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Typology and quality preference of plant leaves used for food packaging in Benin

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Abstract

Plant leaves are used to package various local foods in Benin. Vegetable packaging is a good alternative to plastic packaging in use in the country. A better knowledge of these plants and their different uses is necessary for their valorization. This study aims to identify the plant resources that are used in Benin as food packaging and to determine their preferable characteristics according to food processors and consumers. A survey was carried out considering 300 food processors and 300 consumers in ten municipalities in Benin. The leaves of 58 plant species belonging to 30 families have been identified and are used to pack 29 different types of food sold in the different markets of the survey areas. The choice of a leaf by processors and consumers is performed according to well-defined criteria. The main criteria used by processors are tear resistance (86%), food shelf life (82%) and size (69%), while consumers use organoleptic characteristics (78%) and food shelf life (51%) of the leaf. For all foods, about six major species of leaf including Musa sapientum, Tectona grandis, Thalia geniculata, Manihot esculenta, Gmelina arborea and Isoberlinia doka have the best characteristics according to processors and consumers. Before the leaves are used as food packaging, processors usually apply treatments that are supposed to improve the tear resistance of the leaves and reduce microbial contamination. Regarding the characteristics of these leaves at food artisanal scale, they are potentially good base material useful to produce leaf plates or modern food biodegradable packaging.

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Introduction

Food packaging is used to facilitate the protection, transport and storage of food (Robertson, 2006; Wikström *et al.*, 2014; Ribeiro-Santos *et al., 2017*). Depending on the manufacturing materials, several types of packaging are available on the market with different characteristics: plastic (the largest in volume produced), paper and cardboard (primary material in value), glass, wood, metals and composites (mixture of several materials) (Marsh and Bugusu, 2007). Likewise, researchers and manufacturers have developed modern packaging (active, intelligent, functional and bioactive packaging) capable of actively interacting with food and their environments or providing information on the state of the freshness of food (Realini and Marcos, 2014; Meena *et al.*, 2017). Among all these types of packaging, those made from plastic materials dominated in food industry because of their practical and aesthetic character (Siracusa *et al.*, 2008; Malathi *et al.*, 2014). This petro-based food packaging is non-biodegradable and has replaced a part of the natural packaging that has been used in the world for many centuries (Mustafa *et al.*, 2012; Ribeiro-Santos *et al.*, 2017). This non-biodegradable packaging is used massively and invades as well as urban and rural areas. But because of their non-biodegradable nature, they present several issues including environmental pollution, unhealthy cities and the stuffing of gutters (Adejumo and Ola, 2008; Onzo *et al.*, 2013; Shaikh *et al.*, 2021).

This situation in developing countries has led several countries to put in place regulatory policy which aims to forbid the use of non-biodegradable plastic packaging. The Republic of Benin voted in December 2017 the law No. 2017-39 prohibiting the production, export, marketing, possession, distribution and use of non-biodegradable plastic bags in the country.

Similarly, environmental and public health challenges have increased and have stimulated innovations in food packaging. In this context, natural and biodegradable synthetic packaging constitutes an exploitable resource for finding an alternative solution to non-biodegradable packaging (Davis and Song, 2006). Indeed, before the emergence of non-biodegradable packaging, food production technologies used plant and animal materials to package food (Gupta and Dudeja, 2017). Today, although non-biodegradable packaging is widespread all over the world, plant packaging continues to be used in many regions of the world, mainly in Africa, Asia and South America (Adegunloye *et al.*, 2006; Ahmadi *et al.*, 2019; Kora, 2019). Some plant species used to wrap food have been identified and characterized in Nigeria (Adegunloye *et al.*, 2006), in Ghana (Mensah *et al.*, 2012) and Benin (Onzo *et al.*, 2013, 2016).

According to Onzo *et al.* (2013), besides the protective function that these packages provide, they transfer aroma or colour to packaged foods, while others are also eaten as leafy vegetables or used for their medicinal properties (Mostafa, 2021). Mensah *et al.* (2012), Onzo *et al.* (2014) and Zannou *et al.* (2016) reported that leaf packaging contains physicochemical compounds such as proteins, lipids, minerals, vitamin C and phytochemicals such as tannins, anthocyanins, flavonoids, alkaloids, etc. that could migrate from the leaves to the food. Also, the leaves of some species such as *Daniella oliveri* and *Thalia geniculata* used as food packaging have antimicrobial properties and preserve food quality during storage (Onzo *et al.*, 2015).

In part of the valorization of plant packaging in Benin, some studies have been carried out to provide information on the types of plant packaging, uses, treatments and physical properties of the leaves of plants used as food packaging. However, the most suitable leaf packaging for each food and the criteria for assessing the quality of leaf packaging are not well documented.

The objectives of this study were therefore (i) to inventory the plant resources used as food packaging in Benin (ii) to determine the criteria for assessing the quality of plant packaging and (iii) to identify the best leaf packaging used for food production in Benin.

Methodological approach

Survey areas

The study was carried out in ten (10) Municipalities of the Republic of Benin (West Africa) selected throughout the seven (7) Agricultural Development Poles (ADP) defined by the Beninese government in 2017 based on the main agricultural productions (Fig. 1).

