

CONTRIBUTION OF FUNGI IN THE PRODUCTION OF WEST AFRICA INDIGENOUS FERMENTED FOODS AND BEVERAGES.

Abstract

In West Africa countries, several traditional fermented foods, non-fermented and beverages like *Agbélíma*, *Attiéké*, *Dégué*, *Doklu*, *Gari*, *Gowé*, *fura*, *Kenkey*, *Koko*, *Kunun drink*, *lafun*, *Mawè*, *Nunu*, *Obiolor*, *Ogi*, *Pito*, *Tchapalo*, *Tchoukoutou*, *Wagashie*, *Wara*, *bissap*, *gnamakoudji*, *zoom koom*, etc.... are homemade with artisanal technology. Those traditional foods provide a means of food preservation, improve their shelf life, and add nutrients in the food products. From those foods, LAB is reported to be the most predominant microorganism involved in the fermentation process. Still, also fungi species play a key role in the development of different characteristics of those foods, especially their organoleptic attributes, and contribute to increasing their lifetime by producing different compounds. So, this study attempts to show the role played by yeasts in these various foods. Most of the West African home-made foods harbor a diversity of microorganisms (microbes, yeasts, molds, and mushrooms) that work in a synergic manner in order to make a desired product. More studies are needed to characterize fungi and assess their biotechnology application fully.

Keywords: West Africa, Yeasts, Fungi, Beverages, fermented foods

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I. INTRODUCTION

In West Africa, people consume a wide range of fermented and non-fermented products [1] made from cereals (maize, millet, sorghum, etc.), cassava, milk, ginger, etc., as a result of uncontrolled spontaneous fermentation by a mix of micro-organisms made up of moulds, bacteria and yeasts. The technology used to make these products is artisanal or traditional, handed down from generation to generation, and in some cases is part of the family heritage.

Yeasts, molds and fungi are eukaryotic organisms belonging to the fungi group. Among them, yeasts play a key role in food processing, using different types of substrates (millet, sorghum, milk, maize, cassava, banana, etc.) to produce a wide range of fermented products such as *pito*, *gowè*, *kumu*, *wagashie*. According to Rai, Kumari [2], yeasts enhance bioactive components through the production of enzymes and metabolites, and also act synergistically with other groups of micro-organisms, particular with lactic acid bacteria (LAB), to improve organoleptic properties. Yeasts, molds and lactic acid bacteria are responsible for the production of various traditional West African fermented food products because of their enzymatic equipment. These contain useful metabolites that improve digestion, boost immunity and improve people's health [3]. Traditional fermented foods are an important source of income for local households, particularly for women, helping to improve the population's standard of living [3].

Traditional fermentation processes provide a means of food preservation, improving the shelf life and adding to the nutrients in the food products in several African countries[4]. As with any fermented foods, the associated food microbiota is of great importance and interest, this paper aimed to highlight fungi species colonizing west Africa traditional fermented food and which role they play.

II. TYPES OF WEST AFRICA INDIGENOUS FOODS

Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo are countries belonging to western sub-region of Africa. In this region, several traditional fermented foods, non-fermented and beverages like *Akamu*, *Agbélima*, *Attiéké*, *Dégué*, *Doklu*, *Gari*, *Gowé*, *fura*, *Kenkey*, *Koko*, *Kunun drink*, *lafun*, *Mawè*, *Nunu*, *Obiolor*, *Ogi*, *Pito*, *Tchapalo*, *Tchoukoutou*, *Wagashie*, *Afitin*, *Iru*, *Sonru*, *Wara*, *bissap*, *gnamakoudji*, *zoom koom*, etc....[1, 3] are produced and widely consumed by the population belonging to all classes (farmers, workers, drivers, teachers, students, ...) and all ages (children, adults, teenagers, youths, old men and old women) and all sex (male and female).

III. FUNGI SPECIES INVOLVED IN WEST AFRICA INDIGENOUS FOODS

Yeast has been reported to be involved in several types of indigenous African fermented foods and beverages [5, 6]. As showed by table1, the most predominant fungi species involved in the production of west Africa traditional fermented food are *Saccharomyces species especially Saccharomyces cerevisiae*.

