AFRICAN FERMENTED FOODS AND BEVERAGES. POTENTIAL IMPACT ON HEALTH

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CHAPTER 12

AFRICAN FERMENTED FOODS AND BEVERAGES. POTENTIAL IMPACT ON HEALTH

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Microbial Fermentations in Nature and as Designed Processes, First Edition. Edited by Christon J. Hurst.

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12.1 INTRODUCTION

Centuries ago, believed over 9000 years ago, African civilizations embarked upon spontaneously fermenting foods and beverages with the deliberate purpose to stockpile fresh food raw materials to extend preservation and endure seasonal changes in food availability. In the era of the Neolithic Period, with the beginning of agriculture, there were already traces of many fermented products such as milk, sorghum, millet, fish, meat, bones, hides, skins, hooves, gall bladder, fat, intestines, caterpillars, locusts, frogs, and even cow urine. Beer was not invented but discovered in Egypt (circa 10 000 BCE), as fermentation was a fortuitous by-product of the collection of wild grain.

Nearly every culture in the world developed a single staple crop such as cereals and potatoes, which formed the bulk of its diet. North Africa's climate and geography are very different from those of Sub-Saharan Africa, the main agricultural challenge in the regions being access or lack of water, and arable land. Humans' emergence in Africa as foragers adopting subsistence farming as a way of living occurred quite late relative to some other geographical regions. Agriculture's progress southward from the north of the continent was quite slow, more to support the development of animal husbandry, while domesticated crops did not arrive in South Africa until the seventeenth century, and they came with European sailors, not overland.

According to the UN's World Food Programme (WFP), presently in 2022, there are 44 million people in 38 countries in the "emergency" phase of food insecurity and as many as 38 million Africans are living under the threat of famine, facing the effects of severe food insecurity, including malnutrition, starvation, and poverty, conflicts, or environmental challenges being the largest drivers of the scarcity of food. While many people may not be "hungry" in the sense that they are suffering physical discomfort, they may still be food insecure (Table 12.1).

Subsistence small-scale farming for food security has been a policy focus for many African governments but any agricultural development is highly dependent on stressors such as climate changes, serious and sustained droughts, cyclones, floods, and water availability, namely in Sub-Saharan Africa. Therefore, it is imperative to improve the interpretation of the interconnections among climate, food, sustainable livelihoods, policies, actions, and practical initiatives.

Food security is dependent not only on nutritious food production but also on consistent food access and adequate food utilization. The overall consumption of animal products (dairy, meat, eggs, fish, and seafood) in Africa is well below the global average. Most traditional African dishes, based on hearty vegetable soups and stews, contain starchy items, some meat or fish, and a variety of spices and herbs. Many African dishes consist of maize flour and center around curried dishes.

TABLE 12.1 The most at-risk of food insecurity among the 54 African countries.

Country	% Hungry Population	Total Population (million)
Somalia	68%	12.3
Burkina Faso	61%	19.8
South Sudan	60%	11.0
Mali	60%	19.1
Sierra Leone	55%	8.2
Niger	55%	22.4
Lesotho	50%	2.1
Guinea	48%	12.2
Benin	47%	11.5

Africa is also home to an extensive and diverse functional and medicinal botanical life, which is an essential element of the indigenous African healthcare systems.

Thus, food security, currently firmly aggravated by the pandemic and the war in Europe, continues to be a major concern in Africa and needs to be tackled to eradicate poverty and reduce inequalities through sustainable development. Fermentation portrays an important function in food security in that it can recycle and transform inedible by-products and food wastes into valuable nutrient-rich and healthy food sources.

Fermented foods have a historical tradition in Africa, probably introduced by Arab merchant travelers. Foods and beverages that are prepared via a fermentation process constitute an essential segment of human nutrition in most food cultures around the world, although not illustrated in food guidelines. Fermentative pickled fruits and leafy vegetables are very popular in many regions of Africa, Europe, Asia, America, and the Middle East and can address the problems related to the world's balanced diet.

