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SOME TRADITIONAL FERMENTED FOODS FROM AFRICAN LOCUST BEANS (PARKIA BIGLOBOSA): PRODUCTION AND VOLATILE COMPOUNDS

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Abstract

African locust bean is used for both medicinal and domestical purposes in West Africa. The seeds are processed to nutritive and flavoring fermented condiments such as *netetu*, *iru*, *sonru*, *afitin*, *soumbala*, and *dawadawa*. The production process and the volatile compounds of these fermented condiments were investigated in the present study. The findings showed that dried and cleaned seeds were used to be produced traditional condiments. The processing operations implying mainly and successively a first long boiling (6-24h), dehulling, a second short cooking (1-2h) and fermentation (24-72h). The variations of the operations involving in the production affect physicochemical, biochemical and microbiological characteristics of the final products. More than 160 volatile compounds namely pyrazines, ketones, aldehydes, alcohols, esters, alkanes, alkenes, benzene derivatives, pyridines, furan, volatile phenols, sulfur compounds, and terpenes have been reported in fermented African locust beans. Among these, pyrazines, ketones, aldehydes, and alcohols were found to be the most abundant groups with 2,5-Dimethyl pyrazine, tetramethyl pyrazine, trimethyl pyrazine, 3-methyl butanal, benzene acetaldehyde, 2-nonadecanone, 2-decanone, 3,5-Dimethyl phenylmethanol and 3-methyl-1-butanol as the most important aroma compounds found in the condiments. Production steps mainly fermentation (type and duration), boiling and use of additives conferred to each fermented seed its unique aroma characteristics. Use of pure starter culture enhances overall aroma profile of the finished products.

Keywords: Fermentation, *Parkia biglobosa*, fermented condiments, aroma, West Africa.

1. Introduction

African traditional culinary background is greatly bound by an enormous variety of fermented foods. These concern mainly cereals, tubers, dairy products and some non-timber forest products such as African locust beans. Fermentation is one of the most important steps intervening during the processing of traditional foods in Africa. It is considered as a process which involves microorganisms growth and their metabolic activities [1]. When fermentation occurring, microorganisms transform the available hydrocarbons into organic acids, alcohols, carbon dioxide as well as bacteriocins [2,3]. Bacteriocin designates the small, heat-stable cationic peptides produced by lactic acid bacteria, which displays a strong inhibition power as it kills or inhibits pathogen microorganism, thus assuring food stability, shelf-life, safety [2,4], as well as overall quality. To producers, the process of fermentation is cultural, cheaper, less energy consumption and also needs a short time to be achieved. Fermentation ensures not only the preservation of the processed foods by increasing their shelf life but also increases their flavor quality and nutritional values. Preservative effect of fermentation is usually linked with the generation of the antimicrobials. According to the definition used by the Commission of the European Communities (EU Directive 95/2/EC), preservatives are substances that extend the shelf life of foodstuffs by protecting them against deterioration caused by microorganisms [5]. Similarly, the U.S. Food and Drug Administration (FDA) defines preservatives as any chemical that when added to food tends to prevent or retard deterioration [5]. Natural antimicrobials can be defined as substances produced by living organisms in their fight with other organisms for space and their competition for nutrients and the main sources of these compounds are plants (secondary metabolites in essential oils and phytoalexins), microorganisms (bacteriocins and organic acids), and animals (lysozyme from eggs, lactoferrins from milk). In one hand, the fermentation renders more digestible the raw products [6] and does not request a specific expertise or expensive materials. In another hand, it increases the bioavailability of nutrients such as proteins, lipids, hydrocarbons, minerals, and vitamins. According to [7], the fermentation contributes to the removing of non-useful substances. The fermented foods are associated with numerous health profits as they can not only prevent osteoporosis, allergies, hypertension, carcinogenesis, obesity, intestinal troubles, diabetes and atherosclerosis but also can decrease blood cholesterol and enhance human immunity [8,9,10]. Furthermore, anti-oxidant, anti-microbial, anti-fungal, anti-inflammatory, anti-diabetic and antiatherosclerotic effects are conferred to the fermented products [7].

The genus *Parkia* from the subfamily of *Mimosoideae* which, in return, belongs to the large family of *Fabaceae*, is composed of thirty-four plant species [11]. African locust beans (*Parkia biglobosa*) appertains to the genus of *Parkia*. For West African natives the whole tree of *Parkia biglobosa*, from roots to leaves, is useful and can be utilized either as foodstuffs or in traditional medicine. For instance, a survey performed in the Republic of Benin revealed that the fruits particularly seeds and pulps are the most used, followed by barks, branches, leaves, roots and flowers [12]. Domestical use of this tree has a limitless importance for Africa Savanna's populations. Many studies reported the use of *P. biglobosa* in endogenous arenas. To Kwon-Ndung et al [13], beside the medicinal use, *P. biglobosa* is used as firewood, forage, varnish and for charcoal production, whereas, Irvine [14] and Hagos [15] mentioned *P. biglobosa* wood drifted products which encompass bows, hoe handles, mortarboards, seats, and drumsticks. Its yellow pulps are used as flour for the preparation of enriched porridges and local meals. Bark infusions are used to relieve diseases like febrifuge, toothache, bronchitis, diarrhea, tracheitis, venereal diseases, pneumonia as well as "Cure salée" [16]. Some communities in Ghana use roots, leaf, barks and fruits to recover for bums, fever, boil, diarrhea, and stomach disorders [17]. Furthermore, in the Republic of Benin, *P. biglobosa* is mostly utilized for folk medicine and foods but it is also employed for its medico-magic and cultural characteristics [12]. Leaves, roots, pods and stems of this plant contain important bioactive compounds essentially saponins, tannins, steroids, flavones, glycosides, alkaloids and flavonoids [18,19,20,21,22]. For the same authors, extracts of different parts such as roots, leaves, pod, stem and barks of *P. biglobosa* have been successfully tested on an important number of pathogenic microorganisms including *Enterobacter aerogenes*, *Streptococcus aureus*, *Staphylococcus aureus*, *Salmonella typhi*, *Escherichia coli*, *Salmonella typhimurium*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, *Shigella spp*, *Rhizopus spp*, *Klebsiella sp* and *Mucor spp*. The presence of bioactive compounds and strong antimicrobial properties detected in *Parkia biglobosa* witnessed its remedy value and importance of human health.