Table 1 : Some west African traditional foods and involved fungi species

Indigenous foods	Yeast strains	References
<i>Agbélíma</i>	<i>Candida krusei</i> , <i>C. tropicalis</i> and <i>Zygosaccharomyces bailii</i>	[7]
<i>Akamu</i>	<i>Candida tropicalis</i> , <i>C. albicans</i> , <i>Clavispora lusitaniae</i> , <i>Saccharomyces paradoxus</i> , <i>S. cerevisiae</i> , <i>Aspergillus oryzae</i> , <i>A. niger</i> , <i>Penicillium citrinum</i> , <i>Rhizopus microsporus</i> , and <i>R. oligosporus</i>	[8]
<i>Attiéké</i>	<i>Candida valida</i> , <i>Candida tropicalis</i> , <i>C. holmii</i> , <i>C. krusei</i> , <i>Kloeckera japonica</i> , <i>Saccharomyces cerevisiae</i>	[9, 10]
<i>Dégué</i>	<i>Cyberlyndnera fabianii</i> , <i>Candida glabrata</i> , <i>Kluyveromyces marxianus</i> , and <i>Meyerozyma caribbica</i> .	[11]
<i>Fura</i>	<i>Candida tropicalis</i> , <i>Galactomyces geotricum</i> , <i>Issatchenkia orientalis</i> , <i>Pichia anomala</i> , <i>S. pastorianus</i> , <i>S. cerevisiae</i> , and <i>Yarrowia lipolytica</i>	[12]
<i>Gowé</i>	<i>Clavispora lusitaniae</i> , <i>Pichia anomala</i> , <i>Kluyveromyces marxianus</i> , <i>Candida krusei</i> , <i>C. tropicalis</i> , <i>C. rugosa</i> , <i>C. fabianii</i> , <i>C. norvegensis</i> and <i>Trichosporon asahii</i> .	[13, 14]
<i>Kunu</i>	<i>Aspergillus fumigatus</i> , <i>A. niger</i> , <i>Candida albicans</i> , <i>Fusarium spp.</i> , <i>Penicillium spp.</i> , <i>Rhizopus nigrican</i> , <i>Saccharomyces cerevisiae</i> , <i>Rhizopus oryzae</i>	[15-18]
<i>Lafun</i>	<i>Debaryomyces sp.</i> , <i>Saccharomyces cerevisiae</i> , <i>Candida tropicalis</i> , <i>C. glabrata</i> , <i>Pichia scutulata</i> , <i>P. kudriavzevii</i> , <i>P. rhodanensis</i> , <i>Kluyveromyces marxianus</i> , <i>Hanseniaspora guilliermondii</i> , and <i>Trichosporon asahii</i> .	[19, 20]
<i>Mawè</i>	<i>Clavispora lusitaniae</i> , <i>Candida krusei</i> , <i>C. kefyri</i> , <i>C. glabrata</i> , and <i>S. cerevisiae</i> , <i>Kluyveromyces marxianus</i> , <i>Pichia kudriavzevii</i>	[13, 21, 22]
<i>Nunu</i>	<i>Candida kefyri</i> , <i>C. parapsilosis</i> , <i>C. rugosa</i> , <i>C. stellata</i> , <i>C. tropicalis</i> , <i>Galactomyces geotrichum</i> , <i>Kluyveromyces marxianus</i> , <i>Pichia kudriavzevii</i> , <i>Saccharomyces cerevisiae</i> , <i>S. pastorianus</i> , <i>Yarrowia lipolytica</i> , <i>Zygosaccharomyces bisporus</i> , and <i>Z. rouxii</i>	[23]
<i>Ogi</i>	<i>Saccharomyces pastorianus</i> , <i>S. cerevisiae</i> , <i>C. mycoderma</i> , <i>C. krusei</i> , <i>C. tropicalis</i> ,	[6, 24, 25]