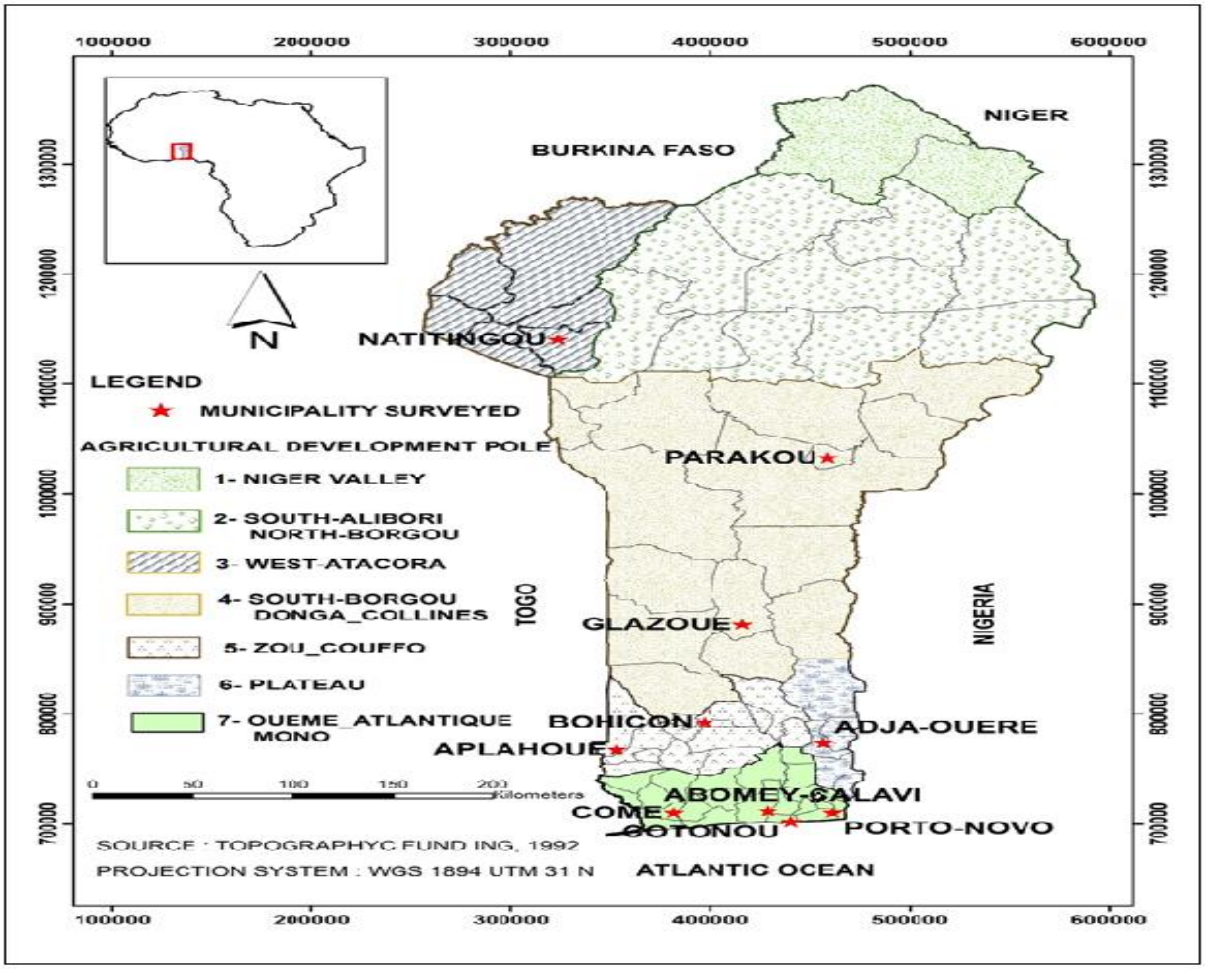

Fig. 1. Geographic location of municipalities surveyed.

Municipalities were selected in these ADPs based on different criteria which are the level of urbanization, and the presence of a large market where it is possible to find a diversity of leaf packaging. The municipalities selected in the ADP for this study are:

ADP 1, ADP 2, and ADP 3: Municipality of Natitingou

ADP 4: Municipalities of Parakou and Glazoué

ADP 5: Municipalities of Bohicon and Aplahoué

ADP 6: Municipality of Adja Ouèrè

ADP 7: Municipalities of Comé, Abomey-Calavi, Cotonou and Porto-Novo.

Sampling and data collection

A preliminary survey was carried out in three of the selected municipalities (Cotonou, Abomey-Calavi, and Parakou). The aim was to test the survey questionnaires and make a direct observation of the status of commercialization and utilization of vegetable material for food packaging in the markets. This allows to identify the different actors across the value chain of vegetable packaging (producers, processors, vendors, and consumers of packaged food) and to improve the questionnaires for a better comprehension by the respondents (meanwhile allowing achieving the study objectives). The survey considered producers and consumers of food packaged in vegetable materials. In each survey municipality, thirty (30) producers and thirty (30) consumers were surveyed. Snowball sampling method was used to determine the population samples. The

interviews were carried out in the main markets of each municipality during the market days using two questionnaires (one for processors and one for consumers). The collected information is related to the nature of plant materials used as food packaging, food packaged, preference and quality criteria of packaging materials.

Data analysis

Leaves of plant species used as food packaging by processors were identified using the method described by Onzo *et al.* (2013). The data collected were processed with Excel. A Correspondence Analysis was carried out to study the relationships that exist between vegetable packaging and the different types of food identified during the survey. A Principal Component Analysis (PCA) was carried out on data related to the quality assessment criteria of leaf packaging of the most cited foods. These Correspondence Analysis and Principal Component Analysis were carried out using software R version 3.6.1.

Results and discussion

Local foods and leaf packaging identified

The use of plant materials to pack food is a common practice in Benin in rural and urban areas. The investigation showed a great diversity of plant species whose leaves are used as packaging in the traditional food industry in Benin. Table 1 shows the foods that are packaged in leaves and the species of leaves that are used to pack each food.

About 60 species of leaves have been identified and are used to package about 30 types of food sold in markets in the survey areas. The identified species belong to 30 families, among which the most represented are Moraceae, Fabaceae and Verbenaceae. Except for *Milicia excelsa* used for Lio (fermented cereal dough, steamed with leaf packaging), the leaf species identified in this study have been reported in previous work conducted in several countries around the world (Mensah *et al.*, 2012; Onzo *et al.*, 2013, 2016;). Two species, *Tectona grandis* and *Musa sapientum* were found in all the survey areas. While *Isoberlinia doka* and *Gmelina arborea* were used mainly in the municipalities in the Centre and North of the country (Glazoué, Parakou and Natitingou), *Cyrtosperma senegalense*, *Lasiomorpha senegalensis* and *Thalia geniculata* were notably cited in the municipalities of the South of the country (Bohicon, Aplahoué, Adja-Ouèrè, Comé, Abomey-Calavi, Cotonou and Porto-Novo). The types of leaves most used by populations as food packaging change sometimes from one area to another depending on factors such as cultural diversity, user preference and factors linked to the ecosystem of the locality (Onzo *et al.*, 2013).

Table 1. Local foods identified and plant leaf species used for their packaging.