In Africa, the most of fermented foods or beverages are obtained through a spontaneous or natural fermentation. Technologies for the production of fermented foods or beverages are mastered by producers, however, they vary depending on cultural background, commodities and geographical situation. Thus, *mawè* [23], *Tchoukoutou* [24], *lafoun*, *koko* [25], *afitin*, *iru* and *sonru* [26], *kisra* [27], *dawadawa* [28], *dèguè* [29], *soumbala* [30], *fura*, *lanhouin*, and so forth, are some fermented foods and beverages encountered in Africa. Foods can be subjected to three types of fermentation namely alkali, lactic acid and alcoholic. These have been combined in two major classes such as aerobic fermentation which includes alkaline and fungal, and anaerobic fermentation which comprises lactic and alcoholic [2]. According to [31], alcoholic fermentation generates ethanol and yeasts as main metabolites and includes mostly wines and beers, while, lactic acid fermentation is usually implemented with lactic acid bacteria and implies mainly cereals, milk and somehow tubers. For the same author, alkali fermentation occurs often in seeds and fishes condiments. Seeds of *Parkia biglobosa* are the most promoted and used to produce both human and animal alimentation. Seeds were detected as a valuable source of nutrients especially proteins for poussins [32,33] and fishes [34]. For human consumption, the seeds are absolutely cooked and fermented in order not only to eliminate antinutritional factor but to improve nutritional, preservative and organoleptic qualities. Thus, the fermented seeds are recognized as a pleasant and nutritious condiment used in various African dishes. They often represent significant substitutes of general proteins sources such as fishes, eggs and animal proteins for the populations of rural, suburban as well as urban zones. The name, cooking and fermentation conditions of the resulted fermented foods, vary extensively according to production regions or countries. For instance, they are known as *iru*, *sonru* and *afitin* in the Republic of Benin [26], *dawadawa* or *daddawa*, *iru* and *ogiri-igala* in Nigeria [35,36], *dawadawa*, *iru* and *kpalugu* in Ghana [35,36], *kinda* in Sierra leone, *netelou* or *soumbara* in Gambia [36], *soumbala* in Burkina Faso [37], *netetu* in Senegal [38], *soumbara* in Ivory Coast and *dawadawa* in Chad. These names are accompanied by the variability of production procedure which confers to each product a characteristic flavor.

The flavor which is defined as a mixture of taste and odor (aroma), is a determinant characteristic that discriminates a food and influences the consumers buying or consumer's choice. According to [39], sensory properties of a food count the most of consumers' decision. Although in smallest amounts as ppm or ppb, aroma compounds are issued from complex biochemical reactions which include fermentation, lipid oxidation, enzymes, amino acids, degradation proteins and hydrocarbons, and Maillard reaction. Since then, numerous techniques have been developed for their extraction from different matrices and sensitive methods such as gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), and gas chromatographic-mass spectrometry-olfactometry (GC-MS-O) have been worked out for their quantification, identification and determination of key odorants, respectively [40]. Extant literature indicated that overall aroma profile of condiments obtained from *P. biglobosa* seeds, is generated mainly during and cooking and fermentation under the metabolic activities of *Bacillus spp* [37,41,42]. Moreover, *Bacillus spp* have displayed great degradation activities of lipids and proteins [43,44,45]. Hence, in this review, an account of the reported production processes of *iru*, *sonru*, *afitin*, *soumbala*, *dawadawa, soumbara* and *netetu* and their respective aroma profile was investigated.

2. Production

Dried *P. biglobosa* seeds are used to produce different condiments. Seeds are washed and sorted in order to eliminate spoiled grains and foreigner particles. Processing of different seeds condiments such as *iru*, *sonru*, *soumbala*, *soumbara*, *dawadawa*, *afitin* and *netetu*, takes place through four common major operations. These include a first long cooking, dehulling, a second short cooking, and fermentation. Nonetheless, some intermediate operations like washing, cooling and addition of additives intervene during manufacturing of the condiments. The technique of production is ancestrally transferred and depend on cultural background, regions, and countries. This transformation activity is mainly performed by women for both house livelihoods and commercial purpose as it represents an important source of income, especially for rural populations. Generally, men are charged to harvest and collect the fruits while women transform the seeds into various condiments [17].