	<i>Geotrichum candidum, G. fermentans, Rhodotorula graminis, Clavispora lusitaniae, Aspergillus niger, Rhizopus nigricans,</i>	
<i>Pito</i>	<i>Candida albicans, C. tropicalis, Hansenula anomala, Kloeckera apiculata, Kluyveromyces africanus, Schizosaccharomyces pombe, Saccharomyces cerevisiae, Torulaspora delbrueckii, Aspergillus clavatus, Mucor hiemalis, Cladosporium sphaerospermum, C. herbarum, Debaryomyces hansenii and Pichia anomala</i>	[26, 27]
<i>Tchoukoutou</i>	<i>Clavispora lusitaniae, S. cerevisiae, Candida krusei, C. rugosa, C. ethanolica, Saccharomyces cerevisiae, Pichia kudriavzevii, and Debaryomyces hansenii</i>	[13, 21, 28]
<i>Tchapalo</i>	<i>Candida tropicalis, Saccharomyces cerevisiae</i>	[5, 29, 30]
<i>Dolo</i>	<i>Saccharomyces cerevisiae, Pichia manshurica, Candida albicans</i>	[31, 32]
<i>Palm wine</i>	<i>Saccharomyces cerevisiae, S. globosus, S. carlsbergensis, Clavispora lusitaniae, Kodamaea ohmeri, Candida haemulonii, C. phangngensis, C. silvae, Pichia kudriavzevii, Hanseniaspora jakobsenii, Hanseniaspora guilliermondii, Meyerozyma caribbica, Geotrichum candidum ADR3, Yarrowia lipolytica ADR4, Hanseniaspora jakobsenii ADR2</i>	[32-36]
<i>Adjuevan</i>	<i>Kluyveromyces marxianus, Hansenula anomala, Saccharomyces cerevisiae, Candida tropicalis, C. zeylanoides, Pichia fermentans, Debaromyces hansenii, Hanseniaspora osmophilic, Rhodotorula glutinis</i>	[37]
<i>Masa</i>	<i>Saccharomyces cerevisiae</i>	[38]
<i>Burukutu</i>	<i>S. cerevisiae, Candida albicans, Aspergillus niger</i>	[26, 39]
<i>Rabilé</i>	<i>Saccharomyces cerevisiae., Rhodotorula mucilaginoso, Candida pseudorhangii, C. heliconiae, C. utilis, Shizosaccharomyces pombe, and Sporobolomyces odoratus</i>	[40, 41]
<i>eblima and epoma</i>	<i>Candida guilliermondii, C. krusei, C. tropicalis, Saccharomyces cerevisiae</i>	[42]
<i>Soumbara</i>	<i>Fusarium oxysporum, Penicillium chrysogenum, P. sclerotiorum, Aspergillus</i>	[43]

	<i>flavus, Absidia corymbifera, Cladosporium uredinicola.</i>	
<i>Lait caillé</i>	<i>Candida parapsilosis, Saccharomyces cerevisiae</i>	[44]
<i>Kulikuli</i>	<i>Aspergillus flavus, A. tamarii, A. niger, Cercospora personata and C. Arachidicola</i>	[45]
<i>fresh and dried vegetable</i>	<i>Aspergillus flavus, A. niger, A. parasiticus, Mucor spp., Penicillium brevicopactum, P. chrysogenum, Fusarium culmorum</i>	[46]
<i>Smoked, Fermented and Dried Fishes</i>	<i>Aspergillus parasiticus, A. fumigatus, A. wentii, A. clavatus, A. ochraceus, A. tamarii, A. candidus A. versicolor, Mucors sp., Rhizopus sp., Rhizomucor sp., Penicillium sp.</i>	[47]
<i>Kokonte</i>	<i>Aspergillus spp., Alternaria spp., Cladosporium spp., Colletotrichum spp., Drechslera spp., Fusarium spp., Monilia spp., Nigrospora oryzae, Phoma sorghina, Geotrichum spp., Aureobasidium spp., Mucor spp., Rhizopus spp., Penicillium spp., Paecilomyces variotii e Wallemia sebi</i>	[48]
<i>Cassava chips</i>	<i>Aspergillus aculeatus, A. candidus, A. clavatus, A. flavipes, A. flavus, A. fumigatus, A. niger, A. nomius, A. ochraceous, A. parasiticus, A. tamarii, A. terreus, A. versicolor Fusarium verticillioides, F. oxysporum, Mucor piriformis, Penicillium chrysogenum, P. sorghina, Rhizopus oryzae, R. nigricans, Nigrospora oryzae, Chrysonilia sitophila, Cladosporium resinae, Cladosporium herbarum</i>	[49, 50]
<i>Cassava flour</i>	<i>Aspergillus niger, A. fumigatus, P. chrysogenum, Penicillium spp., Mucor spp., Neospora spp., Choanophora spp., Cladosporium spp., Rhizopus spp., Rhodotorula spp., S. cerevisiae, F. oxysporum, B. theobromae, Helminthosporium spp. and Trichoderma spp.</i>	[51, 52]
<i>Sesame</i>	<i>Aspergillus candidi, Aspergillus flavi, Aspergillus nigri, Cladosporium sp., Fusarium fujikuroi</i>	[53]

