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Valorization of Ubiquitous Plant Species Used as Food Packaging in Benin: A Sustainable Solution to Improve Quality of Life and Protect the Environment

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Abstract

Vegetal leaves play a significant role in the daily lives of populations in developing countries. This study aimed to highlight the plant species used as food packaging in southern Benin. A survey questionnaire was administered in local markets, and informed consent was obtained from native guides. Data were processed using Google Forms, and a phytochemical screening was conducted on the sampled species. A total of 311 individuals, including elders, vendors, and consumers, participated in the survey. The most commonly used plant species identified were *Tectona grandis*, *Thalia geniculata*, *Musa sapientum*, *Gmelina arborea*, *Manihot esculenta*, and *Terminalia catappa*. Several reasons, primarily cultural, explain the preference for these species. Notably, *Tectona grandis* and *Musa sapientum* demonstrated superior morphological, physical, and organoleptic qualities, measuring 79 cm by 53.5 cm and over 2 m by 50 cm, respectively. They accounted for 33.33% and 32.35% of usage. Additionally, fermented corn paste, making up over 53% of offerings, was the most popular food item. The mechanical properties of these leaves, such as flexibility, toughness, and relative impermeability, along with identified phytochemicals like terpenes, alkaloids, gallic acid, flavonoids, and coumarins, enhance food preservation and limit microbial activity. Promoting the use of these natural packaging materials over plastic alternatives could significantly reduce environmental pollution and mitigate the risks associated with toxic microorganisms in food,

contributing to both ecological health and food safety.

Keywords

Socio-Ethnobotanical Surveys, Food Items, Secondary Metabolites, Bioactive Natural Substances, Phytochemical Screening

1. Introduction

Mainly in developing countries, the vast majority of people (over 80%) still use plant leaves for healthcare [1], 75% of wild plants for their daily diet in the form of leafy vegetables [2] and as food packaging in the small-scale agribusiness [3]. In West Africa, the plant species most commonly used as both food packaging and leafy vegetables are *Manihot esculenta*, *Manihot glaziovii*, *Sterculia tragacantha* and *Triplochiton scleroxylon* [3]. In Benin, plentiful scientific work give pride of place to leafy plants used as food packaging and vegetables. This wealth of local literature, combined with regional studies, has led to the identification of more than sixty plant species belonging to around forty different families. In 2015, plant species such as *Thalia geniculata*, *Lasimorpha senegalensis*, *Tectona grandis* and *Musa sapientum* were the most commonly used food packaging by the people of Benin [4]. Previous studies have also reported the existence of a host of plant leaves used as food packaging in Benin [3] [5] [6], of which the most ubiquitous species, the most used by several socio-cultural groups and for several foods in descending order were *Thalia geniculata*, *Siphonochyllus aethiopicus*, *Cyrtosperma senegalense*, *Sarcocephalus latifolius*, *Daniellia oliveri*, *Agyrea nervosa*, *and Isoberlinia doka* [7]. Recently, *Musa sapientum*, *Tectona grandis*, *Thalia geniculata*, *Manihot esculenta*, *Gmelina arborea and Isoberlinia doka* have been identified as the plant species most commonly used in food packaging in Benin [8]. Thus, despite their geographical distribution, *Musa sapientum* and *Tectona grandis* are the most ubiquitous species. These plants have been identified as being of interest to both producers and consumers. Their antimicrobial properties [9] ensure that the foodstuffs packaged in them are well preserved, thereby increasing their shelf life and reducing losses due to product deterioration, and their known medicinal properties mean that they can be used to prevent and treat many diseases [10]. Moreover, these plant species present little or no danger of food poisoning for consumers [7]. On the contrary, they improve the organoleptic characteristics of packaged foods, which are key to consumer appreciation [11] [12]. Indeed, in addition to their primary function of protection, vegetable packaging transfers aroma, taste and colour to packaged foods [3] in addition to physicochemical compounds such as proteins, lipids, minerals, vitamins and phytochemicals such as tannins, anthocyanins, flavonoids, alkaloids and other metabolites that may migrate from the leaves to the packaged food [5] [13] [14]. This study aims to understand the motivations of people in southern Benin in their choice of plant species used as food packaging, to determine the physicochemical characteristics of

the leaves of the most commonly used plant species, and to explain the pharmacological properties of the various groups of families of chemical compounds they contain.