Food	Percentage of respondents (%)		Number of leaf packaging	Leaf packaging species
	Pro (N=300)	Con (N=300)		
Akassa	35.67	100	24	*Tectona grandis, Musa sapientum, Thalia geniculata, Isoberlinia doka, Gmelina arborea, Cyrtosperma senegalense, Ampelocissus leonensis, Siphonochilus aethiopicus, Sarcocephalus latifolius, Argyreia nervosa, Ampelocissus pentaphylla, Calotropis procera, Canna indica, Cola gigantean, Cola millenii, Dioscorea alata, Icacina trichantha, Lasiomorpha senegalensis, Musa chinensis, Polygonum senegalense, Pouteria alnifolia, Isoberlinia grandiflora, Isoberlinia tomentosa, Lagenaria siceraria***
Lio	26.33	46.00	28	*Elaeis guineensis, Manihot esculenta, Tectona grandis, Musa sapientum, Daniellia oliveri, Gmelina arborea, Manihot glaziovii, Thalia geniculata, Isoberlinia doka, Argyreia nervosa, Calotropis procera, Antiaris toxicaria, Blighia sapida, Calopogonium mucunoides, Canna indica, Cussonia arborea, Ficus capensis, Ficus embellata, Ficus phita, Ficus platiphylla, Ficus polita, Ficus ingens, Ficus sycomorus, Holarrhena floribunda, Lannea microcarpa, Milicia excelsa, Pouteria alnifolia, Triplochiton scleroxylon*
Abla	18.67	14.00	8	*Tectona grandis, Isoberlinia doka, Musa sapientum, Cyrtosperma senegalense, Elaeis guineensis, Gmelina arborea, Thalia geniculata, Lasiomorpha senegalensis*
Toubani	14.00	13.00	15	*Isoberlinia doka, Musa sapientum, Tectona grandis, Gmelina arborea, Thalia geniculata, Triplochiton scleroxylon, Lannea microcarpa, Sarcocephalus latifolius, Canna indica, Piliostigima thonningii, Calopogonium mucunoides, Anthocleista vogelii, Anthocleista*

				djalonensis, Clerodendrum polycephalum, Combretum collinum
Gowé	13.00	17.67	5	*Tectona grandis, Musa sapientum, Thalia geniculata, Isoberlinia doka, Lasiomorpha senegalensis*
Kandji	7.33	13.67	6	*Lasiomorpha senegalensis, Musa sapientum, Thalia geniculata, Pouteria alnifolia, Cussonia arborea, Cyrtosperma senegalense*
Afitin*	5.33	41.67	3	*Elaeis guineensis, Tectona grandis, Thalia geniculata*
Abogo	5.00	6.33	5	*Tectona grandis, Musa sapientum, Isoberlinia doka, Cyrtosperma senegalense, Lasiomorpha senegalensis*
Ikaraèkpa	4.33	4.33	5	*Musa sapientum, Isoberlinia doka, Tectona grandis, Gmelina arborea, Lasiomorpha senegalensis*
Ablo	3.67	4.67	4	*Musa sapientum, Musa chinensis, Thalia geniculata, Cyrtosperma senegalense,*
Fritter*	1.67	1.33	6	*Tectona grandis, Icacina trichantha, Isoberlinia doka, Mangifera indica, Vitellaria paradoxa, Sterculia tragacantha*
Abloyoki	2.33	1.33	2	*Cussonia arborea, Cussonia barteri*
Tchohoumbo	2.00	2.33	4	*Musa chinensis, Musa sapientum, Tectona grandis, Isoberlinia doka*
Karanan	0.67	3.67	6	*Adenodolichos paniculatus, Gmelina arborea, Piliostigima thonningii, Alchornea cordifolia, Detaricum macrocarpum, Annona senegalensis*
Sonru*	2.67	7.00	2	*Tectona grandis, Isoberlinia doka*
Amanminnou	1.33	1.33	6	*Zea mays, Elaeis guineensis, Pouteria alnifolia, Musa sapientum, Isoberlinia doka, Cyrtosperma senegalense*
Come	1.00	1.67	1	*Zea mays*
Aboété	0.67	5.33	2	*Musa sapientum, Thalia geniculata*
Batè	1.00	0.00	2	*Blighia sapida, Cussonia arborea*
Adjagbé	0.67	3.67	4	*Tectona grandis, Icacina trichantha, Musa sapientum, Elaeis guineensis*
Olèlè	0.67	4.00	2	*Tectona grandis, Isoberlinia doka*
Boiled cassava*	0.33	3.00	2	*Cyrtosperma senegalense, Tectona grandis*
Smoked fish*	0.33	3.00	2	*Tectona grandis Isoberlinia doka*
Kowé	0.67	0.00	3	*Tectona grandis, Musa sapientum, Isoberlinia doka*
Kpo	0.67	0.00	2	*Tectona grandis, Musa sapientum*
Zankpiti*	0.33	0.00	2	*Tectona grandis, Cyrtosperma senegalense,*
Agnan*	0.33	0.67	3	*Cyrtosperma senegalense, Tectona grandis, Lasiomorpha senegalensis*
Boiled yam*	1.00	0.33	3	*Cyrtosperma senegalense, Lasiomorpha senegalensis, Tectona grandis*
Iru*	0.33	0.67	1	*Tectona grandis*

* Food pack in leaf packaging for transportation;
** Calabash Pro: Processor Con: Consumer.

Foods mostly mentioned by respondents are Akassa, Lio, Abla, Toubani, Gowé and Kandji. Akassa, Lio and Kandji are cereal fermented doughs whose processes are well documented (Onzo *et al.*, 2013). Akassa and Gowé are cooked before being wrapped, while Abla, Toubani, Lio and Kandji are wrapped before being steamed. Gowé is a non-alcoholic cereal beverage traditionally produced from a malted sorghum flour (Hounhouigan *et al.*, 1994; Michodjèhoun-Mestres *et al.*, 2005; Onzo *et al.*, 2013). Abla is produced from cereal, legumes and unrefined palm oil, while Toubani is produced from legumes, roots and tubers (Hongbete *et al.*, 2017). For the food packaging, different leaves are used. Akassa is packaged in leaves of twenty-four (24) species, principally *Tectona grandis*, *Musa sapientum* and *Thalia geniculata*, respectively, to 69.7%, 51.8% and 39.3% of respondents. Lio is packaged with leaves of twenty-eight (28) species, mostly in *Manihot esculenta*, *Tectona grandis* and *Musa sapientum*, respectively to 54.8%, 32.3% and 22.3% of respondents. *Manihot esculenta* and *Daniellia oliveri* leaves are only used for Lio. Regarding Abla, eight (8) species of leaves are used and the most cited are *Tectona grandis*, *Isoberlinia doka* and *Musa sapientum*, respectively to 45%, 33.6% and 19.7% of respondents. Among the fifteen (15) species which are used for Toubani, the most cited are *Isoberlinia doka*, *Musa sapientum* and *Tectona grandis* by 77.6%, 52.8% and 49.3%, respectively. Five (5) species are mentioned for Gowé, mostly *Tectona grandis* (66.5% of respondents), *Musa sapientum* (38.7% of respondents) and *Thalia geniculata* (16.3% of respondents). For Kandji, six (6) species are used including mainly *Cyrtosperma*

senegalense, *Musa sapientum*, *Thalia geniculata,* respectively cited by 60.7%, 31.5% and 15.2% of respondents. *Tectona grandis* and *Musa sapientum* are used as packaging for all other foods and are, therefore, multiproduct packaging (Onzo *et al.*, 2013). *Tectona grandis*, *Musa sapientum* and *Thalia geniculata* are reported by some authors as food packaging used for several types of food because of the organoleptic quality they confer to food or their ability to preserve food quality (Adegunloye *et al.*, 2006; Onzo *et al.*, 2013, 2015; Dewi *et al.*, 2021) . Among the foods that are packaged with leaves, 18 foods (64.3%) are packaged with *Tectona grandis*, while *Musa sapientum* is used for fourteen (14) foods (50%). The leaves of *Isoberlinia doka*, *Cyrtosperma senegalense*, *Lasiomorpha senegalensis*, *Gmelina arborea* and *Thalia geniculata* were mostly cited and are found in several localities. Although they do not grow in all localities, they are encountered in several survey areas through commercial activities favouring their transfer from the countryside to the cities or from one city to another. This could justify the fact that some species including *Tectona grandis*, *Thalia geniculata* and *Musa sapientum* are considered multi-local and multiproduct packagings (Onzo *et al.*, 2013).