IV. ROLE OF YEAST IN THE WEST AFRICA INDIGENOUS FOODS PROCESS

For Johansen, Owusu-Kwarteng [54], indigenous fermented foods and beverages represent a cultural heritage of the people of sub-Saharan Africa. Moreover, Sub-Saharan Africa has one of the richest collections of fermented food products in the world. Yeasts play an important role in obtaining these foods, as they are found on raw materials in symbiosis with other microbial genera. Yeast diversity in native fermented foods is influenced by processing methods, hygiene conditions and interactions between yeasts and other commensal microorganisms.

The main beneficial microorganisms that are responsible for the fermentation of African indigenous fermented foods and beverages are lactic acid bacteria and yeasts which may be present as microflora on the substrates or added as starter cultures. The synergistic interaction between these microorganisms in the fermented food matrices result in improved nutrient availability, food quality, palatability, organoleptic properties, increased shelf life, safety, digestibility and also play beneficial roles in modulating host immune system thereby minimizing the risk of certain diseases as reported by [55]. Possible roles described are:

- In general yeasts contribute to the organoleptic properties of the final fermented products [56];
- capable of upgrading the nutritional value of the foods [57, 58];
- and reported to have several probiotic effects[12, 52, 59, 60] that can contribute to the improvement of human health [53, 61].

V. KEY ROLES PLAY BY CERTAIN SPECIES OF YEAST IN FOODS

Each strain of fungus or yeast plays a key role in the food process. Some of these roles are described below:

- *Candida krusei* plays an important role in flavor development through its proteolytic activity [62]. It is used as a starter culture in dairy products to maintain the activity and increase the longevity of LAB and can also have a positive impact on the organoleptic quality of fermented corn dough [63] ;
- *C. glabrata* used as a starter culture [64] is in fact a major pathogen responsible for nosocomial fungal infections;
- *Candida* species are ubiquitous organisms and their ability to co-metabolize with lactic acid bacteria has been reported as desirable for adequate fermentation of traditional African foods [57, 58, 65, 66]. Their high resistance to acidity and high environmental temperatures may explain their predominance in mawè fermentation [67] ;
- *P. kudriavzevii* and LAB are in symbiotic association in *nunu*, where they play a useful role in flavor development [23] ;
- *Lactobacillus* and *Saccharomyces cerevisiae* are involved in flavor development during fermentation of maize for *ogi* production [68] ;
- *Saccharomyces cerevisiae* is responsible for the final alcoholic fermentation that increases the alcohol yield of *burukutu* [39], as for sorghum beer [69] and is fully accepted for human consumption because is the most common food-grade yeast [70].