2. Material and Methods

2.1. Methodology

The work consisted of researching articles covering the last ten years (2012 - 2022), with particular emphasis on articles from 2017 to 2022. Indeed, 2017 was the year in which the import, marketing and use of non-biodegradable plastic bags was banned in Benin by Decree 2017-39 of 26 December 2017. This year therefore marked a turning point in the scientific interest shown in plant-based food packaging, with a flurry of scientific articles devoted to plant species used as food packaging. Between 2012 and 2022, we have listed more than 100 articles, half of which relate specifically to our objective. More than twenty plant species are used as food packaging and leafy vegetables in Benin. We carried out a socioethnobotanical survey in the southern region of our country to confirm the literature data and to gather the inclinations of the populations for certain plant species to the detriment of others. The survey covered the departments of Couffo (Municipalities of Aplahoué and Dogbo), Mono (Municipalities of Lokossa and Comè), Atlantique (Municipalities of Ouidah, Allada, Zè, Abomey-Calavi), Ouémé (Municipalities of Porto-Novo, Adjarra), Plateau (Municipalities of Sakété, Pobè, Kétou) and Zou (Municipalities of Bohicon, Abomey), most of which are home to international trade markets and are used as transport points for products processed in outlying villages and hamlets. The main markets and some secondary markets, as identified by the resource persons referenced and surveyed, were visited. A survey form was used as a basis for questioning (appendix). The informations was collected on the survey form or on audio support with the informed verbal consent of the respondents after negotiations with the guide.

2.2. Data Analysis

An online automatic Google Forms application was used to treat the data that had been gathered.

2.3. Sampling Sheets

Six (6) plant species which people has a strong inclination were selected after survey results and presented in Table 1 below for further study.

All the leaves were collected in their natural habitat at the University of Abomey-Calavi and at Agla in Cotonou in July 2023. The leaves were prepared and various protocols were used to extract and identify the metabolites present by colorimetric reactions, the formation of mosses and colourless or coloured precipitates.

Table 1. Plant species commonly used as food packaging in southern Benin.

Plant species	Family	Scientific names	Local names (fon)
Teak leaves	Lamiaceae	*Tectona grandis*	Têkiman
Spurred thalia leaves	Marantaceae	*Thalia geniculata*	Afléman
Banana tree leaves	Musaceae	*Musa sapientum*	Kokoueman
White teak leaves	Lamiaceae	*Gmelina arborea*	Forfiman
Cola leaves	Combretaceae	*Terminalia catappa*	Colaman
Cassava leaves	Euphorbiaceae	*Manihot esculenta*	Finyinman

Legend: Local name: common name used by the population in the Fon language.

2.4. Leaves Extracts Analysis

Most relevant protocols was used to reveled the presence of family of secondary metabolites.

3. Results

3.1. Data Analysis

From a total of over 350 respondents, we collected and processed 321 responses, giving a response rate of over 91%.

Atlantic department is most visited of all departments, with several large markets and small secondary markets held regularly (every 5 days) and only a few kilometres apart. Most of the other departments have regional (departmental) markets located on the outskirts of major roads, which are open almost every day, although they are generally open every 5 days. This is the case for the Comé, Lokossa, Dogbo and Azovè markets in the Mono and Couffo departments. All markets visited are illustrated in Figure 1 below.

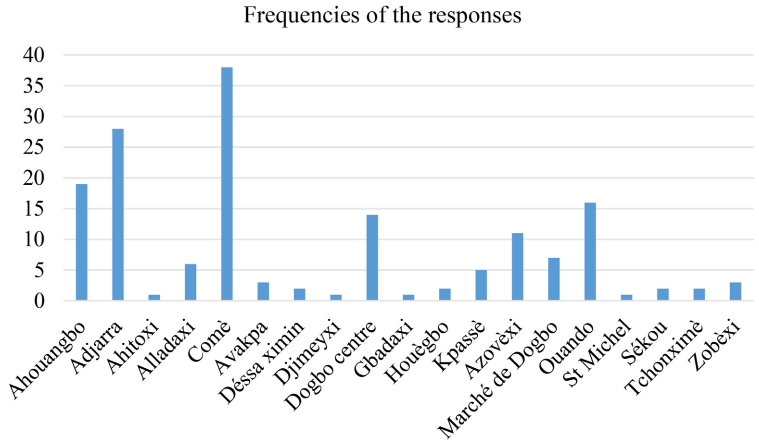

Figure 1. Statistics of the markets visited in the surveyed municipalities.

