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Agroforestry species of *Chrysophyllum albidum* (G. Don), *Irvingia gabonensis* (Baill.) and *Dialium guineense* (Willd.): An overview focused on ethnomedicinal uses, phytochemical properties, recent achievements and future prospective

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Abstract
Food is an essential need for a healthy life and leads to the search for balanced diets rich in fruits and containing sufficient amounts of nutrients and bioactive compounds. However, there are countless wild fruits with high nutritional potential that are undervalued and rot each year in large quantities. For lack of adequate valorization, these agroforestry species are disappearing from their natural ecosystems. The present study therefore aims to review the state of the art of research on agroforestry species of *Chrysophyllum albidum*, *Irvingia gabonensis* and *Dialium guineense*. To do this, search was carried out in scientific databases, including Science Direct, Scopus, PubMed and Agora, followed by a selection of suitable scientific research works that were analyzed. From the results obtained, it appears that scientific research on these different plant species are mainly on their agronomic and nutritional aspects, identification of bioactive compounds, as well as their ethnobotanical uses, showing that these agroforestry species have a great potential use in food and pharmaceutical industries. However, it would be interesting that future investigations were more focused on their biotechnological applications, such as production of compounds with high added value, propagation and fertilization, domestication and genetic improvement.

Keywords: *Chrysophyllum albidum*, *Irvingia gabonensis*, *Dialium guineense*, ethnomedicinal uses, phytochemistry, future prospective

Introduction
Forest formations provide a large number of animal and plant resources which are sources of food, medicine, supply of wood for energy production (Goussanou *et al*., 2011) [47]. Apart from agriculture, livestock or fishing, non-timber forest products are an important source of income for rural communities (Salhi *et al*., 2010; Allabi *et al*., 2011) [84, 14] and plants became cultural and economic markers of human history (Chibembe *et al*., 2015) [29]. However, among these plant resources, there are some agroforestry species whose fruits are poorly valued and rot each year in large quantities.

Indeed, *Chrysophyllum albidum* (G. Don) is a tropical tree widely distributed in West, Central and East Africa and is considered as a tree with a high socio-economic level. *Chrysophyllum albidum* fruits are plump and juicy, and can be used as potential sources of drinks. These fruits are used for the production of jams and jellies (Gbeyetin *et al*., 2011) [44]. *Chrysophyllum albidum* has an efficient nutrient cycle and the high leaf mineralization rate which contributes to the improvement of soil quality, and their bark, leaves, fruits, roots and seeds are used to cure various diseases (Adewusi, 1997) [2].

Irvingia gabonensis, also known as "bush mango", is a native from tropical Africa. Its wood is used for making utensils and its fruits are eaten as food and medicine, and its kernels are rich in oil (Mateus-Reguengo *et al*., 2020) [65].

Dialium guineense is a wild plant specie found in several regions of sub-Saharan Africa. It is also one of the best-known wild fruits used by local populations (Ambe, 2001) [15]. Traditionally, the leaves and roots of this plant are used as antimalarial agents and dietary supplements for pregnant women (Madge, 1998) [60].

Fruits are naturally eaten, or transformed into several products such as cakes or juices (Fall, 2001; Orhue *et al*., 2007) [40, 80]. Additionally, bio-economy principles, which is a new economic system based on the sustainable use of resources (Lewandowski 2018) [59], highlighted the valorization of biodiversity resources including a demand for low-cost and effective medicines that can assist as an alternative or complementary medication for healing diseases (Nunes *et al*., 2022) [70]. However, despite the importance of agroforestry resources, demographic pressure, deforestation, wildfires, intensive agriculture, livestock and climate change, contribute to the loss of native plants (Assogbadja *et al*., 2011) [19]. For example, in some African countries such as Benin, the annual losses in forest cover over the period from 2005 to 2010 are estimated at 50,000 ha according to the United Nations Food Organization (FAO, 2011) [42] resulting in the disappearance of useful plant species from their natural ecosystems (Adomou *et al*., 2017) [4]. It is therefore necessary that scientific research items more focused on these endangered species by listing scientific studies carried out, in order to identify relevant information and points of interest capable of supporting future researches.