The first cooking is the first important operation that seeds undergo during condiments production and it consists of boiling seed in water for 6 to 24 hours. This operation allows not only a loss of astringency or bitterness of the seed but also the softening of the seminal integument [38]. For this cooking, the parameter time is very important and varies highly depending on the type of condiments and country or culture. Thus, during processing of fermented condiments of the Republic of Benin (*iru*, *afitin* and *sonru*), seeds are cooked for about 12 hours [26] while for *iru* and *dawadawa* of Nigeria, seeds undergo a cooking of 6-12 and 12 hours, respectively [46,47,48]. Likewise, to obtain *soumbala* of Burkina Faso, seeds are boiled for 24 hours [37] while for *netetu* of Senegal, seeds are cooked for 15-24 hours [38,49]. After this step, the cooked seeds are let to cool and wash in order to take off any remaining impurity and astringency. Seeds are then ready for dehulling.

Dehulling is the second major operation involving in the production of the fermented condiments and consists removing seed coats. Traditionally, seeds are marched by feet in a large timbered mortar and further seed coats are taken off by pressing between palms of hands. In the Republic of Benin, fine sand or ash is added [26] with a goal to render the dehulling easier as this operation is tedious and needs more physical force. Afterward, seeds are minutely washed and sorted, and the cleaned cotyledons are sent to the second cooking.

The second cooking is a short 1 to 2 hours boiling of cotyledons in water. This operation is also important as it is associated with a kind of bleaching that helps to minimize secondary contamination which may result from the various manipulations during dehulling [38]. During the production of *iru* and *sonru*, additives *iku-iru* and *yanyanku* are appended towards the end of the second cooking [26]. *Yanyanku* is a ground dried seeds of *Hibiscus sabdariffa* while *iku-iru* is a mixture of ground dried seeds of *Hibiscus sabdariffa* L. and pepper as shown in Fig 2. *H. sabdariffa* also named Roselle, hibiscus, Jamaica sorrel or red sorrel (English) and karkadeh (Arabic) is a herbaceous plant largely planted in tropical and subtropical areas [50]. It appertains to *Malvaceae* family and is recognized as an annual, bushy plant with a height of up to 2.5 m, characterized by smooth, cylindrical red stems, reddish veins and long, green leaves [51]. *H. sabdariffa* seeds are revealed to contain potential nutrients as they displayed important values of proteins, fat, carbohydrate, fiber, minerals and, vitamins [52,53,54]. The introduction of additives from *H. sabdariffa* seeds may enhance not only the nutritional value and flavor of the condiments but also may improve their medicinal properties. Previous studies showed that additives impacted microbiologic characteristics of condiments [26]. In Nigeria, this second cooking can be extended from 45 minutes to 6 hours [46,47] while in the most of the countries it lasts 1 to 2 hours [26,37,38,49]. After the cooking, cotyledons are well drained.

The fermentation represents the last most important operation involved in the production of seeds condiments. Although above-cited operations prepare cotyledons to render the fermentation most successful, this step is the most sensitive amongst all operations. It gives to cotyledons all their nutritional capacities, microbiologic properties, and organoleptic characteristics. Cotyledons are spread in basket trays, calabash trays or containers, wrapped with heavy cloths, jutes backs and/ or polyethylene bags and then left for fermentation which lasts from 24 hours to days at room temperature. In the Republic of Benin, cotyledons are fermented for 24 hours to obtain *afitin*, whereas, for *iru* and *sonru*, they are subjected to 48 hours of fermentation [26]. As for *netetu* produced in Senegal, the fermentation takes 3 days [38,49] while in Burkina Faso, *soumbala* is obtained after 36 to 48 hours of fermentation [37,55]. Thus, time is a discriminative factor which characterizes the condiments. Furthermore, long fermentation leads to more softening of cotyledons [26]. Temperature is another important factor which influences the fermentation. Generally, fermentation occurs at room temperature, about 30°C, as this temperature represents the average of the most condiments producers countries. [38] suggested 28-40°C and this was supported by the study of [48], in which 40°C was detected as the optimum temperature to yield more proteins. After the fermentation, the condiment is either dried, ground or dumped.

The Fermentation of *P. biglobosa* seeds is a spontaneous and lactic type carried out in alkaline condition [38,49]. Microbiologic studies revealed that *Bacillus* species are dominant microflora implying in the fermentation of *P. biglobosa* seeds [26,35, 38,43,49,56,57,58]. These microorganisms showed high metabolic activities during seeds fermentation with degradation of proteins, lipids and carbohydrates [43,44,45,57]. Furthermore, they showed antifungal activity in condiments by secreting mainly Iturin A and Surfactin [38]. The fermented condiments are safe for consumption, however, a few *Staphylococcus* germ was detected in some condiments. The presence of *Staphylococcus* in condiments is probably due to bad handling during manufacturing and commercialization [26,49,56]. Therefore, hygienic conditions have to be set up and respected during and after production. In addition, salting was suggested to reduce the microbial load of the fermented seeds condiments [59].

The raw African locust beans are too hard and almost unedible, however, they become soft, edible with strong appreciated flavor since they are processed to the fermented condiments. These are incorporated in traditional soups and stews as flavorous, protein and fat-rich foodstuffs. They are also eaten together cereal-based dumplings and porridges. Furthermore, the condiments are introduced in traditional vegetable sauces and can be reduced in powder. In addition, they replace animal and fish proteins in some dishes. The variations of the operations involving in the production affect absolutely physicochemical, biochemical and microbiological characteristics of the final products.