Table 2. Consumers' preferences for leaf packaging by food.

Foods / ADP	Number of respondents	Percentage (%) of preference for each species of leaf packaging per food and per Agricultural Development Pole										
		Daniellia oliveri	*Gmelina arborea*	*Icacina trichantha*	*Isoberlinia doka*	*Lasiomorpha senegalensis*	*Manihot esculenta*	*Musa sapientum*	*Sarcocephalus latifolius*	*Tectona grandis*	*Thalia geniculata*	No preference
Akassa	300		5,7	0,7	14,3	2		28,7		29,7	17	2
ADP3	30		16,7		60			10		13,3		
ADP4	60		20		41,7			20		16,6		1,7
ADP5	60							46,7		43,3	10	
ADP6	30							20		43,4	33.3	3,3
ADP7	120			1,7		5		30,8		30	29,2	3,3
Lio	130	26,9					61,6	1,5	3,1	3,8		3,1
ADP3	3	100										
ADP4	17	41,2					35,3		23,5			
ADP5	54	24,1					70,3	3,7				1,9
ADP6	4						100					
ADP7	52	23,1					61,5			9,6		5,8
Afitin	125									84	2,4	13,6
ADP3	5									80		20
ADP4	33									81,8	3	15,2
ADP5	33									84,8		15,2
ADP6	2									100		
ADP7	52									84,6	3,8	11,6
Gowé	53							28,3		67,9		3,8
ADP5	17							17,6		82,4		
ADP7	36							33,3		61,1		5,6
Abla	44				11,4			61,3		27,3		
ADP4	19				26,3			57,9		15,8		
ADP5	14							64,3		35,7		
ADP6	2									100		
ADP7	9							77,8		22,2		
Kandji	41				12,2	73,2		12,2			2,4	
ADP4	5				60			40				
ADP5	11					81,8		9,1			9,1	
ADP7	25				8,0	84,0		8,0				
Toubani	39				82,1			2,6		12,7		2,6
ADP3	29				82,8			3,4		13,8		
ADP4	10				80					10		10
Total	895	4.2	2.1	0.5	12.7	5.3	9.3	21.9	0.5	31.3	7.6	4.6

ADP: Agricultural Development Poles. ADP 3: Natitingou; ADP 4: Parakou and Glazoué; ADP 5: Bohicon and Aplahoué; ADP 6: Adja-Ouèrè; ADP 7: Porto-Novo, Cotonou, Abomey-Calavi and Comé.

Relations between local food and leaf packaging

On the one hand, local foods packaged in vegetable leaves are produced from various types of raw materials. Correlation analysis showed that there is no statistically significant link ($p>0.05$) between the raw materials used to produce the food and the leaf species that are used. Thus, there is no leaf packaging clearly or specifically linked to foods depending on the fact that they are derived from cereals, roots and tubers, or legumes. Likewise, the choice of leaves does not depend on the characteristics of the food (acidic or not, high in fat or not). On the other hand, it was demonstrated a significant link ($p<0.05$) between the step at which the food is packaged during production and the species of plant leaves that are used to pack the food. Indeed, local foods are packaged at steps that differ from one food to another. The variable 'packaging step' was used with three modalities: food packaged before steaming, food packaged after cooking and food packaged just for transport. Foods identified have therefore been classified into three groups according to these modalities.

Table 3. Treatment carried out on leaf packaging before use.

Species of leaf packaging	Number of respondents	Percentage (%) of processors who apply the treatment					
		Tailing	Blanching	Flaming	Sun drying	Washing	Wiping
Tectona grandis	256	100	-	-	-	27.3	72.7
Isoberlinia doka	234	-	-	-	-	29.9	70.1
Musa sapientum	218	-	-	100	-	5	95
Thalia geniculata	198	100	86.4	-	-	3.0	10.6
Gmelina arborea	154	-	80.5	-	-	17.5	2
Lasiomorpha senegalensis	128	-	32.7	-	67.3	15.8	_52.5
Manihot esculenta	111	-	-	-	-	62.2	37.8
Daniellia oliveri	70	-	-	-	-	81.4	18.6
Sarcocephalus latifolius	42	-	100	-	-	-	-

The Correspondence Analysis showed that the leaf packaging cited by at least 10% of respondents can be classified into four categories (Fig. 2).

Category 1: This category shows the leaves that are used for all foods. *Tectona grandis* and *Cyrtosperma senegalense* are therefore used for all types of food. They are used for foods that are packaged before cooking, foods packaged after cooking and foods that are packaged just for transport. It was noted that the leaf also used as transport packaging have a large size and are available. This is the case of *Tectona grandis* available in all survey areas and *Cyrtosperma senegalense* available in the South of the country, mainly in swampy areas.

Category 2: Among the most used leaves, *Siphonochilus aethiopicus*, *Ampelocissus leonensis*, *Sarcocephalus latifolius*, *Thalia geniculata*, *Icacina trichantha* have been classified as those used for foods which are packaged after cooking such as Akassa, Gowé, Abogo. The mechanical and barrier properties of these leaves could be reduced under the action of prolonged contact with heat. This could explain the fact that they are mainly used for foods that are packaged after cooking.

Category 3: Leaves of *Lasiomorpha senegalensis*, *Triplochiton scleroxylon*, *Zea mays*, *Lannea microcarpa*, *Blighia sapida*, *Danielli oliveri*, *Manihot esculenta*, *Piliostigima thonningii*, *Cussonia arborea* are classified as the leaves packaging particularly used for foods which are packaged before being steamed such as Lio, Abla, and Toubani.