Material and methods

Literature search was carried out in various databases, such as Science Direct, Scopus, Google Scholars, PubMed and Agora. Regarding *Chrysophyllum albidum*, key terms such as: "*Chrysophyllum albidum*", "Nutritional properties of *Chrysophyllum albidum*", "Nutritional profile of *Chrysophyllum albidum*", "Pharmacological effects of *Chrysophyllum albidum*" have been entered into the search editors of databases used. For *Irvingia gabonensis*, the following keywords were used: "*Irvingia gabonensis*", "African Mango", "Bush Mango", "Dika Fruit", and "Dika Kernel". Regarding *Dialium guineense*, keywords such as "*Dialium guineense*", "Black tamarind", and "velvet tamarind", have been edited in the search engines used. A manual search of the bibliographies was also carried out in order to identify the retrieved articles.

Results and discussion

Origin, general characteristics and importance in ethnomedicinal context

In Africa, agroforestry species are alternative sources of food commonly used by people of various socio-economic categories as a supplement to the daily diet and therefore contribute greatly to diversity, food security and reduction of poverty (Fandohan *et al*., 2010, Gouwakinnou *et al*., 2011, Bolanle-Ojo and Onyekwelu, 2014) [40, 48 28]. Among these agroforestry species are *Chrysophyllum albidum, Irvingia gabonensis* and *Dialium guineense.*

Chrysophyllum albidum, commonly known as African star apple tree, is an agroforestry specie from African origin, belonging to the Sapotaceae family and comprising approximately 800 species (Ehiagbonare *et al*., 2008) [35]. It reaches twenty-five (25) to thirty-sept (37) meters in height with a maturity circumference varying on average between 1.5 and 8 meters. It is a lowland rainforest tree and its natural occurrences have been reported in various ecological zones from Sierra Leone to East Africa (Bada, 1997) [26]. On the upper side, leaves of the species are green and become silver-grey on the lower side and of elongated elliptical oval shape, 12-30 cm long and 3.8-10 cm wide. They have indistinct or invisible secondary tertiary veins and a petiole length is from 1.7 to 4.2 cm (Kantende *et al*., 1995) [55]. It is essentially a forest food tree species widely distributed in West, Central and East Africa (Orwa *et al*., 2009; Ugwu and Umeh, 2015) [82, 88]. The species is an important source of income for rural populations (especially women) and has become a commercially valuable plant in Nigeria (Oyebade, 2011) [83]. Leaves, seeds, bark and roots are used by local populations in Benin and elsewhere in traditional medicine (Houessou, 1997) [49]. According to Oboh (2009) [72], *Chrysophyllum albidum* seeds absorbed metal ions and could be used for the development of cheap effluent treatment technology. From an ethnomedicinal point of view, the bark of *Chrysophyllum albidum* is effective against yellow fever and malaria (Annongu *et al*., 2017) [17]. Gum extracts from the fruits showed good physicochemical properties and can be used in drug development (Aletor, 1993) [13]. The leaf is used for the treatment of stomach-ache and are effective in the treatment of vaginal ailments and skin infections in western Nigeria (Christensen and Kharazmi, 2001) [30]. Seeds and root extracts are used to stop bleeding from fresh wounds, and have also property to inhibit microbial growth (Dandare *et al*., 2017) [31]. In southern Benin, the leaves of this plant are useful in traditional rituals. They possess medico-magical properties in addition to their common uses. Indeed, according to local socio-cultural considerations, the leaves are used to ward off evil spirits. The fruit of *Chrysophyllum albidum* (Figure 1-c) is a large fleshy and juicy edible berry. The fleshy pulp of the fruit is eaten by many local communities (Aletor, 1993) [13] and also used for the development of soft drinks (Adisa, 2002) [3]. Seed from fruits can be used to produce oil (Akin-Osanaiye *et al*., 2018) [10]. According to Akin-Osanaiye *et al*., (2018) [10], the fruit also contained large amounts of anarcardic acid used in industry for wood protection.