Africa has a rich tradition in fermented foods and beverages of plant and animal sources, essentially homemade under unhygienic substandard environments for own consumption or offered for sale in informal small markets. Indigenous knowledge concerning these foods is found in elderly rural women.

African fermented foods can be grouped into three clusters: (i) the foodstuffs; (ii) the relishes, condiments, and sauces; and (iii) the beverages. However, the absence of writing culture in most of Africa makes their origin difficult to trace. The most documented of the fermented foods is sour milk but over 5000 fermented products have long been a part of the human diet, and their traditional and cultural value varies among countries.

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Traditional fermentation processes in Africa provide a means of food preservation, stalling the rottenness of perishable foods, extending the shelf life, and reducing food waste. Indeed, microbiota metabolize the raw materials, improving organoleptic properties, adding nutritional value, and repairing biosafety through the synthesis of anti-microbial metabolites.

African fermented foods and beverages are so specific that they identify cultures and civilizations. There is a difference in gut microbiota from distinct origins. The enteric microbial community of infants from rural Africa is dominated by bacteria able to utilize cellulose and xylan

(hemicellulose) contrary to the gut microbiota of European children. As justified by different diets, African children's microbiota is based on foods rich in starch, fiber, and plant polysaccharides whereas European children's microbiota represents their being accustomed to protein and fat rich foods.

Research has shown that the fermentation of sorghum raises the digestibility of its protein from a value as low as 45% to as high as 86%. Despite the awareness of the favorable impact of fermented foods and beverages on well-being and diseases, their many healthcare benefits or suggested systematic consumption have not been generally contemplated in most world food guidelines.

Knowledge about the specific multispecies microbial biodiversity of each food and beverage ecosystem is essential to understand the eventual impact on human welfare and health, but progress has been slow, namely with traditional African products. The understanding of food microorganisms' contribution to health is still in its infancy and much remains to be discovered.

The present global regulatory frameworks are confusing and limiting and do not accommodate the increased rate of digitalization which influences our communities and markets. Science is relentlessly developing, and many exciting new technologies will continue to transform the developing world and improve human welfare. Foods prepared by fermentation will increase in amount and its use will spread to different parts of the world, as they contribute to the requirements of the vast diversity of gut microbiota, now known to have an indirect impact on general and even mental health.

In Africa, the potential risk of microbiological contamination is vast, raising the question of balance between food security and food safety. The overall advantages of indigenous or ethnic fermented foods and beverages are accepted, the doubt is if they are safe for human consumption and approved as an everyday food.

Differences in flavor compounds and bacterial communities of traditional and modern fermentation are poorly understood. Furthermore, many challenges remain regarding the establishment of dietary guidelines integrating education, agriculture, health, environment, economy, and industry.

The purpose of this chapter is an illustration of some African fermented foods and beverages, their potential health implications, and eventual hazards. Identifying social determinants and formulating appropriate strategic responses is not an easy task and no suggestion is made on possible master plans for improving their nutritional composition and potential well-being and general health benefits.

12.2 SOME STAPLE FERMENTABLE FOODS IN AFRICA

Africa, the second-most populous, vast, and diverse continent, has numerous varieties of gastronomic traditions with very distinct regions of unique cultures and cuisines. Trying to figure out the most popular foods in the continent is an impossible task since African foods are as diverse as its people and they are typically overlooked by scientists, policymakers, and the world at large.

The vast potential of each vegetable in Africa has been mainly screened for nutraceutical and pharmaceutical potential and less to help curb malnutrition, boost food security, foster rural development, or create sustainable land care in Africa. The limited information is not perfectly aggregated and is fragmentary and widely dispersed in many different journals and books.

While the customary African diet is miscellaneous, vegetables are the largest staple. Cereals (maize, sorghum, millet), cassava, sweet potatoes, African spinach, okra, cabbages, beans, lentils, carrots, aubergine, pumpkin, onions, tomatoes, tropical fruits, spices, and herbs, are common ingredients in African dishes.