These leaves are mostly small in size and are well appreciated for their resistance to steam and their ability to preserve or improve the organoleptic characteristics of foods. Although statistical analyses did not show a correlation between food

characteristics and leaves, it was observed that among the leaves packaging of this category, some are mainly used for specific foods. This is the case of *Lasiomorpha senegalensis* leaves, which are most used for Kandji. Likewise, the leaves of *Zea mays* and *Manihot esculenta* are used respectively for Come and Lio. Category 4: This category groups the leaves which are used both for food packaged after cooking and food which is cooked before steaming. The leaves in this category are those of *Gmelina arborea*, *Argyreia nervosa*, *Musa sapientum*, *Musa chinensis* and *Isoberlinia doka*. Correspondence Analysis has shown that there is no significant use as transport packaging for the leaves of these species.

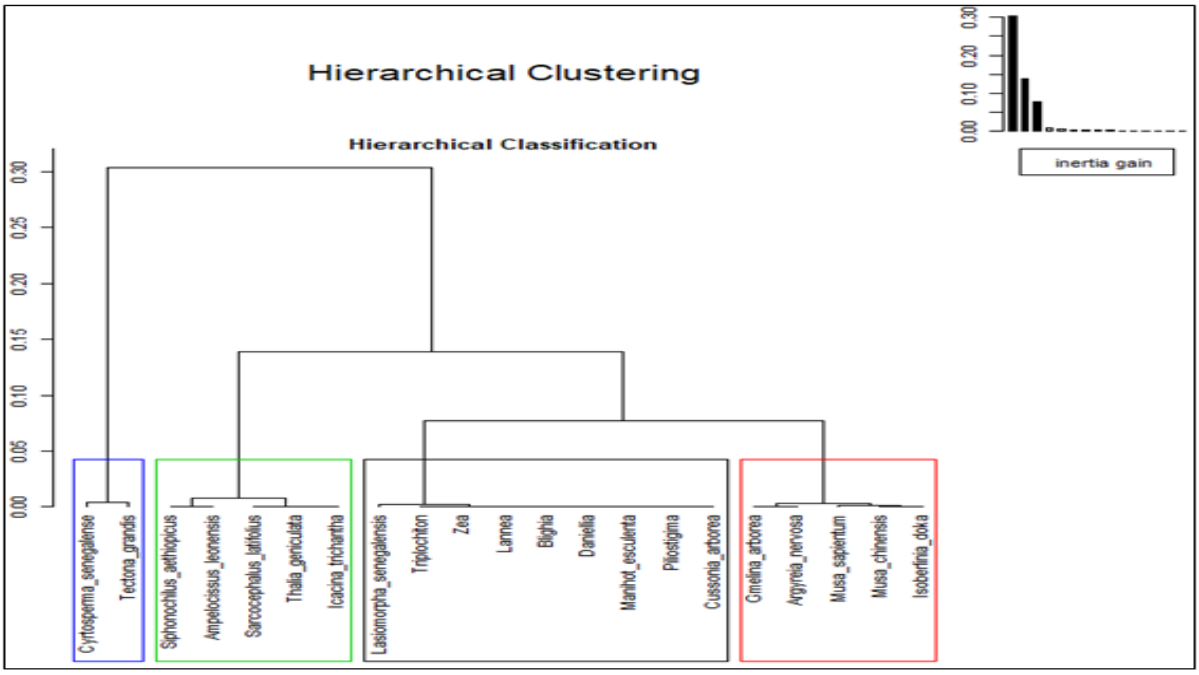

Fig. 2. Hierarchical classification by dendrogram of leaf packaging species most used in food craft according to the packaging step.

The work carried out by Mensah *et al.* (2012) in Ghana, has also shown that certain leaves such as *Musa paradisiaca* are used both for foods that are cooked before being packaged and for foods that are wrapped and cooked with its packaging. According to Kora (2019), *Musa* species are particularly used for various types of food due to their tear resistance, size and ability to transfer special flavours to food and their facility to be removed from the later.

Leaf packaging quality criteria used by processors and consumers

The importance of a criterion varies from one respondent to another (Fig. 3). The leaf shelf life represents an important criterion used only by processors. It has been observed that the other most important criteria for processors are the size of the leaf, tear resistance, smooth character, thickness, flexibility, the effect of the leaf packaging on food organoleptic characteristics and the food shelf life. These main criteria were used by more than 50% of the processors surveyed.

The criteria, ability to be cleaned, ability to be easily removed from the food, leaf shelf life and therapeutic virtues are less important for the processors because they were used by less than 50% of them. Thus the main criteria that are used by processors are related to the characteristics of the leaves and their ability to preserve food. Moreover, during the rainy seasons, processors have access to a variety of leaves, then use these main criteria to choose which one to use. But when the leaves of their preference are not available (in the dry season, for example), processors use the ones they have access to. Apart from the leaf shelf life, the other preference criteria for processors and

consumers are the same, but the most important criteria for consumers are the effect of leaf packaging on food organoleptic characteristics and food shelf life. (Kora, 2019)) and (Asawadechsakdi and Chavalkul, 2021)) reported that users of leaf packaging prefer leaves that are wide enough to carry food, resistant and easy to form. (Kora, 2019)), added that some leaf packaging are preferred due to its durability (shelf life) and colour and flavour transmission when steaming food. Then, these leaves have properties that allow them to transfer tastes and aromas to foods. (Mensah *et al.*, 2012) reported in contrast that medicinal virtue is the main reason for producers' preference for corn meals in Ghana.