Irvingia gabonensis is a widely distributed wild fruit plant belonging to the Irvingiaceae family. Often found in West and Central Africa, its range extends from Casamance (Senegal), Zaire and Angola (Ayuk *et al*., 1999) [25]. It is often present in the humid forest zone of Cameroon, Congo, Côte d'Ivoire, Gabon, Ghana, Liberia, Nigeria and Sierra Leone. African countries like Cameroon and Nigeria have a high density of the species. Apart from these humid regions where the abundance of the species is noted, it is also found in sub-humid regions such as Senegal (N'Doye *et al*., 1998) [67] and in the dry corridor of the Dahomey Gap: Benin (Sokpon and Lejoly, 1996) [86] and Togo (Ainge and Brown, 2004) [5]. Several studies have revealed that fruits of *Irvingia gabonensis* (Figure 1-b) can be used for the production of juice, wine and jam (Ainge and Brown, 2001; Aworh, 2015) [5, 22]. Akubor (1996) [12] also reported that fruits are suitable for juice and wine production. However, this juice has low protein and high ascorbic acid content when compared to other tropical fruit juices Akubor (1996) [12]. Fruits are also susceptible to osmotic dehydration (Aworh, 2015) [22], and almond are often used for the preparation of a sauce in Africa (Awono and Manirakiza, 2007) [21]. In Benin, almond is available and represents one of the condiments most used by the populations in the south of the country (Sokpon and Lejoly, 1996) [86]. The oil-free almond paste is used as a condiment, because it can replace *Okra* (*Hibiscus esculentus*) and peanuts, which are among the condiments very present in

the traditional soup of Central and West Africa (Kengni *et al*., 2011) [56]. The sales of these almonds therefore hold a significant place in the ranks of trade in Non-Timber Forest Products (NTFPs) in West and Central Africa (Ayuk *et al*., 1999) [25].

Dialium guineense is a wild fruit species, native to Africa and belonging to the Fabaceae family and the Caesalpinioideae subfamily (Gnansounou *et al*., 2014) [46]. The average height of this tree is 30m with a densely leafy, but often shrubby crown. The leaves of *D. guineense* are finely hairy. They have a common petiole 5-13 cm long, with an odd terminal leaflet and usually two pairs of opposite or alternate leaflets. The fruits of this tree are usually abundant, more or less circular and flattened, but sometimes almost globose, up to 2.5 cm in diameter, densely velvety and black (Figure1-c). They have a brittle shell containing one or exceptionally two seeds, embedded in a dry, brownish, sweet, acidic and edible pulp (Hong *et al*., 1996). *Dialium guineense* is also a multipurpose plant. Indeed, Idu *et al*. (2009) [53] reported that the bark of *D. guineense* is used for oral hygiene and stomach ailments among the Esan tribe of Edo state. Fruits (Figure 1-c) are used in the treatment of diarrhea (Arbonnier, 2004). *D. guineense* is used as a chewing stick in Nigeria (Akinpelu *et al*., 2011) [11]. Lawal *et al*. (2010) [58] reported that leaves of *D. guineense* is used as an anti-ulcer agent and as a vitamin supplement for some tribes in southern Nigeria. The tree is also used as fuel and is used to make firewood and charcoal (Akinpelu *et al*., 2011) [11]. The fruit pulp is edible and sweet. It contains ascorbic acid and tannin in small quantities. Fruits are a good source of protein and minerals (Arogba *et al*., 2006) [18]. Among some women in southeastern Nigeria, the fruits are eaten to improve lactation and control genital infections (Nwosu, 2000) [71]. The red colored pulp with an astringent sweet, can be eaten raw when dry by humans and animals (Matsuda, 2006) [61]. The thirst-quenching and refreshing pulp can also be soaked in water and drunk as a beverage (Efiong *et al*., 2009), or used for the production of jam and jellies (FAO, 2004) [41].

a) Fruits of *Chrysophyllum albidum* (Orwa *et al*., 2009) [82]	b) Fruits of *Irvingia gabonensis* (Tsobeng *et al*., 2021) [52]	c) Fruits of *Dialium guineense* (Orwa *et al*., 2009) [82]

Fig 1: Fruits of *Chrysophyllum albidum*, *Irvingia gabonensis* and *Dialium guineense*