3. Aroma profile of the fermented condiments of *P. Biglobosa*

Quality of the fermented condiments of *P. biglobosa* is important for their commercial value and is consisted of color, flavor, and freshness. The flavor is defined as taste, which consists of non-volatile compounds, and aroma, which consists of volatile compounds. likewise, phenolic compounds are accountable for the color. Aroma compounds are important not only for the distinction of the condiments but also for the evaluation of their quality. Nowadays, more than 160 volatile compounds namely pyrazines, ketones, aldehydes, alcohols, esters, alkanes, alkenes, benzene derivatives, pyridines, furan, volatile phenols, sulfur compounds, and terpenes have been reported in fermented African locust beans. Most of these compounds are generated during the manufacturing process mainly during fermenta-

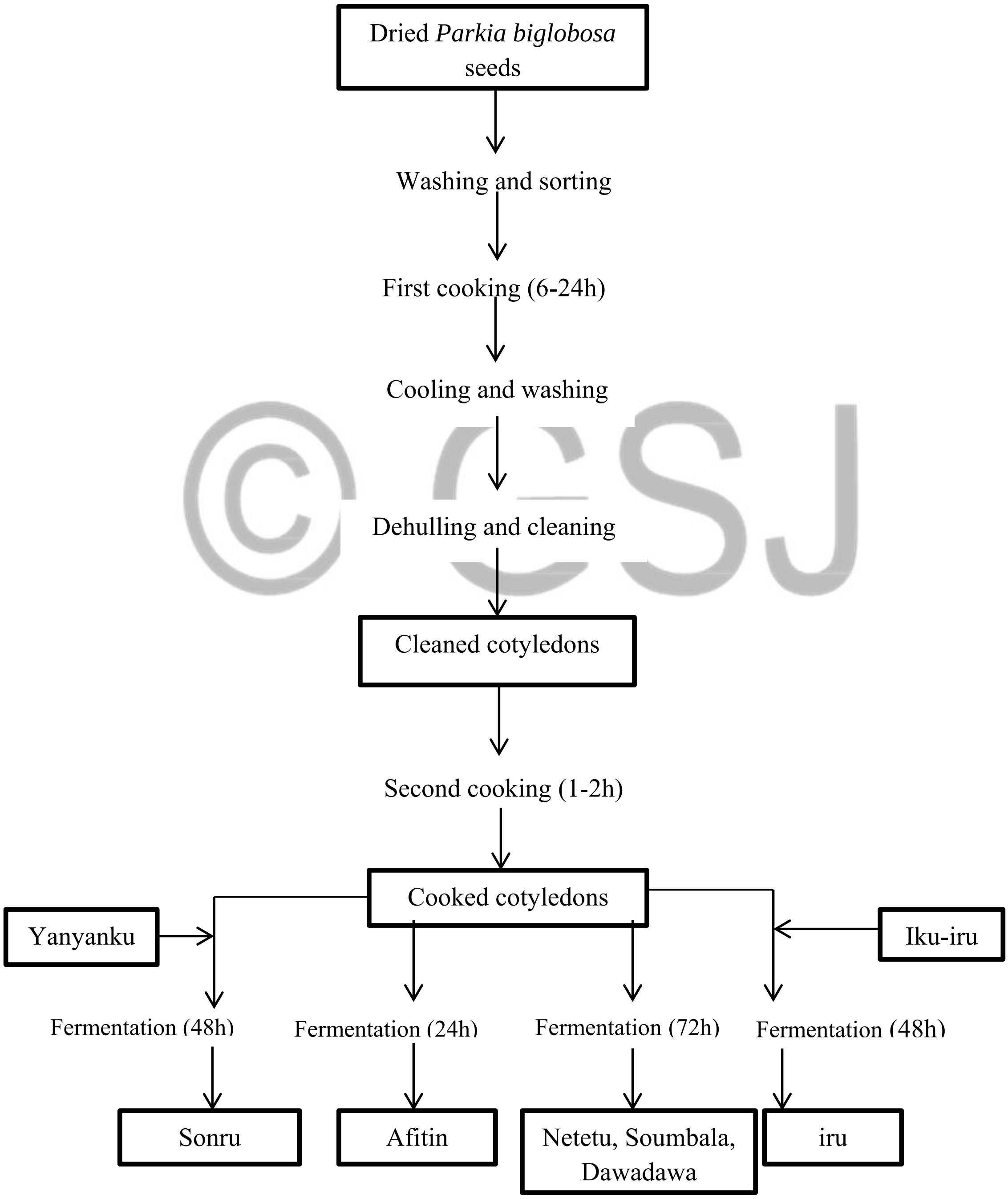

Fig 1: Flow diagram of some African locust beans condiments

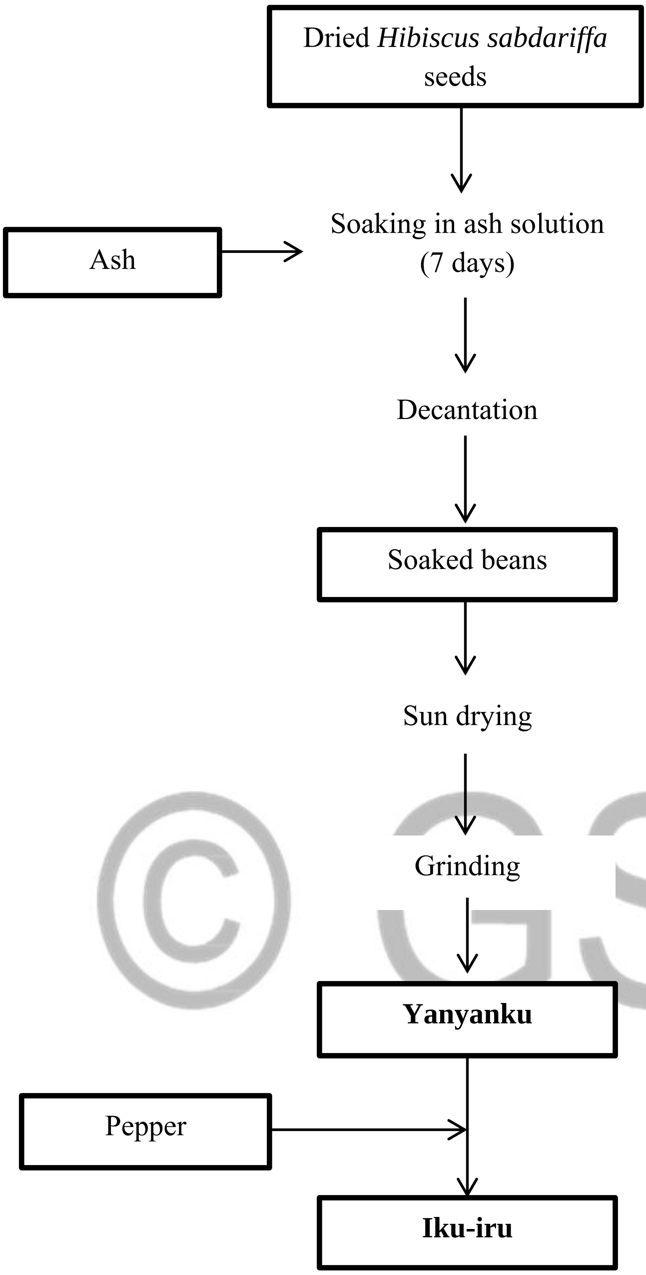

Fig 2: Flow diagram of yanyanku and Iku-iru [26]

Tion, and heating [37,41,60]. The main precursors of the volatile compounds in the fermented condiments are peptides, fatty acids and amino-acids [41]. Some variations have been quantitatively and qualitatively noticed in the overall aroma profile of *iru*, *sonru*, *afitin* and *dawadawa* (Tab. 1). This may probably due to the origin of the raw material, extraction technique, solvent as well as processing conditions notably heating and fermentation parameters.

Pyrazines represent the most important class detected in the investigated *P. biglobosa* condiments [37,42,60]. Also known as 1,4-diazine, pyrazines are six-membered aromatic heterocycles containing nitrogen atoms. They are naturally encountered in plants, animals and many foodstuffs as odorous and pharmacological agents. Pyrazines have been reported with roasted, toasted, nut-and peanut-like odor in roasted soybeans oils, yogurt, coffee, teas, roasted sorghum, fermented soybeans, roasted almond, wines and seeds of *B. Officinalis* [43,61,62,64,65,66]. They are increasingly used for medicinal purposes due to their anti-inflammatory, diuretics, antineoplastics, anti-infective, antidepression, antiviral and neuroprotective properties [67]. The release of pyrazines is stimulated by heating. Furthermore, bacteria and fungi can produce and use pyrazines [68]. Although pyrazines are found in numerous products, they