These markets offer a wide range of fresh, pre-cooked and cooked food products for direct consumption. Figure 2 shows the names of some of the food

products in the local language and statistic of several food sold.

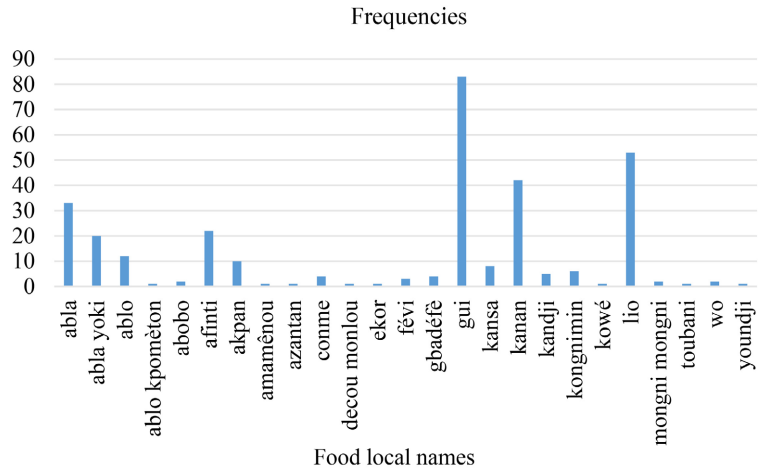

Figure 2. Food products are commonly sold to the population in the markets visited in the local language of the area.

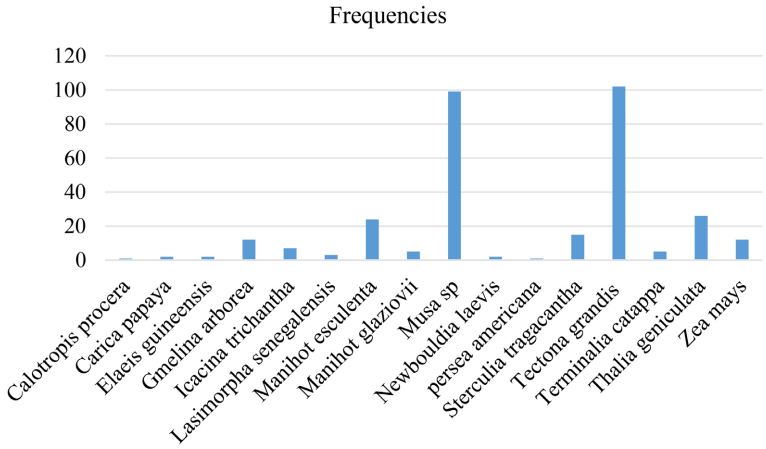

Figure 3. Main plant species used as leaf packaging for food preparations in southern Benin.

From the Fon to the Katafon, from the Adja to the Mina, from the Goun to the Aïzo, in Yoruba, the same food product is called by different names depending on the linguistic code of the ethnic group. Akassa (fermented maize paste), for example, is called "Gui" by the Fon, "Ogui" by the Kotafon, the Aïzo, "Kannan" by the Goun, "akpan" by the Mina, etc. This foodstuff is also known as "akpan" by the Yoruba. In fact, this is the most popular foodstuff on the market. All these names combined, it is by far the most popular food preparation offered, the most sold and therefore the most consumed in southern Benin, accounting for more than 53% (graph 3). Like most food products and preparations, it is often sold in balls in vegetable packaging made from local or imported plant species such as "aflé-man" *Thalia geniculata* (**Figure 3**), a plant species that only grows in the shallows but is found in several of the markets visited. Plastic packaging, although rare, is also sometimes used. The difficulties associated with linguistic variations in local

names suggest that the scientific names of the species used as plant packaging should be considered (Figure 3).