The microbiota in any fermenting food substrate is an outcome of the hygio-sanitary conditions of the raw material, the local environment settings, the tools used, and the handlers, leading to a wide range of fermented foods and beverages.

12.2.1 Maize (*Zea mays*)

In Africa, maize is mostly grown in small-holder farming systems. It is common and relevant with a double harvest happening in a year. Maize being a C4 plant, like sugar cane and sorghum, is more efficient than others (e.g. rice, wheat, potato, soybean) and presently there are many challenges when attempting to improve crops through C3-to-C4 engineering, namely in warmer climates.

Maize is produced in all African countries albeit mainly in Nigeria, South Africa, Egypt, and Ethiopia, and is common in drought or humid areas. The desired genetic enhancements for early and extra-early maturing germplasm, for striga (*Striga hermonthica*) resistance and management, higher levels of lysine and tryptophan, more resistance or tolerance to drought, and low soil nitrogen needs, have been researched and used in the continent.

The introduction of insect-resistant Bt genetically modified (GM) maize, cotton, and soybeans, which include a gene from the *Bacillus thuringiensis* (Bt) bacterium, can provide insect protection. We also can try to create plants that are more resistant to pesticides or produce pesticides themselves, changing the way that pesticides are used in agriculture and perhaps helping small-scale farmers to improve yields and control pests without chemical insecticides. However, many countries still ban this technology, with several pros and cons, and continue to adopt the indigenous white maize, which requires the use of more land, water, fertilizers, pesticides, and herbicides, which are not only energy expensive but also detrimental to the environment.

12.2.2 Cassava (*Manihot esculenta*)

Cassava (Figure 12.1) is produced not only for its root vegetable, but also for its leaves (*matapa*), and for the production of biofuels, foods (*gari*), feedstock, starch, beverages, flour, glucose syrup, and glue. Traditionally, cassava root is peeled, cleaned, and boiled to soften the tissue, then the microbial starter culture is added and incubated to ferment (*fufu*) for four to six days to effect sufficient detoxification of the roots, eliminating cyanide.

FIGURE 12.1 Cassava roots and leaves.

Every part of Africa has developed its own process to ferment and use cassava and their designations are extensive, providing over 50% of the average daily energy intake in some countries. The cassava fermented foods are quite similar except the plant varieties and ingredients are different and there is diversity in the associated microorganisms in cassava fermentation.

12.2.3 Fermented Beans

Africans consume reduced amounts of protein of animal origin and their main sources of essential amino acids are beans, legumes, nuts, and seeds, which usually means their diet is lacking one or more of the nine essential amino acids. All beans primarily lack the essential sulfur amino acid methionine.

Generally, beans may have numerous anti-nutritional factors such as condensed tannins, trypsin inhibitor activity, α-galactoside oligosaccharides, polyphenols, lectins, and pyrimidine glucosides. Processing food by fermentation may be positively associated with enhanced nutritional quality by reducing the levels of these anti-nutritional factors.

These beans and other seeds are mainly fermented to yield condiments and convert substrates into products that contribute to the chemical composition and taste of the final product. *Bacillus subtilis* seems to be the most predominant microorganism followed by *Escherichia*, *Proteus*, *Pediococcus*, *Micrococcus*, *Staphylococcus*, and *Streptococcus*, but surely the microbiota profile will be much wider.

Some of the most popular condiments based on fermented vegetables in West Africa comprise *daddawa* and *soumbala* from soybean (*Glycine max*), *iru* or *dawadawa* from locust bean (*Parkia biglobosa*), *ugba* from African oil bean seed (*Pentaclethra macrophylla*), *ogiri* from melon seeds (*Citrullus lanatus* subsp. *vulgaris*), and *owoh* from cotton seeds (*Gossypium hirsutum*).