are known to be aroma compounds of heated products. A total of 19 aroma compound pyrazines (Tab. 1) have been quantified and identified *soumbala*, *afitin*, *sonru*, *iru*, and *daddawa*. These aroma compounds have been generated during heating and fermentation by metabolic reactions of the *Bacillus spp* [37,42,60]. The metabolic reactions of the *Bacillus spp* occurring during fermentation *P. biglobosa* cotyledons concerned degradation of lipids, proteins and poly and oligosaccharide [43,44,45,69]. Among all detected pyrazine, 2,5-dimethyl pyrazine is most the abundant aroma compounds figured out in the fermented condiments, followed by tetramethylpyrazine and trimethyl pyrazine. These aroma compounds have been reported in the similar fermented soybeans condiments [61]. 2,5-Dimethyl pyrazine (earthy, potato sweet) is one of the most important aroma compounds detected in palm sugars [70] and cooked *Digitaria exilis* Stapf (Lasekan et al., 2001), while tetramethylpyrazine (Nutty) and trimethyl pyrazine (nutty) have been detected as key odorants in the fermented Chinese Baijiu [71].

Aldehydes revealed to be the second most significant volatile class identified quantitively in the *P. biglobosa* condiments [26,42,60,72]. Aldehydes are synthesized from the oxidative reaction of fatty acid mainly α-linolenic acid and linoleic [73]. They can be also liberated from Strecker degradation, non-enzymatic and heat-induced of amino acids [74]. Aldehydes displayed green and citrus notes and have been reported in various food including hazelnuts, wines, beer, saffron, virgin olive oil, olive oil, fermented soybeans and canola oil [61,75,76,77,78]. The presence of aldehydes in the fermented condiments of *P. biglobosa* is associated with Maillard reaction occurring during the fermentation [26,42]. A total of 33 individual aldehydes have been found in the data regarding volatile compounds of *P. biglobosa* (Tab. 1). Among these, 3-methyl butanal, benzene acetaldehyde, benzaldehyde, and

2,4-decadienal (E, E) are the most significant as they displayed higher concentrations in the condiments. Previously, benzaldehyde (sweet, almond) and benzene acetaldehyde (sweet, honey-like) have detected to contribute to the active odorants of kinds of honey [79], whereas, 2,4-decadienal (E, E) (fryer oil) and 3-methyl butanal (fruity, malty) have been found in liquid whey and black sapote, respectively, as aroma active compounds [80,81].