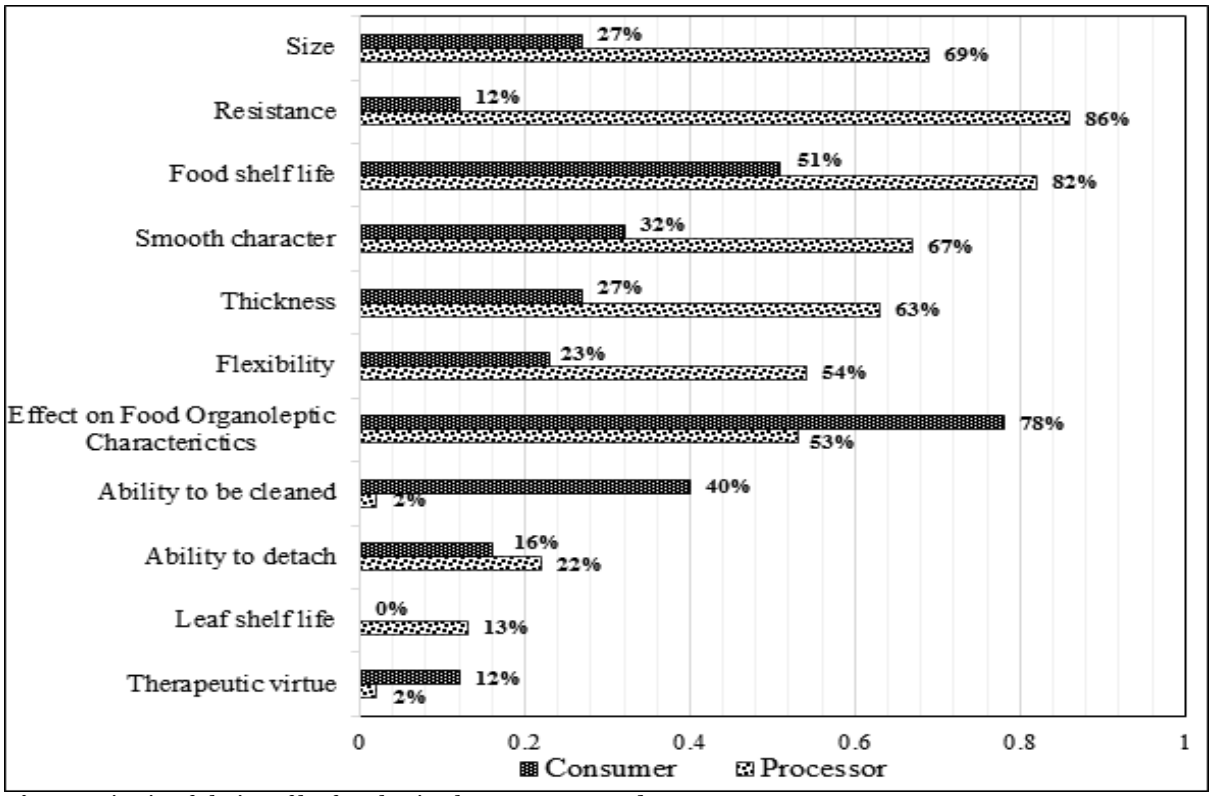

Fig. 3. Criteria of choice of leaf packaging by processors and consumers.

Leaf packaging quality appreciation by processors

A well-defined criterion guides the choice by processors of a leaf packaging for a food product. A Principal Component Analysis (PCA) was performed using the results obtained for the assessment of the leaf quality by processors.

The projection of the main species in the factorial plane represented by axes 1 and 2 allow identifying the plant species whose leaves are most appreciated by processors for foods most mentioned.

For the packaging of Akassa, analysis showed that the leaves of *Thalia geniculata*, *Musa sapientum*, *Isoberlinia doka* and *Tectona grandis* show the best characteristics (Fig. 4A). For processors, the leaves of these species have a good size to pack Akassa. They are resistant, flexible, supple, detached easily from food and preserve organoleptic quality of Akassa. Among the four species most appreciated by processors for Akassa, the leaves of *Thalia geniculata* and *Musa sapientum* were particularly valued for their ability to impart a special flavour to Akassa, as observed by Onzo *et al.* (2013).

Although *Thalia geniculata* is one of the species whose leaves are well valued for Akassa, processors who used it have reported that the shelf life of Akassa packaged with *Thalia geniculata* leaves is low (2 to 3 days), whereas with the leaves of *Isoberlinia doka* or *Musa sapientum* this shelf life is 4 to 5 days and 3 to 4 days with the leaves of *Tectona grandis*.

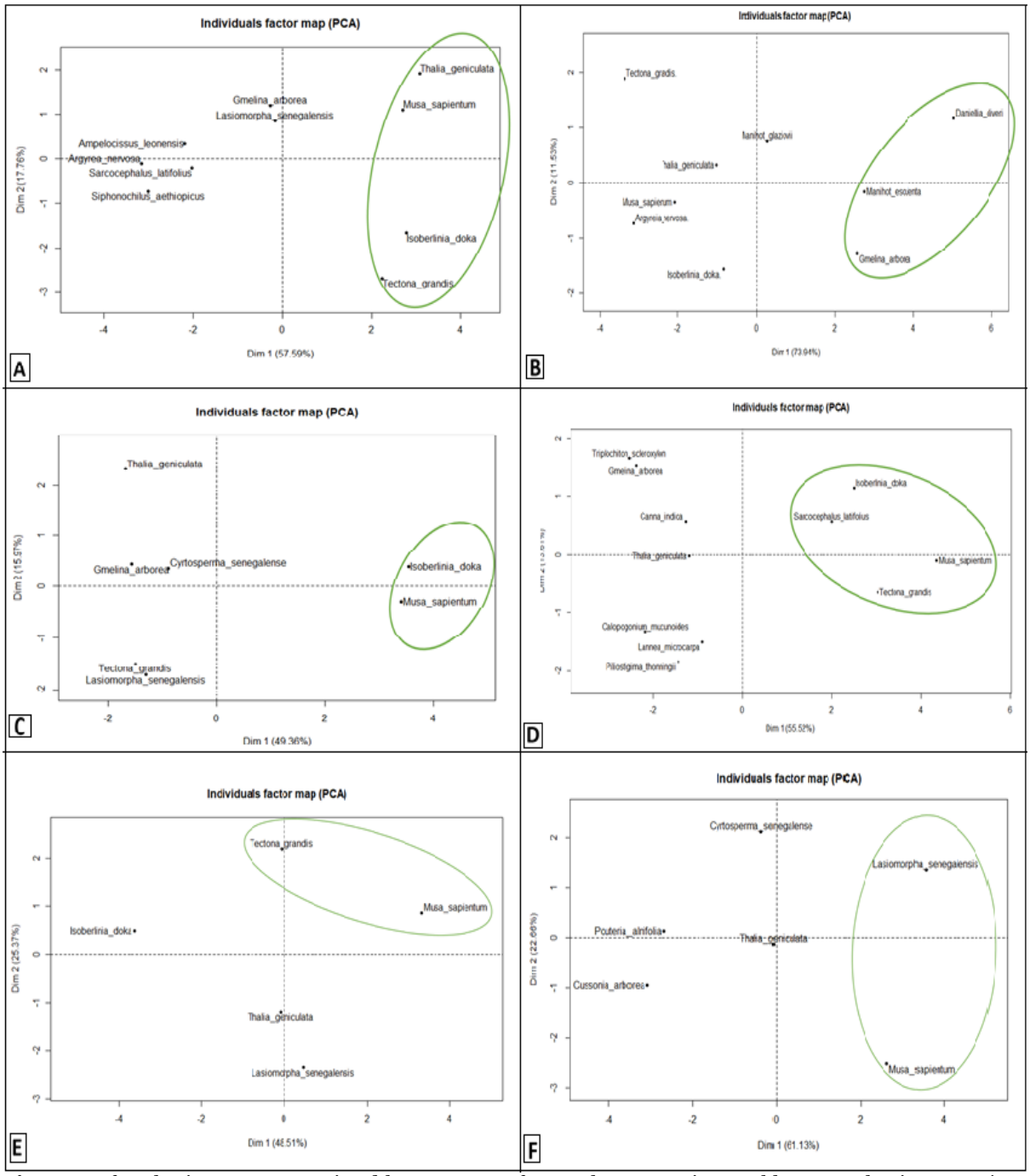

Fig. 4. Leaf packaging most appreciated by processors for A: Akassa, B: Lio, C: Abla, D: Toubani, E: Gowé, F: Kandji.