Cowpea (*Vigna unguiculata*) is a valuable legume widely cultivated. Fermentation of this bean seems to significantly improve its nutritional value, by improving amino acid digestibility and mineral (P, Mg, and K) bioavailability.

12.2.4 Moringa (*Moringa oleifera*)

There are many valuable evergreen trees and shrubs in Africa producing the three vital "F's" that desert dwellers require, Fruit, Fodder, and Fuel. Rural populations in arid regions use these trees to meet their daily requirements of biomass or biomass-based products, such as food, fuel (firewood), fodder, fertilizer (organic manure, forest litter), building materials (poles), and medical herbs.

All parts of moringa are sources of food or medicine. It is a plant that is often called the miracle tree used for centuries due to its medicinal properties and health benefits (Figure 12.2). Rich in vitamin C, 7 times more than oranges, and in potassium 15 times more than bananas, 10 times more vitamin A than carrots, 25 times more iron than spinach, 17 times more calcium than milk, 9 times more protein than yogurt, it is known to have some 540 compounds that can treat or prevent 300 health issues.

There has been considerable research to prove it has antifungal, antiviral, antidiabetic, antidepressant, anti-inflammatory, and anticholesterol properties. However, most tests have mainly taken place on animals as opposed to humans. The concentrations of crude protein, small peptides, and amino acids present in moringa leaves may increase significantly after fermentation. Antinutritional factors in moringa, such as tannins and glucosinolates, could affect the palatability, digestion, and absorption of nutrients but fermentation degrades these elements.

Very few studies have examined the dynamic changes of nutrients and antioxidant components during moringa fermentation, and almost none have reported on the antioxidant activity of moringa leaf powder after fermentation.

FIGURE 12.2 Moringa leaves and trees.

World-renowned cosmetic enterprises have established vast moringa plantations in Africa claiming to help feed and medicinally treat poor people, but their main interest is in the food-grade moringa seed bright yellow oil. The oil can be exported as an added value raw material, to be manufactured elsewhere as skin moisturizing compounds, for cleansing the skin, anti-aging, and hair treatment.

12.2.5 Olives (*Olea europaea*)

Table olives (*O. europaea*) have been produced extensively in North African countries for centuries, with Morocco, Algeria, Tunisia, and Egypt being the main producers of olives and olive oil. This fermented vegetable has several interesting nutritional and bioactive compounds that have even been proposed as functional foods with known microbial stability and as a source and carrier of probiotic lactic acid bacteria (LAB).

Considered one of the largest agricultural business sectors it is highly industrialized and along with following traditional methods, new sophisticated processes have been introduced. Refineries and cooperatives have made several attempts at industrial upgrading.

The wild olives (*O. europaea* subsp. *cuspidata*) are native to the South African region but are inedible although it is considered a very valuable tree medicinally by indigenous people, used to boost the immune system, lower blood pressure, combat viral, fungal, and bacterial infections and improve circulation and brain function.

12.2.6 Tropical Wild Fruits

The traditional fermented products include beverages from indigenous fruits often mixed with functional herbal medicinal products. In Africa, blessed with huge agrobiodiversity, there are more than 50 wild indigenous tree species that bear highly valued edible fruits essential for food security, health, and nutrition. Africans live surrounded by vast readily accessible wild fruit and

FIGURE 12.3 *Uapaka kirkiana* or wild loquat (*mushuku/muzhanje*); *Ziziphus mauritiana* in an open informal market.

vegetables normally free and easy reaching. They are an important source of income for poor people, but their value chains are poorly developed.

Wild fruits such as *Adansonia digitata* (baobab), *Ziziphus mauritiana* (Indian jujube), and *Sclerocarya birrea* subsp. *caffra* (marula) provide micronutrients such as vitamins and minerals. These seasonal wild fruits are collected and consumed either fresh or made into various products such as jams, pickles, chutneys, and spontaneously fermented juices.