Ketones are products of complex biosynthesis reactions which imply the degradation of fatty and amino acids [82,83] and Maillard reaction [84]. In the case of fermented seeds like fermented *P. biglobosa* seeds or fermented soybeans, it believed that ketones are originated from the degradation of lipids, amino acids and saccharides [26,42,61,85]. They contribute highly to the aroma profile of the fermented condiments of *P. biglobosa* as 21 individual aromatic ketones have been recorded in all the studied spices (Tab. 1). The distribution of ketones in the investigated products varied and depended on the type of the condiments, type of fermentation (spontaneous or controlled) and type of starter culture. For instance, the most important ketones discovered the in traditional and controlled fermentation soumbala are 2-nonadecanone, acetophenone, 2-heptanone and 2-heptadecanone [37], while, the most abundant aromatic ketones in the controlled fermentation *afitin*, *iru* and *sonru* are 2-decanone, 1-butanone, 3-hydroxy-2-butanone and 2-pentadecanone [60]. Most these volatile compounds have been reported in the fermented soybean condiments [61]. Acetophenone has been reported in the essential oil of *Camellia sinensis* L. [86] while 2-Nonadecanone has been indicated in both essential oils of *Salix aegypiaca* L. [87] and *Camellia sinensis* L. [86]. On one hand, *Salix aegypiaca* L. is used to treat a headache and also showed cardiovascular protective, sedative and analgesic effects, and on another hand, *Camellia sinensis* L. in various forms is used as anti-inflammatory, antiviral, immunoprotective and anti-histaminic [88]. Furthermore, 2-decanone, 3-hydroxy-2-butanone and 2-nonadecanone have been detected to contribute the scent of the fermented baobab (*Adansonia digitata* L.) seeds [89].

A total of 27 alcohols have been reported in the condiments. Generally, lipoxygenase in the presence of oxygen, acted on unsaturated fatty acids to produce volatile alcohols [90]. Additionally, they could be released during fermentation of *P. biglobosa* cotyledons under microorganisms action [26,45]. In spite of the similarities between traditional and starter culture condiments, the highest concentration of volatile alcohols have been recorded in the controlled fermentation products. 3,5-Dimethyl phenylmethanol, 2-phenyl butanol, 3-methyl-1-butanol, and 2-hexanol represented the major alcohols in the fermented condiments of the Republic of Benin [42,60] while 3-methyl-1-butanol, 2-pentanol, 1-octen-3-ol and 3,7,11-

trimethyl-2,6,10-dodecatrien-1-ol were found in *soumbala* [37]. Previously, 1-octan-3-ol has been found in the fermented soybeans [61]. Likewise, 2-hexanol and 1-octen-3-ol have been detected as aroma contributors of essential oils of *Camellia oleifera* Abel. seeds [91]. It is well-known that seeds oils of *Camellia oleifera* seeds are comparable to olive oils with health benefits including antioxidant properties, reduction of cholesterol and blood pressure [92,93,94]. Moreover, 3-methyl-1-butanol (cheese-like, ripe onion) and 1-octen-3-ol (earthy, dusty, spicy, mushroom) have figured out as aroma active compounds of *Tuber melanosporum* and *Tuber aestivum* [95] in one hand and of essence and puree of kiwi [96] in another hand.

Table 1: Volatile compounds of the fermented seeds of *P. biglobosa*

No	**Compounds**	**Afitin**	**Sonru**	**Iru**	**Dawadawa/ Daddawa**	**Soumbala**
	Pyrazines					
1	2,5-Dimethyl pyrazine	✓	✓	✓	✓	✓
2	Methyl pyrazine	✓	✓	✓		✓
3	2,6-Dimethyl pyrazine	✓	✓	✓	✓	✓
4	Ethyl pyrazine					✓
5	2,3-Dimethyl pyrazine	✓	✓	✓		✓
6	2-Ethyl-6-methyl pyrazine	✓	✓	✓	✓	✓
7	2-Ethyl-5-methyl pyrazine				✓	✓
8	Trimethyl pyrazine	✓	✓	✓	✓	✓
9	2,6-Diethyl pyrazine					✓
10	3-Ethyl-2,5-dimethyl pyrazine				✓	✓
11	2-Ethyl-3,5-dimethyl pyrazine	✓	✓	✓		✓
12	Tetramethyl pyrazine	✓	✓	✓	✓	✓
13	2,5-Dimethyl-3-(2-methyl) pyrazine					✓
14	2,3-Dimethyl-5-propylpyrazine	✓	✓	✓		✓