Phytochemical and nutritional characteristics

Several studies reported the phytochemical and nutritional properties of *Chrysophyllum albidum*, *Irvingia gabonensis* and *Dialium guineense*. Indeed, Egharevba *et al*. (2015) [34] reported that *Chrysophyllum albidum* leaves contain phenols, terpenoids, flavonoids, saponins, steroids and alkaloids. The pulp of the fruit is rich in phenols, alkaloids, tannins, saponins, flavonoids, terpenoids, reducing sugars and glycosides (Imaga and Urua, 2013) [54]. The pericarp of the fruit is rich in alkaloids, tannins, saponins, flavonoids and terpenoids (Ibrahim *et al*., 2017) [51]. Ajewole and Adeyeye (1991) [9], reported that *C. albidum* seeds contained crude protein, carbohydrates, crude fat, crude fiber and minerals. Furthermore, Kpodo *et al*. (2021) [57] reported that unripe fruit of *C. albidum* had higher content of carbohydrates, crude protein and crude fat, compared to ripe and overripe fruit. Overripe fruits contained more crude fiber and had higher ash content. Macdonald *et al*. (2014) [64] reported that *Chrysophyllum albidum* root extracts possess antimicrobial properties against *Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Bacillus subtilis, Aspergillus niger, Penicillium notatum, Mucor mucedo* and *Candida albicans*. Ajetunmobi and Towolawi (2014) [8] revealed that *Chrysophyillum albidum* leaf extract also has an antimicrobial effect against pathogenic bacteria and fungi of the gastrointestinal tract in humans. Duyilemi and Lawal (2009) [32], reported that a mixture of water and methanol extract of *C. albidum* leaves at different concentrations are effective against *Staphylococcus aureus, Escherichia coli, Salmonella typhimurium* and *Shigella spp*. Idowu *et al*. (2006), Okwu and Iroabuchi (2001), Olorunnisola *et al*. (2008), Savithramma (2011) [85] reported that *C. albidum* is an excellent antimicrobial, antimalarial, antioxidant, antidiabetic, anti-inflammatory, anticancer, antifungal and antibacterial plant. Ehigiator and Adikwu (2019) [36] reported that ethanolic extract of *Chrysophyllum albidum* stem bark also prevents alloxan-induced diabetes. Kpodo *et al*. (2021) [57] reported that *Chrysophyllum albidum* fruits can be used as nutraceuticals in functional food developments.

Concerning *Irvingia gabonensis* plant, Ayivo *et al*. (2011) [24] reported that the bark extracts have antibacterial and antifungal properties. In Benin, Allabi *et al*. (2011) [14] reported that the leaves of *Irvingia gabonensis* are effective in the treatment of jaundice. Ezeabara and Ezeani (2016) [38] reported the presence of alkaloids, flavonoids and anthraquinone in the leaves of *Irvingia gabonensis*. On the nutritionally, Onimawo *et al*. (2003) [78] reported that the soluble solids content (°Brix) of *Irvingia gabonensis* fruit pulp is around 10% with a pH ranging between 4.7 and 6.2. The presence of minerals such as potassium (1114 mg/100 g),

calcium (118 mg/100 g), sodium (12 mg/100g) in *Irvingia gabonensis* fruit pulp, has been reported (Olayiwola *et al*., 2013) [75]. Etebu (2012) [37] reported the presence of phytochemical groups like alkaloids, flavonoids, saponins, tannins and glucosides in the fruit mesocarp. High carotenoid contents have been reported by Aina (1990) [6] and Olayiwola *et al*. (2013) [75]. *Irvingia gabonensis* fruit kernels are eaten in many West African countries. They contain many amino acids essential to humans in significant proportions (Ainge and Brown, 2001) [5]. Ngondi *et al*. (2005) [68] also reported that the consumption of oil extracted from almonds could have an effect on weight regulation.

Phytochemical studies of crude stem bark extract of *Dialum guineense* have revealed that the plant has bioactive compounds such as glycosides, tannins, saponins, terpenoids, steroids, triterpenes, alkaloids, flavonoids, reducing sugars and carbohydrates, while phytochemicals identified in the leaf extract are tannins, alkaloids, flavonoids, saponins, steroids and cardiac glycosides (Gédeon and Raphael, 2013) [45]. Several chemical substances identified in *Dialum guineense* plant are known to be biologically active and their presence has been reported as antibacterial (Orji *et al*., 2012) [81], molluscicide (Odukoya *et al*., 1996) [73], anti-diarrheal (Gédeon *et al*., 2012) [45], anti-vibrio (Akinpelu *et al*., 2011) [11], antioxidant (Gédeon *et al*., 2013) [45]. From a nutritional point of view, Ayessou *et al*. (2014) [23] reported that the fruits of *D. guineense* have a high fructose content (90.78% of total soluble sugars) and are a potential source of iron (4.82–8.4 mg/100 g), manganese (0.03–0.05 g/100 g), copper (0.67–0.7 mg/100 g) and zinc (0.53–1.59 mg/100 g). Gnansounou *et al*. (2014) [46] reported that the pulp of *D. guineense* fruits has a good content in minerals with interesting values for iodine (04.34 ± 0.12 mg/100 g), iron (14.75 ± 0. 25 mg/100 g), calcium (70.14 ± 10 mg/100 g) and potassium (366 ± 0.26 mg/100 g). Nicholas *et al*. (2014) [69], revealed the presence of essential vitamins such as ascorbic acid, beta-carotene and tocopherol in *D. guineense* fruits. These results indicated that the consumption of fruit of *D. guineense* could contribute to reaching the recommended daily intakes of certain essential micronutrients (Nicholas *et al*., 2014) [69].