Just an example, *Uapaca kirkiana*, wild fruit (Figure 12.3) rich nutritionally and high in phytochemicals antioxidants, was reported growing in miombo areas in Angola, Burundi, Malawi, Mozambique, Tanzania, Zaire, Zambia, and Zimbabwe, but in need of being scientifically exploited and incorporated into the diets to help solve some nutrition-related concerns. The significance of the *U. kirkiana* fruit tree as a food resource as compared to other indigenous fruit trees has been researched and its fermentation resulted in the degradation of phytases leading to increased bioaccessibility and bioavailability of magnesium, iron, calcium, and zinc content.

In Zimbabwe, *Uapaca* pulp infused with cold water is left to ferment until the mixture turns cloudy. The solution is utilized to manufacture a thin porridge by adding milled maize. Sometimes the pulp is allowed to ferment into a candied alcoholic beverage called *mutandavira*. This seasonally abundant wild fruit fermented on a small scale (household-level craft industry) has the potential to turn into a large-scale production of *makumbi* (industrially processed fermented foods).

12.3 THE DIVERSITY OF GUT MICROBIOTA

The establishment and development of gut microbiota over the lifecycle moved from the previously accepted dogma that the mammalian healthy placenta and fetus were germ-free and considered to be sterile, to an understanding that the placenta and fetus are microbially colonized under conditions critical to the developing newborn's immune system. Our actual knowledge is that in-utero humans harbor unique prenatal microbiomes.

Many species of bacteria, specifically those found in the invisible universe of the human microbiota, are non-pathogenic commensals from the phyla Firmicutes, Bacteroidetes, Actinobacteria, Proteobacteria, and Verrucomicrobia. The gut microbiota form an interactive and complex microecosystem composed of trillions of microorganisms. This vast community plays vital roles in

mucosal immunity, nutrient metabolism, and intestinal epithelium differentiation. Its collective metabolic activities and host interactions influence both normal physiology and disease susceptibilities.

Having a stabilized gut bacterial community is one of the preconditions for a host to perform its normal physiological functions, metabolism, and immune functions. Temporal fluctuations in the composition of gut microbiota may result in multiple gastrointestinal diseases and even affect mental health.

Indeed, the digestive process is dependent on gut maturation and function of the mucus layer, motility, hormones, enzymes, and the activity of the microbiota, and its efficiency is affected by critical interactions between these highly diverse factors and microbial communities.

Our understanding regarding the activity and interactions among microorganisms in biological processes like fermentation has recently been revolutionized by advanced omics techniques and next-generation gene sequencing methods. Metaproteomics workflows also is a promising technique for advancing understanding of the functional roles of the microbiome in disease. However, research is required to develop databases of disease-associated microbial biomarkers since current models lack information regarding the interaction between different microorganisms.

Among the various molecular techniques used to study bacterial diversity, culture-independent methods (e.g. cloning of 16S rRNA and denaturing gradient gel electrophoresis) rely on the principle of amplifying rRNA or functional gene PCR products to study microorganisms within their original environments.

These molecular methods, in conjunction with additional procedures such as chemical analysis, imaging, and stable isotope labeling, can assist species identification of the immense diversity of the microbiota and the complex interactions among microbial community composition and kinetics.

The recent move from studying microbiology to microbiomes, with awareness of diverse microbial life and their symbiotic relationships, and how host and environmental factors affect gut microbial ecology, may in the future promote well-being, health, and lifespan by guiding therapeutic strategy development.

The discipline of microbiome and probiotic investigation has expanded rapidly, and despite the continuous development of new methods and equipment, these techniques well-used to characterize microbial pathogens in human patients are not yet implemented in detailed studies of the microbiome of fermented foods and beverages and depend on cellular-level activities and biochemical process-level phenomena.