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15	2,3-Dimethyl-5-propenyl pyrazine (E,E)	✓	✓	✓			✓
16	2,5-Dimethyl-3-(3-methyl) pyrazine						✓
17	2-Methyl pyrazine	✓	✓	✓			
18	3-Ethyl-3,5-dimethyl pyrazine						
19	2,3,5-Trimethyl-6-ethyl pyrazine	✓	✓	✓			
	Aldehydes						
20	3-Methyl butanal	✓	✓	✓			✓
21	Pentanal	✓	✓	✓	✓		✓
22	2-Butenal	✓	✓	✓			✓
23	Hexanal				✓		✓
24	Heptanal	✓	✓	✓	✓		✓
25	3-Methyl-2-butenal	✓	✓	✓			✓
26	Octanal	✓	✓	✓			✓
27	Nonanal				✓		✓
28	2-Octenal (E)	✓	✓	✓			✓
29	3-Methylthio propanal						✓
30	3-Furancarboxaldehyde						✓
31	2,4-Heptadienal (E,E)	✓	✓	✓			✓
32	Benzaldehyde	✓	✓	✓	✓		✓
33	Nonenal	✓	✓	✓			
34	2-Nonenal	✓	✓	✓	✓		
35	2-Nonenal (E)	✓	✓	✓			✓
36	Benzeneacetaldehyde	✓	✓	✓	✓		✓
37	2,4-Decadienal				✓		✓
38	2,4-Decadienal (E,E)	✓	✓	✓			✓
39	2-Phenylpropenal						✓
40	2-Phenylbutanal	✓	✓	✓			✓
41	5-Methyl-2-phenyl-2-hexanal	✓	✓	✓			✓

42	3-Phenyl-2-propenal	✓	✓	✓		
43	3-Phenyl butanal					
44	1-Decanal	✓	✓	✓	✓	
45	1-Tetradecanal	✓	✓	✓		
46	2-Butyl-octenal				✓	
47	Dodecanal				✓	
48	2,4-Nonadienal				✓	
49	Hendecanal				✓	
50	2-Nonanal				✓	
51	2,4-Undecadienal				✓	
52	2,4,6-Dodecatrienal				✓	
	Ketones					
53	2-Methyl-3-pentanone	✓	✓	✓		✓
54	5-Methyl-3-hexanone	✓	✓	✓		✓
55	2-Heptanone	✓	✓	✓		✓
56	2-Octanone	✓	✓	✓		✓
57	2-Decanone	✓	✓	✓		✓
58	2-Undecanone					✓
59	Acetophone				✓	✓
60	Acetophenone				✓	
61	2-Tetradecanone	✓	✓	✓		✓
62	2-Pentadecanone	✓	✓	✓		✓
63	2-Heptadecanone	✓	✓	✓		✓
64	2-Nonadecanone	✓	✓	✓	✓	✓
65	2-Pentacosanone	✓	✓	✓		✓
66	3-Hydroxy-2-butanone	✓	✓	✓		
67	1-Butanone	✓	✓	✓		
68	6-Methyl-2-heptanone	✓	✓	✓		
69	3-Ethyl hexanone				✓	
70	3-Ethyl heptanone				✓	
71	3-Ethyl octanone				✓	
72	Ethyl nonanone				✓	
73	2,5-Hexadione				✓	

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	Alcohols					
74	2-Methyl-1-propanol	✓	✓	✓		✓
75	3-Pentanol	✓	✓	✓		✓
76	2-Pentanol					✓
77	3-Methyl-1-butanol	✓	✓	✓		✓
78	1-Pentanol	✓	✓	✓		✓
79	2-Methyl-2-buten-1-ol					✓
80	1-Octen-3-ol				✓	✓
81	2-Ethyl-1-hexanol	✓	✓	✓		✓
82	3,7-Dimethyl-2,6-octadien-1-ol					✓
83	3,5-Dimethyl benzenemethanol	✓	✓	✓		✓
84	Benzyl alcohol	✓	✓	✓		✓
85	Octadecanol	✓	✓	✓		✓
86	3,7,11-Triemthyl-2,6,10-dodecatrien-1-ol					✓
87	2-Ethyl cyclobutanol					✓
88	2-Hexanol	✓	✓	✓		
89	1-Hexadecanol	✓	✓	✓		
90	Decanol	✓	✓	✓		
91	2-Phenyl ethanol	✓	✓	✓		
92	2-Butanol	✓	✓	✓		
93	1-Hexanol	✓	✓	✓		
94	Ethanol				✓	
95	Propanol				✓	
96	1,2-Ethanediol				✓	
97	Octanol				✓	
98	Dodecanol				✓	
99	Undecanol				✓	
	Esters					
100	2-Methylpropyl butanoate	✓	✓	✓		
101	Methyl benzeneacetate					✓

102	Ethyl benzeneacetate					✓
103	Methyl pentadecanoate					✓
104	Ethyl 4-ethoxy-benzoate					✓
105	Methyl hexadecanoate	✓	✓	✓		✓
106	Ethyl hexadecanoate					✓
107	Methyl octadecanoate					✓
108	3-Hexenyl acetate, (E)	✓		✓		
109	9-Methyl oleate, (Z)	✓	✓	✓		
110	Ethyl oleate		✓			
111	9,12-Methyl octadecadienoate, (Z, Z)	✓	✓	✓		
112	Ethyl linoleate	✓	✓	✓		✓
113	2-Methyl-ethyl-butanoate	✓	✓	✓		
114	Ethyl acetate				✓	
115	Ethyl hexanoate				✓	✓
116	Octadecyl acetate				✓	
117	Octyl formate					✓
	Phenols					
118	2-Methoxy phenol					✓
119	2-Methoxy-4-methyl phenol					✓
120	Phenol	✓	✓	✓		✓
121	4-Ethyl-2-methoxy phenol					✓
122	2,4-Diisopropyl phenol					✓
	Acids					
123	9,12-Octadecadienoic acid (Z, Z)	✓	✓	✓	✓	✓
124	Hexadecanoic acid					✓
125	9-Hexadecanoic acid (Z)	✓	✓	✓		✓
126	2,3-Dimethoxy butanedioic acid	✓				✓
127	2-Methyl butanoic acid	✓	✓	✓		
128	1,2-Benzendicarboxylic	✓	✓	✓		✓