These results provide an overview of the different species used as leaf packaging for foodstuffs. Figure 4 below gives an overview of the most plant species used.

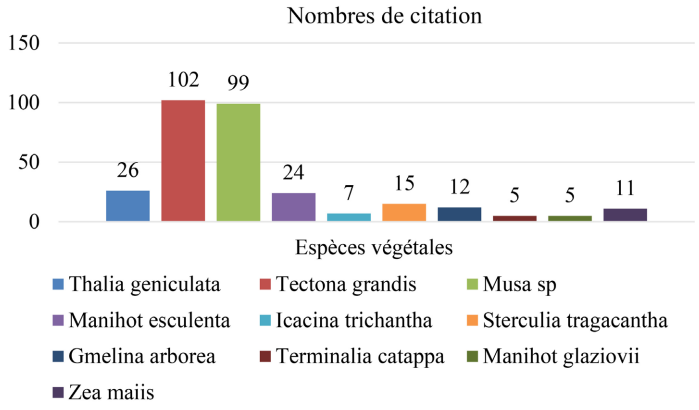

Figure 4. Statistics of plant species commonly used as food packaging in southern Benin.

3.2. Phytochemical Compounds Analysis

Results of the phytochemical screening in the leaves of these plant species are presented in Table 2 below.

Table 2. Phytochemical screening test results.

Chemical compounds	Plant leaves						Protocols
	Gmelina arborea	*Manihot esculenta*	*Musa sp*	*Tectona grandis*	*Terminalia catappa*	*Thalia geniculata*	
Alkaloids	+++	+++	-	++++	++++	-	(El Haoud *et al.* 2018)
Anthocyanins	+	+++	+	++	+++	++	(Houghton et Raman 1998)
Coumarines	+++	+++	+++	++	++	++	(Bechro *et al.* 2007)
Cyanogenic derivatives	-	-	-	-	-	-	(Houghton et Raman 1998)
Flavonoids	++	++++	+	+	++	++++	(Krishnamoorthy *et al.*, 2014)
Glycosides	-	-	-	-	-	-	
Leuco anthocyanins	+	…	+	+	++	…	(Houghton et Raman 1998)
Mucilages	+++	++	+++	++	++	+++	(El Haoud *et al* 2018)
Phenols	-	+++	-	+	++++	+	(Krishnamoorthy *et al.*, 2014)
Proteins	-	…	…	++	+++	+	(Bechro *et al.* 2007)
Quinones	-	-	-	+	-	-	
Saponins	++	…	-	++++	…	+	(El Haoud *et al.*, 2018)

Continued

Steroids	-	++	-	-	-	-	Liebermann Burchard reaction
Reducing sugars	+++	+++	+++	+++	++++	++++	(Bechro *et al.*, 2007)
Tannin	-	++	-	+	++++	++	
Terpenes	…	-	…	+++	++	++	Liebermann Burchard reaction

Legend: -: No determined; …: Traces (weak arguments in favour of a presence); +: Not abundant; ++: Fairly abundant; +++: Abundant; ++++: Plentiful.

4. Discussion

Results confirm several previous studies on plant-based food packaging, in particular those by Onzo *et al.* [3] [5] [7] and Ouétchéhou [8]. *Tectona grandis* and *Musa sp* are the leading plant species used as vegetable food packaging. They are followed by *Thalia geniculata* and *Manihot esculenta*.

Food packaging is used to protect, preserve and transport food [15]. In the least developed countries, people mainly use vegetable packaging to protect and preserve food from physical or organoleptic deterioration [3]. Results from fieldwork have shown that people in south-west Benin (Comè, Lokossa, Dogbo, Azovè) base their inclinations mainly on plant species used as animal fodder. For these people, animals have a "sense" that directs them towards non-toxic plants, whereas even starving animals will not eat plants that present a risk of toxicity. These theoretical perceptions of populations have been proven by empirical work by Onzo *et al.* [7], who have shown that plant-based food packages present little or no toxicity for consumers. Apart totems and superstitions, which prevent people from using certain plant species, such as the leaves of *Tectona grandis* at Lokossa in the Mono department, choice of people for plant species is based on the availability of plant material, ease of access (usually family plantations), their very low cost and their physical, morphological and organoleptic characteristics. This was the case for the populations surveyed during our investigations.