In a recent clinical trial with 36 healthy adults, it was shown that while microbiota diversity was stable in a fiber-rich diet, with a high-fermented-food diet a relevant raise in the diversity of gut microbiota was evident, with a simultaneous decrease of molecular markers of inflammation, modulating the gut microbiome, which may favorably impact the immune system (Figure 12.4).

The countless blending of foods as substrates for microbial enzyme fermentation yields products with vastly different sensory and nutritional profiles. Fermentation improves the bioavailability of certain macro- and micronutrients, induces reductions in anti-nutritional compounds, and generates nutrients and bioactive compounds of microbial metabolism with specific nutritional and potential health functionalities.

LAB (e.g. *Lactobacillus*, *Streptococcus*, *Pediococcus*, and *Leuconostoc*), widely used in the fermentation of animal and vegetable products, also exhibiting probiotic properties, are known to produce several biogenic compounds, currently known as metabolic by-products or "postbiotics," including fatty acids, sugars, enzymes, bacteriocins, and bioactive peptides.

LAB may ferment dairy, meat, and vegetable products, whereas acetic acid bacteria (e.g. *Gluconobacter, Gluconacetobacter,* and *Komagataeibacter*), associated with the biotechnological

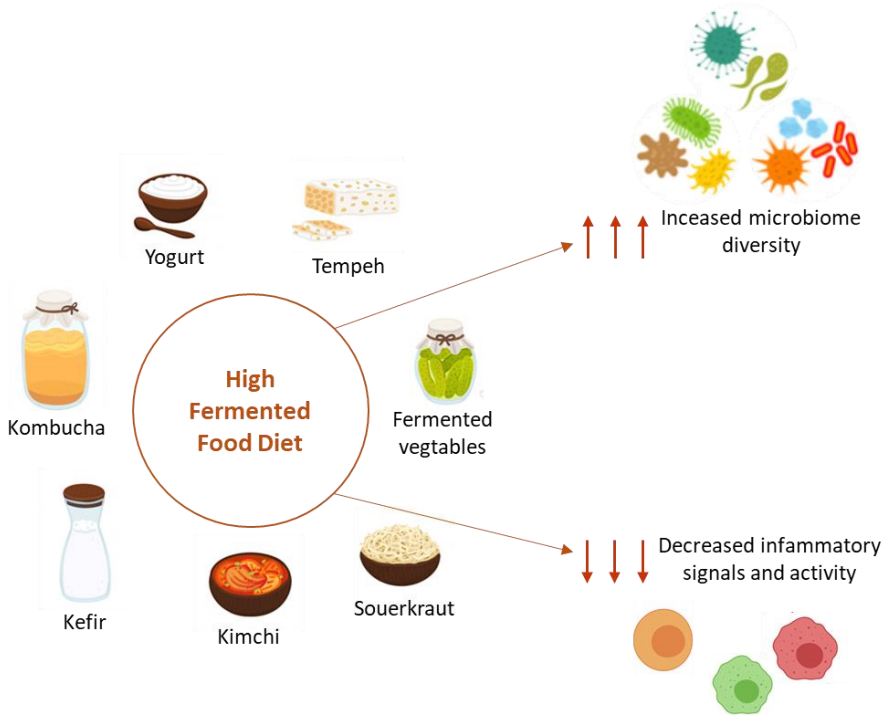

FIGURE 12.4 A diet high in fermented food or beverage decreases inflammatory proteins, reduces molecular signs of inflammation, and improves immune response. Therefore, improving digestive health with a high-quality fermented diet may improve immunity against infections and diseases.

process of vinegar and cellulose production, are responsible for the fermentation of cocoa bean, acidic beverages (e.g. kombucha, milk kefir, water kefir), and vinegars made from a wide range of base ingredients.

Alcoholic fermentations, where some 95% of sugars in the substrate are converted into ethyl alcohol and carbon dioxide, are mainly driven by yeasts (e.g. *Saccharomyces cerevisiae*) to produce beer, wine, and bread.