For Lio, the leaves of *Daniellia oliveri*, *Manihot esculenta* and *Gmelina arborea* present the best characteristics (Fig. 4B). According to processors, the use of these leaves provides a product with good organoleptic characteristics. Likewise, they are flexible and detached easily from food. The leaves of the species *Daniellia oliveri* and *Gmelina arborea* allow conserving Lio for a longer period (6 to 8 days) while the leaves of *Manihot esculenta* allow a conservation of 4 to 5 days. Thus, *Daniellia oliveri* and *Gmelina arborea* particularly are recognized for their ability to conserve Lio. *Manihot esculenta*, although they are small in size and preserve Lio for a shorter time, they are well appreciated by processors because they are very flexible, easy to use, without technological constraints and give organoleptic characteristics highly appreciated by consumers. For Abla, the leaves of *Isoberlinia doka* and *Musa*

sapientum show the best characteristics (Fig. 4C) while for Toubani the leaves most appreciated are *Musa sapientum, Tectona grandis, Isoberlinia doka and Sarcocephalus latifolius* (Fig. 4D). However, for Abla, most of the processors (69.8%) use the leaves of *Tectona grandis* as secondary packaging. These processors have reported that some consumers (particularly in municipalities of Parakou and Glazoué) do not like the product packaged in *Tectona grandis* leaves because they would contain dirt that is left on the food when the leaves are not well cleaned. These consumers who do not like Abla in *Tectona grandis* report that the red colour of this food prevents consumers from appreciating the cleanliness of the leaves used. In times of rarity of *Musa sapientum* and *Isoberlinia doka*, 69.8% of processors use them as primary packaging (directly in contact with food) and *Tectona grandis* leaves are used as secondary packaging to cover food well. This consideration of the cleanliness of the packaging was not reported for other foods. Also, according to processors, Abla and Toubani have a short shelf life (8 to 14 hours). Beyond this shelf life, the organoleptic characteristics of these foods drop considerably.

Fig. 5. Processing and shaping of leaf packaging. A: Washing of *Tectona grandis* leaves, B: Wiping *of Musa sapientum* leaves with a cloth, C: Tailing of *Tectona grandis* leaves with a knife, D: Flaming of *Musa sapientum* leaves, E: Blanching *of Thalia geniculata* leaves, F: Sun drying of *Cyrtosperma senegalense* leaves, G: Akassa wrapped with *Thalia geniculata* leaves, H: *Gmelina arborea* leaves arranged in a calabash (*Lagenaria siceraria*) to wrap Akassa, I: Akassa wrapped with *Isoberlinia doka* leaves arranged in calabash.

Regarding Gowé, a food made from sorghum (cereals) and packaged after cooking, five (5) species of leaves were identified as leaf packaging. Among them, *Tectona grandis* and *Musa sapientum* are the most appreciated by processors (Fig. 4E). Processors of Gowé reported that the leaves of *Tectona grandis* and *Musa sapientum* are very large and allow an easy packing of the product. These leaves are available and have no negative effect on the organoleptic characteristics and allow storing Gowé for 4 to 5 days. For the packaging of Kandji, six species of leaf were identified during the investigation. The most appreciated leaves for this product by processors are *Lasiomorpha senegalensis* and *Musa sapientum* (Fig. 4F). Most Kandji producers (81.46%) reported that all leaves are not resistant to dry steam. For example, the leaves of *Tectona grandis* cannot be used for Kandji because after cooking with dry steam, they crumble and leave debris on the food. This constraint leads processors to prefer *Lasiomorpha senegalensis* which gives a special flavour to the food and allows conservation for 4 to 5 days.

Leaves of several species are used as packaging for a diversity of foods and are sometimes suitable for specific foods. For the same food, the shelf life at room temperature (28 ± 2 °C) varies according to the leaves. These differences in shelf life could probably justify the antimicrobial activity of the leaves that are traditionally used for packaging foods (Zannou *et al.*, 2016; Mostafa, 2021; Sivasamugham *et al.*, 2021). But, the shelf life of food remains low (at most 8 days). This short shelf life of food wrapped in leaves is probably due to microbial growth that occurs in the packaging after 2 to 4 days of storage (Adegunloye *et al.*, 2006; Adejumo and Ola, 2008). Likewise, the treatments carried out on the leaves before their use do not eliminate all the microorganisms. These conditions may contribute to the proliferation of microorganisms during storage.

Consumers' preferences for leaf packaging

Among the packaged food identified during the survey, consumers mainly cited Akassa (100%), Lio (43.3%), Afitin (41.7%), Gowé (17.7%), Abla (14.7%), Kandji (13.7%), and Toubani (13%). Table 2 shows consumer preferences for leaf packaging used for the foods most cited.

For Akassa, *Tectona grandis* and *Musa sapientum* were the most preferred, respectively, by 29.7% and 28.7% of consumers. In Natitingou (ADP 3), Parakou and Glazoué (ADP 4) *Isoberlinia doka* were the most preferred with a percentage of 60% and 41.7%, respectively. In Bohicon and Aplahoué (ADP 5), *Musa sapientum* and *Tectona Grandis* leaves were preferred, respectively by 46.5% and 43.3%. In Adja-Ouèrè (ADP 6), it is rather the leaves of *Tectona grandis* that were preferred by 43.3% of consumers. While in Porto-Novo, Cotonou, Abomey-Calavi and Comé (ADP 7), the leaves of *Musa sapientum*, *Tectona grandis*, and *Thalia geniculata* were preferred by 30% on average for each species. For Lio, two species of leaf were preferred; *Manihot esculenta* and *Daniellia oliveri*, respectively by 61.5% and 26.9% of consumers. Specifically, *Daniellia oliveri* leaves were preferred by consumers in Natitingou (ADP 3), Parakou and Glazoué (ADP 4), while in all other municipalities *Manihot esculenta* leaves were preferred. *Tectona grandis* was preferred by most afitin consumers (84.0%). This preference for Afitin was observed in all survey areas. Afitin is a condiment produced from the alkaline fermentation of African locust beans (*Parkia biglobosa*). It is usually packaged with leaves just for transportation. According to consumers, this food is mainly packaged in the leaves of *Tectona grandis* because they are available, very wide and protect the organoleptic characteristics of the product during storage. For Gowé which was cited mainly in Bohicon, Aplahoué (ADP 5), Porto-Novo, Cotonou, Abomey-Calavi and Comé (ADP 7), *Tectona grandis* was the most preferred with percentages of 67.9%.Also, consumers report that Gowé is increasingly packaged in plastic packaging by some processors, resulting in a considerable reduction in the production of Gowé wrapped in leaves. Abla consumers preferred *Musa sapientum* with an average percentage of 61.4%. Indeed, Abla was cited by consumers in all municipalities surveyed except Natitingou (ADP 3).