4.1. Physical Properties of Plant Leaves

Food packaging in general, and vegetable film packaging in particular, forms a physical fence between its contents and the immediate environment, which is often polluted with microorganisms and dust. These leaves are often chosen by consumers for their physical and mechanical properties, such as toughness, elasticity, hardness, resilience, ability to retain heat and improve the taste of the food, etc. In fact, some of the properties of these sheets come from their internal constitution, their surface being formed by a layer of wax and various materials ensuring their impermeability to water, giving them both the flexibility and mechanical strength required for packaging [5]. Other sheets acquire their remarkable properties after undergoing pre-treatments such as bleaching, flaming, rinsing, etc. [3].

4.2. Morphological Properties

For the measurements carried out in the laboratory after returning from the field, the size of some of the *Tectona grandis* leaves sampled varied between 0.80 and 1 m long and 0.50 to 0.70 m wide, or even more. As for the *Musa sapientum* leaves, the sizes measured varied between 2 and 2.5 m long along the main vein and 0.50 to 0.60 m wide. Generally speaking, the vegetable leaves used in Benin's traditional food industry are particularly well suited to the purchasing power of the mostly low-income population. The relatively large surface area of the leaves and their low cost of production or acquisition are major factors in people's choices.

4.3. Composition of Natural Substances

Several families of secondary metabolites are present in the leaves of species used as vegetable packaging: alkaloids, phenolic compounds, quinone derivatives, saponosides, terpenoids and steroids, mucilages, coumarins and reducing compounds.

In fact, apart from the alkaloids, saponosides, reducing sugars and terpenes found in abundance, and the less abundant anthocyanins, coumarins, mucilages and proteins, the tests carried out on the leaves of *Tectona grandis* do not present sufficiently strong colourimetric arguments in favour of an abundance of tannins, flavonoids, phenols, quinones and leucoanthocyanins, l*et al*one the presence of glycosides and steroids. Although *Gmelina arborea* belongs to the same family (*Lamiaceae*), its phytochemical composition differs significantly from that of *Tectona grandis*. Rich in alkaloids, coumarins, mucilages, flavonoids, saponosides and reducing sugars, the leaves of *Gmelina arborea* differ from those of *Tectona grandis* in the absence of tannins, proteins, quinones and phenols. Phytochemical composition therefore varies from one species to another within the same family. These results confirm those of Ogunmefun *et al.* [16] on the high concentration of alkaloids, abundant flavonoids and total phenols in *Tectona grandis* leaves and those of Jajere *et al.* [17] on the absence of tannins in *Gmelina arborea* leaves. The absence or low presence of tannins in the leaves explains their widespread use as food packaging. In fact, apart from *Terminalia catappa*, which has the highest concentration of tannins of all the leaves and which is, moreover, the leaf least widely used as food packaging, all the other plant leaves have low concentrations of tannins, justifying their high use in food processing. Tannins are unpleasant to the taste. Their astringency is proportional to their concentration in the leaves, fruit and other parts of the plant.

Species in the *Lamiaceae* family are mainly used for their ability to smell, which helps to improve the organoleptic quality of packaged foods [18]. This explains the heavy use of *Tectona grandis* leaves, which, as well as flavouring akassa (maize fermented paste), give it a slightly reddish tint that is much appreciated by customers.

Musa sp leaves contain fewer secondary metabolites than any other plant. They contain large quantities of chemical compounds such as coumarins, mucilages and reducing sugars, and small quantities of anthocyanins, flavonoids and

leucoanthocyanins. However, some studies report that *Musa sapientum* leaves contain tannins, alkaloids and phenols [19] [20]. They are, however, widely used because of their physical and morphological properties. *Thalia geniculata* and *Manihot esculenta* have very interesting secondary metabolites. These results confirm those of Henneh *et al.* [21] on the leaves of *Manihot esculenta*. Composition of secondary metabolites of plants depends to a number of environmental and geographical factors, the period and time of collection and storage conditions [22]. These factors may explain the small differences in phytochemical composition observed. Other factors of variation are linked to the sensitivity of methods used.