	aid					
129	Tetradecanoic acid	✓	✓	✓		
130	9,12-Methyl octadecadienoic acid (Z, Z)	✓	✓	✓		
131	2-Methyl-2-pentanoic acid					✓
132	Cyclopropanenonanoic acid					✓
133	Decanoic acid				✓	
	Alkanes					
134	Tridecane					✓
135	1-Heptyl-2-methyl cyclopropane					✓
136	Cyclododecane				✓	✓
137	Cyclotetradecane				✓	
138	Cyclohexadecane				✓	
139	2-Methyl undecane					✓
140	Docosane	✓	✓	✓		✓
141	Tetracosane	✓	✓			✓
142	Octacosane					✓
143	Heptacosane	✓	✓	✓		
144	Eicosane	✓	✓	✓		
145	9-Octyldocosane	✓	✓	✓		
146	Heneicosane	✓	✓	✓		
147	Hexacosane				✓	
	Alkenes					
148	3-Ethyl-2-methyl-1,3-hexadiene					✓
149	1,5-Cyclodecadiene (E, Z)					✓
150	1-Octadecene					✓
151	1-Dodecene	✓	✓			
152	1-Decene	✓			✓	
153	1-Heptadecene		✓	✓		

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154	Tetradecene				✓		
	Benzene derivatives						
155	1-Ethyl-2,4-dimethyl benzene						✓
156	1-Ethyl-3,5-dimethyl benzene						✓
157	1,2,3,5-Teramethyl benzene						✓
158	1,2-Dichloro benzene						✓
159	Benzeneacetoitrile						✓
160	1,3-Dimethyl benzene	✓	✓	✓			
161	1,2-Dimethyl benzene				✓		
162	Toluene				✓		
163	Chlorobenzene	✓	✓	✓			
	Pyridines						
164	Pyridine						✓
165	2-Propyl pryridine						✓
166	2-Diphenylmethyl pyridine						✓
167	2,6-Diphenyl pyridine				✓		✓
	Furans						
168	2-Ethyl furan	✓	✓	✓			✓
169	2-Pentyl furan	✓	✓	✓			
	Sulfur compounds						
170	Dimethyl disulfide	✓	✓	✓	✓		✓
171	Dimethyl trisulfide	✓	✓	✓			✓
172	1-(Methylhthio) propane						✓
173	1,2,4-Trithiolane	✓		✓			✓
	Terpenes						
174	Limonene						✓
	Others						
175	Indole						✓
176	Trimethyl oxazole						✓

177	3,4,5-Trimethyl pyrazole	✓
178	5-Methyl isothizole	✓
179	4,5-Dihydro-2-methyl thiazole	✓

✓ : Presence; Source: [37,42,60,72]

Esters, Phenols, benzenes derivatives, alkanes, alkenes, acids, sulfur compounds, pyridines, furans, and others are contributors to the overall sensorial characteristic of the fermented seeds of *P. biglobosa*. Similarly, alkanes, alkenes, benzenes, sulfur compounds, and furans have detected in a small amount in the fermented seeds of baobab and soybeans [61,89,97]. Volatile compounds of the fermented seeds of *P. biglobosa* increased quantitatively and qualitatively during fermentation. This observation is linked with the degradation of primary and secondary metabolites by microorganisms notably *Bacillus spp* [26,37,42,43,44,45]. A similar increase of volatile compounds after fermentation has been registered in the fermented seeds of baobab and soybeans [61,89]. Duration of fermentation affects aroma compounds of the fermented seeds as a long fermentation provided a higher amount of aroma compounds. It has been noticed that the product obtained with 48h of fermentation are richer in volatile compounds that the product obtained at 24h of fermentation [42,60]. Alike, results have been noted in Japanese fermented soy (*natto*) [97]. Likewise, type of fermentation as it is spontaneous or controlled, influence scent of the condiment. For instance, the condiments resulted from the controlled fermentation (use of *Bacillus spp* as starter culture) contained more aroma compounds that the condiments obtained with spontaneous fermentation [37,60]. Other factors which influence sensorial properties of the fermented seeds are processing conditions mainly boiling or roasting, additives and post-fermentation operations like drying. The extant literature showed that both boiling and roasting before fermentation, affected the global chemical and biochemical constituents of the fermented condiments of African locust beans [46] and this consequently affects aroma profiles of the finished products. In the same way, boiling and roasting revealed to affect the overall aroma of the fermented soybean condiments [98]. Moreover, the use of additives such as *Iku-iru* and *Yanyanku* increased microorganisms counts [26] together with aroma compounds [42]. Additionally, drying after fermentation has been revealed to decrease volatile compounds of the fermented seeds condiments [89,97].

4. Conclusion

The present study described the production process and volatile profiles of different fermented condiments of African locust bean seeds encompassing *afitin*, *soumbala*, *sonru*, *iru*, *dawadawa* and *netetu*. Four mainly operations including successively a first long cooking, dehulling, a second short cooking and fermentation were applied during the production of all studied condiments. However, some production parameters such as time, temperature and additives rendered each condiment unique. About 130 volatile compounds have identified and quantified in these products. Pyrazines, aldehydes, ketones, and alcohols have been detected to contribute mainly to the overall aroma profile of the products. Further experiments should be performed for characterizing aroma-active compounds of these fermented condiments.

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