Alkaline fermentations make use of fungal (e.g. *Aspergillus, Penicillium, Rhizopus, Mucor, Humicola, Thermoascus, and Thermomyces*) enzymes (e.g. amylase, glucosidase, glucose oxidase, protease, pectinase, cellulase, invertase, laccase, ligninase, lípase) during the production and maturation of cheese, fermented meats, and fermented soybean products.

The presence of non-specific spontaneously fermenting microorganisms can hinder successful monitoring of the fermentation process, leading to finished products of variable quality. Some undesirable noxious contaminants and metabolites of the unintended microbiota will be released into the fermented food matrix. Commonly emerging toxic compounds in fermented foods and beverages include mycotoxins, biologically active amines (e.g. dopamine, histamine, norepinephrine, serotonin, and tyramine), and cyanogen glycosides (e.g. linamarin, dhurrin, prunasin, and amygdalin).

Research on these important topics is scarce while extension services and smallholders' family farmers do not have adequate knowledge of specific substrates and types of microbiota inocula. Therefore, the final fermented product quality at the rural African household level remains unknown and difficult to be standardized.

Further research is still needed to clarify some of our present understanding of the fermentation of foods and beverages regarding the role of microbiota in micronutrient bioavailability, bioaccessibility and metabolism, and the related biological mechanisms.

12.4 TRADITIONAL FERMENTATION STRATEGIES

In most African countries, traditional village-art practices and age-old systems are still used for agro-processing including fermentation. Fermented foods and beverages are produced by the controlled growth and enzymatic activities of microorganisms, through basically four main fermentation processes (lactic, acetic, alcoholic, and alkaline).

Frequently it implies tossing the mixture to be fermented with a previously fermented mash melange. Clay crocks and pots or repurposed polyethylene drums are used for traditional fermentation, covered with a cloth that creates a slightly anaerobic environment or completely closed to create stricter anaerobic conditions.

It is important to address the common misconception that fermented foods are the same thing as probiotics. Substantial confusion exists between fermented foods and beverages and the probiotic concept. Contrary to general expectations, fermented foods are generally not sources of probiotics. Nevertheless, some fermentation processes perpetuate the multiplication of pre-existent beneficial live microbes called probiotics. They are not probiotics, although they may contain them, as their live microbial content is undefined.

These live microbes beneficially affect the host by improving its gastrointestinal microbial equilibrium. LAB dictate the fermentation operation and lead to a low pH, eliminating the evolution of a pathogenic bacterial community, thereby preventing spoilage and increasing the shelf-life and safety of the food.

The current status of fermented products commercially available in Africa is less than ideal. Prevailing obstacles include failure to identify the constituent microorganisms and deficient feasibility of probiotic microorganisms which lead to inadequate shelf-life. Given the potential benefits of manipulating the human microbiota for beneficial effects, there is a clear need for improved regulation of fermented foods and beverages and carried probiotics.

There are various reasons why foods may be fermented. Perhaps the most important one is to produce a variety of flavors of existing foods. Others are to mask some undesirable flavors, to make some inedible foods edible, and to mainly preserve some foods and beverages. There is a wide geographical variation of numerous fermented foods and beverages across the continent thus impossible to mention all of them.

Considerable ways of rustic farm food processing and concoction are often used at rural dwellers and community levels to enhance the bioavailability of micronutrients including de-hulling, threshing, drying, grinding, soaking, cooking, wet, or dry milling, fermentation, and germination.

Most yeasts can ferment hexose sugars (e.g. glucose, fructose, galactose, or mannose) to ethanol anaerobically (Figure 12.5) and this has been well studied since Pasteur in the mid-nineteenth century, where the glycolytic pathway, a series of reactions used by aerobic organisms generate energy (ATP) through the oxidation of acetyl-CoA derived from carbohydrates, fats, and proteins into carbon dioxide and chemical energy.

Pentoses (e.g. xylose or arabinose), however, are not easily fermented by *S. cerevisiae*, the preferred microorganism in crop-based glucose fermentation.