VI. METABOLITES PRODUCED BY FUNGI CELLS IN FOODS

Yeasts spoil food and beverages, and some can be pathogenic [71]. Indeed, according to Rai, Kumari [2], agricultural produce is susceptible to invasion by fungi such as *Aspergillus*, *Penicillium*, *Fusarium* and *Claviceps* species, which can produce mycotoxins in products before harvest, during harvest, or during storage and processing. In fact, the fungal strain, climatic and geographical conditions, cultivation technique and crop protection, particularly during cultivation and storage, are all factors that influence mycotoxin production. Fungal species are also known to produce exopolysaccharides (EPS) [72]. The metabolites produced by fungal species in foods are listed below:

- 1. Exopolysaccharides (EPS)** have antioxidant, anti-tumour and anti-viral activities. They also improve soil aridity and the nutritional value of foods consumed by humans. Their innocuous domestic and commercial versatility and biotechnological relevance are a reliable confirmation of the recent attention given to EPS by the global research community [72].
- 2. Aflatoxins (AF)** are mycotoxins produced by certain species of *Aspergillus* (*flavus*, *parasiticus* and *nomius*). There are more than 20 types of aflatoxin, but the four most common are aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1) and aflatoxin G2 (AFG2) [73]. Aflatoxin B1 (AFB1) is carcinogenic and genotoxic in vitro and in vivo [74], and has been classified in group 1 by the International Agency for Research on Cancer. Contamination of foodstuffs and beverages by mycotoxins can compromise the safety of the supply of foodstuffs intended for human and/or animal consumption and is therefore a cause of the appearance of harmful effects on the health of humans and animals [75]. In Togo, aflatoxin B1 was detected in 38% of maize samples with maximum contamination levels of 256 µg/kg, and in 25% of sorghum samples (range 6-16 µg/kg) [76]. These aflatoxin producers colonise peanuts, cereals, oilseeds, cow's milk and spices [77].
- 3. Ochratoxin A (OTA)** is a fungal secondary metabolite produced by *Aspergillus niger*, *A. ochraceus*, *Aspergillus carbonarius* and *Penicillium verrucosum*. OTA has a number of adverse effects on animals and humans, including nephrotoxicity, teratogenicity, embryotoxicity, immunotoxicity, genotoxicity and neurotoxicity [78]. OTA has been found in human and animal foods such as cereals, wine, cocoa, dried vine, fruit, olives, coffee, beer and spices [79, 80]. Their production in these products is influenced by temperature, water activity, pH, nutrient availability and the competitive growth of other microorganisms. Mycotoxin contamination of food can represent a direct source of human exposure through direct consumption or an indirect source through consumption of products derived from animals fed on contaminated food.
- 4. Phytate** is considered an anti-nutritional factor due to its ability to chelate cations such as Fe^{3+} , Zn^{2+} , Ca^{2+} and Mg^{2+} (which reduces the absorption of minerals by the human intestine). Phytate complexes can only be absorbed in the human intestine if they are digested by phytases, a class of phosphatases that catalyse the hydrolysis of phytate phosphate [81]. The enzyme is naturally synthesised in plants and certain microorganisms. The phytate content of foods could be reduced by using microorganisms with high phytase activity, in addition to food phytases, as recommended by

Fischer, Egli [82]. The authors [83] noted a reduction in phytases in traditional Senegalese foods fermented with yeast.

5. A study conducted in Togo showed that maize and sorghum were contaminated by fungi that produced fumonisins (88 and 67% for maize and sorghum respectively) with concentrations ranging from 101 to 1838 µg/kg for maize and 81.5 to 361 µg/kg for sorghum, respectively [76].

VII. CONCLUSION

The main spoilage agents in human and animal foodstuffs are fungi, which are ubiquitous in the environment and in plants and animals. There are two types of fungi: macroscopic fungi (some of which are edible) and microscopic fungi. The presence of microscopic fungi compromises the nutritional and organoleptic quality and safety of foodstuffs intended for animals and humans. In addition to their negative impact on nutritional and organoleptic properties, moulds and fungi are known to be producers of mycotoxins, which can be more dangerous to humans than phytosanitary residues. Fungal cells are our daily companions. African industries need to focus their research on fungal species isolated from traditional African foods to add more value to our indigenous foods.

Conflict of Interest

“The authors declare no conflict of interest.”

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