. July 2014.

[89] Giami, S.Y., Okonkwo, V.I. and Akusu, M.O. “Chemical composition and functional properties of raw, heat-treated and partially proteolysed wild mango (*Irvingia gabonensis*) seed flour.” *Food Chemistry* 49: 237-243. March 1994.

[90] Olawale, O., “Evaluation of lipids extracted from mango and melon seeds”. *Pacific Journal of Science and Technology* 11(2):508-510. November 2010.

[91] Ogaji, I.J., Nan, A. and Hoag, S.W., “A Novel Extraction Method and Some Physicochemical Properties of Extractives of Irvingia Gabonensis seeds.” *Journal of Young Pharmacists,* 4(2): 66-72. April 2012.

[92] Sanni, D.M., “Isolation, Partial Purification and Characterization of Polyphenol Oxidase from Two Species of African Mango Seeds (*Irvingia gabonensis and Irvingia wombolu*).” *Advances in Biochemistry,* 2016; 4(4): 47-52. June 2016.

[93] Stege van der, C., Prehsler, S., Hartl, A. and Vogl, C.R., "Tamarind (*Tamarindus indica* L.) in the traditional West African diet: not just a famine food." *Fruits* 66: 171-185. May 2011.

[94] Fajimi, O. Sarumi, M.B. Olayode, M.N., Gamra, E.O. and Sanusi, S.I. "In vitro propagation of Irvingia gabonensis." *African journal of biotechnology*, 6(8):976-978. April 2007.

[95] Nwigbo, S.C., Ngini, J.O., and Atuanya C.U. "Physical and mechanical properties of *Irvingia gabonensis* and *Irvingia wombolu* at varying moisture content and temperature 2013." *International Journal of Multidisciplinary Sciences and Engineering*, 4(6):10-14. July 2013.

[96] Bennett, B.C., & Balick, M.J. 2008. Phytomedicine 101: Plant taxonomy for preclinical and clinical medicinal plant researchers. *Journal of the Society for Integrative Oncology* 6(4): 150-157.

[97] Onakpoya, I., Davies, L., Posadzki, P. and Ernst, E., "The efficacy of *Irvingia gabonensis* supplementation in the management of overweight and obesity: a systematic review of randomized controlled trials." *Journal of Dietary Supplements,* 10(1): 29-38. March 2013.

[98] Amubode, F.O. and Fetuga, B.L., "Amino acid composition of seeds of some lesser-known tree crops." *Food Chemistry* 13: 299-307. February 1984.

[99] Onyeike, E.N., Olungwe, T. and Uwakwe, A.A. "Effect of heat treatment and defatting on the proximate composition of some Nigerian local soup thickeners." *Food Chemistry* 53 I73- I75. May 1995.

[100] Ekpe, O.O., Umoh, I.B. and Eka, O.U., Effect of a typical rural processing method on the Proximate composition and amino acid profile of bush mango seeds (*Irvingia gabonensis*). *African Journal of Food, Agriculture, Nutrition and Development*, 7(1):1-12. January 2007.

[101] Lukhoba, C.W. and Siboe G.M. Use of ethnobotanical data in the search for and identification of potential drug plants. *East and Central African Journal of Pharmaceutical Sciences* 11: 43-48. May-August 2008.

[102] Womeni, H.M., R. Ndjouenkeu, C. Kapseu, F.T. Mbiapo, M. Parmentier and J. Fanni, 2006. Aqueous enzymaticoil extraction from Irvingia gabonensis seed kernels. Eur. J. Lipid Sci. Technol., 110: 232-238.

[103] Ladipo, D.O., "The Development of quality control standards for ogbono (*Irvingia gabonensis* and *Irvingia wombolu*) kernels: efforts towards encouraging organized and further international trade in a NWFP of West and Central Africa. In: Sunderland, T.C.H., Clark, L.E. and Vantomme, P. (Eds). Current research issues and prospects for conservation and development. *FAO, Rome, Italy*, 245-250. May 1999.

[104] Adeniyi, S.A.A., Adedotun, A.A. and Akinniyi O. "The effect of postharvest mycodeterioration on the proximate composition of *Irvingia gabonensis* seeds." *International Journal of Phytopathology* 3(01):41-48. April 2014.

[105] Etebu, E. and Bawo D., "Fungal quality and phytochemicals of *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) kernels sold in Yenagoa metropolis of Bayelsa State, Nigeria" *Journal of Biology, Agriculture and Healthcare*, 2(11)41-51. June 2012.

[106] Awono, A., Djouguep, A., Zapfack, L. and Ndoye, O., "The potential of *Irvingia gabonensis*: can it contribute to the improvement of the livelihoods of producers in Southern Cameroon? *International Journal of Social Forestry*, 2(1):67-85. June 2009.

[107] Schreckenberg, K., Awono, A. Degrande, A., Mbosso, C., Ndoye, O. and Tchoundjeu, Z., "Domesticating indigenous fruit trees as a contribution to poverty reduction." *Forests, Trees and Livelihoods* 16:35-511. April 2006.

[108] Smelcerovic, A., Verma, V., Spiteller, M., Ahmad, S.M., Puri, S.C. and Qazi, G.N., "Phytochemical analysis and genetic characterization of six *Hypericum* species from Serbia." *Phytochemistry*, 67:171-177. January 2006.

[109] Kumar, D., Singh, B.P. and Kumar P., "An overview of the factors affecting sugar content of potatoes." *Annual Applied Biology,* 145:247-256. March 2005.

[110] Beckles, D.M., Hong, N, Stamova, L., and Luengwilai, W., "Biochemical factors contributing to tomato fruit sugar content: a review." *Fruits,* 67:49-64. December 2012.

[111] Drewnowski, A. and Gomez-Carneros, C., "Bitter taste, phytonutrients, and the consumer: a review." *American Journal of Clinical Nutrition*. 72:1424-35. December 2000.