Kandji consumers preferred the leaves of *Lasiomorpha senegalensis* with a percentage of 73.2%. But Kandji consumers in Parakou and Glazoué (ADP 4) preferred the leaves of *Isoberlinia doka* with an average percentage of 60%. The preference of *Isoberlinia doka* for Kandji in Parakou and Glazoué (ADP 4) could be because the leaves of *Lasiomorpha senegalensis* are not available in this locality and therefore are not used by processors. Natitingou (ADP 3), Parakou and Glazoué (ADP 4) were the only areas where Toubani was cited. Consumers preferred *Isoberlinia doka* for this food with a percentage of 82.1%.

These results showed that consumer preferences from the Center to the North of the country are different from those in the South. For example, for Akassa, the leaves of *Isoberlinia doka* were preferred from the Center to the North (ADP 3 and 4) while in the South (ADP 5, 6 and 7), the leaves of *Musa sapientum*, *Tectona grandis* and *Thalia geniculata* were preferred. It is observed that the leaves which were preferred in the North are not commonly used in the South. For example, the leaves of *Isoberlinia doka* are more used in the North because they are more available in the North regions. The leaves of *Manihot esculenta*, which are widely used for Lio in the Southern part of the country, are, on the other hand, less used in the Northern part of the country. Consumers' preferences for leaf packaging vary by the availability of leaves, regions, and food, as reported by Onzo *et al.* (2014). Likewise, certain types of leaf packaging are preferred because they probably contain active compounds (aromatics, dyes, enzymes, antimicrobial agents) which could migrate from packaging to food products (Sudha and Srinivasan, 2014; Dewi *et al.*, 2021). This transfer of material induces changes in the sensory profile (colour, taste, aroma, texture) of packaged foods. The leaves of *Thalia geniculata* and *Daniellia oliveri* are particularly recognized for their aroma; while the leaves of *Tectona grandis* are full of colouring molecules and are known for their colouring. Leaf packaging is therefore appreciated by consumers because of its ability to increase the organoleptic quality of the packaged product (Zannou *et al.*, 2016). Besides, Severin *et al.* (2011), Onzo *et al.* (2015) and Sivasamugham *et al.* (2021) reported the antimicrobial activities of some leaves used in food packaging, such as *Thalia geniculata*, *Musa spp*, *Manihot esculenta* and *Daniellia oliveri*.

Treatment carried out on leaf packaging by processors before use

The leaf packaging that is used by processors undergoes technological treatments which aim to make the packaging easier to use and reduce the load of microorganisms. For all the leaf packaging identified during this study, six treatments were performed: washing with water, wiping with a cloth, tailing, blanching in steam or in hot water, flaming and sun drying. After these treatments, the leaves are arranged in layers or placed in a container (calabash) to wrap the food in different forms (Fig. 5). The treatments applied to depend mainly on the species of the leaf and sometimes on the food. Table 3 shows the treatments that are applied on the leaves most used by processors.

Cleaning with cloth and washing are the most common treatments. They are carried out on leaves such as *Isoberlinia doka*, *Tectona grandis*, *Daniellia oliveri* and aim to considerably decrease the microbial load. Following the observations by Onzo *et al.* (2013), washing before use is carried out by some processors in the dry season. During the dry season, the dirt present is significant and wiping alone cannot ensure the leaf cleanliness.

For the leaves of *Tectona grandis*, washing with water or wiping are carried out after tailing. These treatments aim to make the leaves malleable and reduce their microbial load. It was noted that 72.7% of processors who use the leaves of *Tectona grandis* for Akassa do not wash but instead wipe them with a clean cloth. For these processors, washing increases the water content of the leaves and reduces the shelf life of Akassa. Blanching is a heat treatment that involves heating with steam or in hot water. It is carried out on the leaves of *Sarcocephalus latifolius*,

Thalia geniculata, Gmelina arborea and *Lasiomorpha senegalensis* with respective percentages of 100%; 86.4 %, 80.5% and 32.7% of processors. Blanching significantly reduces the content of anti-nutritional factors (Mosha *et al.*, 1995; Udoetok and Uffia, 2012; Patel *et al.*, 2018) and for some leaves, it increases the tear resistance of the leaves. Processors reported that, for the leaves of *Sarcocephalus latifolius* and *Gmelina arborea*, blanching is the main treatment carried out with the purpose of ridding the bitter taste they impart to foods, while for *Lasiomorpha senegalensis* and *Thalia geniculata* it is applied to increase the tear resistance of the leaves. It was noted that 13.6% of processors who use the leaves of *Thalia geniculata* do not apply blanching. Instead, the leaves are washed or wiped when they are used to pack Gowé. Flaming is also a heat treatment that consists of heating the leaves on fire to make them flexible and manageable during use. This treatment is only carried out on *Musa sapientum* leaves. It has therefore been observed that 100% of processors who use these leaves apply flaming followed by wiping. Forero-Cabrera *et al.* (2017) reported that in India, the leaves of *Musa sapientum* are heated and used to cover certain traditional foods. Only the lamina of *Musa sapientum* is used by the processors. The leaf is composed of the lamina, midrib and petiole. After flaming, the processors use a knife to remove the lamina, which is then cleaned and used as packaging.

Sun drying is a solar treatment applied by the processors for the leaves of *Lasiomorpha senegalensis*. This treatment consists of spreading the leaves on a flat surface and exposing them to the sun for 10 to 20 hours depending on the intensity of the sun's rays. In this study, it was observed that sun drying is only applied to *Lasiomorpha senegalensis* leaves used to produce Akassa, while for the production of kandji the processors sometimes apply the blanching of the leaves. According to Kora (2019), sun-drying is also applied to other types of leaves, such as *Borassus flabellifer* which are dried and stitched together using grass stem sticks or sewing machine to produce food packaging. This treatment softens the leaves and thus facilitates their use as packaging

Conclusion

A great diversity of plant leaves is used to package many foods produced from cereals, legumes or tubers in Benin. The choice of packaging for a food is made according to several criteria used by processors or consumers. Depending on the characteristics of the food, some species of leaves are more suitable compared to others. These species, widely used as packaging in traditional food processing in Benin, are potential alternatives to replace non-biodegradable materials and may therefore be used for modern biodegradable food packaging processing.

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