Recent Achievements

In recent years, scientific research has focused on forest resources, not only as potential sources of useful biomolecules in the treatment of various diseases, but also as a source of food rich in nutrients, especially in times of food crises or of starvation. Forest species, in particular *Chrysophyllum albidum*, *Irvingia gabonensis* and *Dialium guineense* have been the subject of several fruit development trials, including the production of almond flour, unconventional vegetable oil, fruit juice, wine, and powder made from fruit pulp. Main scientific researches made in the valorization of fruits of *Chrysophyllum albidum*, *Irvingia gabonensis* and *Dialium guineense* are presented in Table1.

Future prospective

From scientific researches carried it appears that *Chrysophyllum albidum*, *Irvingia gabonensis* and *Dialium guineense* not only represent an important food sources, but also contain bioactive compounds which could be of great use for future research focused on biotechnological applications, in particular the research of biomolecules of interest in medicine or pharmacy, or the production of substances with high added value. Similarly, it would also be interesting to strengthen studies on methods of propagation, fertilization, development of management plans and domestication. Indeed, according to Ganglo (2018) [43], among the agroforestry species which should be preserved, *Chrysophyllum albidum* and *Dialium guineense* have a particular attention due to their multipurpose uses; and as a strategy to conserve these species, the researcher has suggested to identify their favorable areas and introduce them where they were absent or in insufficient densities. Moreover, the reinforced study on genes and metabolic pathways of the production of bioactive compounds, would be interesting for applications in genetic engineering, because there are few innovative technological products based on these species.

Table 1: Main scientific researches made in the valorization of fruits of *Chrysophyllum albidum, Irvingia gabonensis* and *Dialium guineense*

Plant species	Types of valorization	References
Chrysophyllum albidum	Production of wine	Aniaku et Ogunbodede (2022) [16]
	Production of unconventional oïl	Nartey *et al*. (2021) [66]
	Production of almond flour; Production oil; Production of wine; Production of powder made from fruit pulp; Production of juice from fruits	Audu *et al*. (2019) [20]; Olowoyeye *et al*. (2019) ; Oyetayo *et al*. (2019) [79]; Airaodion *et al*. (2019) [7]
	Production of flour using dessicated fruits	Oluwole *et al*. (2017) [76]
Irvingia gabonensis	Production of fruit juices; production of powder from almond	Ibeanu *et al*. (2020) [50]; Sunmonu *et al*. (2020) [87]
	Production of flavored yoghourt, production of fruit juices.	Omoniyi *et al*. (2017) [77]; Mbaeyi et Taylor (2017) [62]
	Production of wine	Mbaeyi-Nwaoha et Okorie (2016)
	Production of almond flour	Bamidele *et al*. (2015) [27]
Dialium guineense	Production of wine; Production of flavored yoghourt	Ojukwu et Ozugha (2019) [74]; Mbaeyi-Nwaoha *et al*. (2019) [63]
	Production of almond flours	Abiodun *et al*. (2017) [1]

Conclusion

The challenges for scientific researchers and political decision-makers are not only to define strategies for the sustainable development and conservation of forest ecosystems, but also to consider processes for the development of agroforestry species, while taking into account human needs. The exploitation of unconventional fruit residues for industrial recovery should be considered more for economic and environmental reasons. The importance of these unconventional agricultural products is in their abundance, their low cost and also is related to the fact that they represent a good natural organic source available.

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