4.4. Pharmacological Properties

The following uses were provided by resource persons during the survey.

4.4.1. *Tectona grandis*

Infusions or decoctions of young *Tectona grandis* leaves are widely used by people in southern Benin to treat malaria and prevent and treat anaemia. They are also used as an antipyretic during fever attacks, and to prevent and treat dizziness and tiredness. Young teak leaves (buds) also combat ageing and treat skin diseases.

4.4.2. *Musa sapientum*

These leaves are used by people to treat haemorrhage, fatigue, anaemia, fever, bodily infections, coughs, flu, toothache, vomiting, accelerate wound healing and facilitate childbirth. These roots are used to treat male sexual weakness.

4.4.3. *Thalia geniculata*

These leaves are mainly used to treat all forms of malaria.

4.4.4. *Manihot esculenta*

Manihot esculenta leaves are highly prized in gastronomy in southern Benin. Rich in vitamins, they are used to treat avitaminosis and prevent malnutrition in children and maintenance in the elderly. They are used to treat malaria and anaemia. They add flavour to food and help to improve memory.

4.4.5. *Gmelina arborea*

These leaves are used to treat malaria and provide energy to the body weakened by the disease.

4.4.6. *Terminalia catappa*

Different parts (the moix) of this plant are used in the food industry to make food supplements, yoghurts, wines and alcoholic beverages, as well as body care and weight loss (obesity) products and to treat abscesses... Leaf extracts have highly effective antifungal properties. They are therefore used to treat aspergillosis [23]. In fact, certain chemical molecules such as monoterpenes and sesquiterpenes have very interesting antifungal activity [24]. They are thought to be involved in disrupting the growth of microorganisms such as *Aspergillus fumigatus* [25] by

interacting with the fungal cell membrane [26].

Some of the bioactive molecules in natural substances found in the leaves of plant species used as food packaging have either a fungistatic or bacteriostatic effect. They interfere with the growth of microorganisms and thus limit their development, or they have a fungicidal or bactericidal effect. They cause the death of microorganisms. However, the effects of natural substances depend on their dose [27]. The static effect is caused by partial inhibition of respiration and membrane permeability, while the lethal effect causes total inhibition of the above functions, with irreversible damage to the cell membrane causing death [28]. Other effects, such as deactivation of enzymes or proteins, disruption of energy production and interference with metabolic cycles, are lethal to microorganisms. These results deserve to be further explored through new investigations to promote the value of these plant species. Nevertheless, the promotion, even now, of these plant species over plastic packaging offers several benefits for both the populations and the environment: good food preservation, the prevention and treatment of certain endemic diseases such as malaria, and the fight against pollution caused by non-biodegradable plastic waste.

5. Conclusion

In addition to this wealth of tourist attractions, the southern Benin is also home to a wealth of plant species used by local people to package their products and food preparations for preservation, transport and sale to customers. Of the plant species listed, *Tectona grandis*, *Musa sp*, *Thalia geniculata*, *Manihot esculenta*, *Gmelina arborea* and *Terminalia catappa* are the most commonly used by people in southern Benin to package cooked foods such as fermented maize paste (Akassa, Lio), Kandji, beans paste with maize flour (Abla), Konginmin, and other pre-cooked foods such as African mustard (Afinti), cowhide (Kpanman), dried or smoked fish or other fresh products. The bioactive molecules contained in these plant leaves help preserve the action of microorganisms, ensure good preservation, and improve the organoleptic quality of the foodstuffs packaged in them. They are also involved in the prevention and treatment of many diseases, including malaria.

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Author Contributions

The Laboratory of Biochemistry and Molecular Biology (LBBM) consists of five members working as a team under the leadership of Dr. (MC) ADJOVI. The

conceptualization of this research project was collectively decided, along with the methodology. The interdisciplinary nature of the team members contributed to a division of labor. The first author conducted fieldwork based on the collaboratively established guidelines. Sampling was carried out by the first and third authors. Activity tests were supervised by the fourth and fifth authors. The results and their interpretations were overseen by the corresponding author, along with the funding. The manuscript was written by the first author, while all authors contributed to the revisions and editing. The validation and publication of the results were managed by the Laboratory Head.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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