Within the human microbiome, ethanol is not a truly endogenous substance of human cells, but enters them from the blood, originating from the microbial enzymes' fermentation of carbohydrates in the gastrointestinal tract. However, the problem of ethanol synthesis inside human cells remains unresolved since the presence of alcohol dehydrogenase and aldehyde dehydrogenase in all cell types including neurons also argues for an intracellular origin of ethanol.

Fermentation, via the action of microbial phytase enzymes, which hydrolyzes phytic acid, the primary source of phosphorus in plant seeds, lowers inositol phosphates, decoupling the complex links with calcium, zinc, and iron, enhancing the absorption of these minerals.

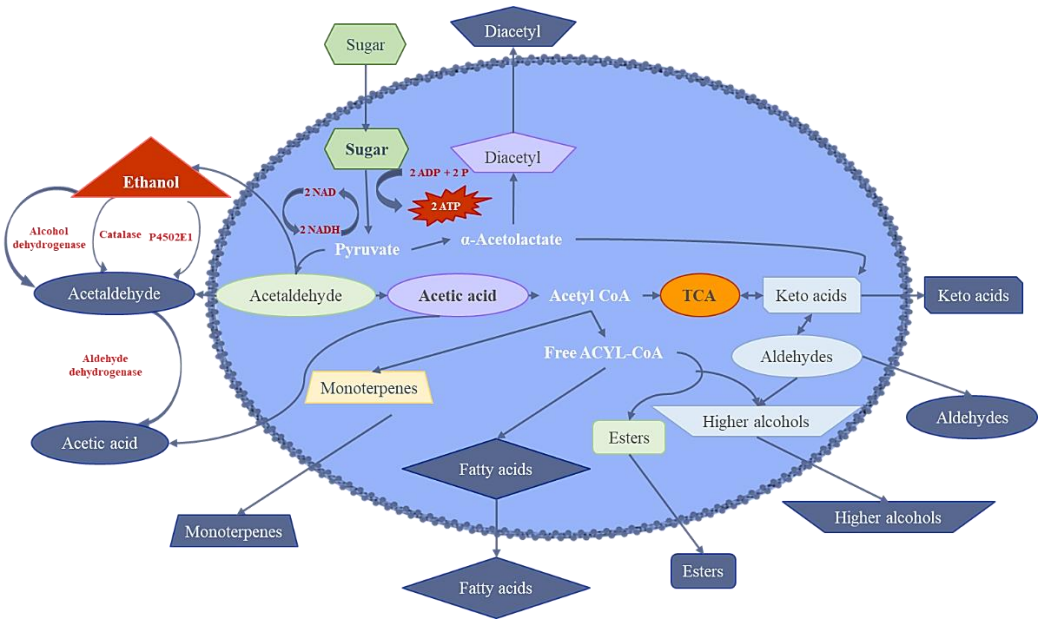

FIGURE 12.5 Mitochondrial yeast metabolism, maltose being the best sugar source. Secondary metabolites and metabolism intermediates are shown in ethanol formation.

Fermented beverages have been produced and consumed for ages, contributing to the nutrition of many communities and cultures worldwide. Traditional fermentation has evolved for millennia as a process of raw food conservation and a way to yield new foods with improved sensorial characteristics, such as appearance, texture, taste, and smell, and probably not to improve nutritional value.

Fermented foods constitute a significant component of African diets. Most African countries have a history of food processing passed down for generations and fermented products comprise some 5–40% of the diet in some populations. Fermented milk (yogurt, curds, and cheese) and, to a lesser extent, meat and fish as well as wine and beer, are the result of traditional methods of preservation, rooted in ancient tradition but with several innovations and technological adaptations introduced over time.

Northern African countries between the Sahara and the Mediterranean Sea (Morocco, Algeria, Mauritania, Egypt, Libya, Sudan, Tunisia, and Western Sahara) share many traditional fermented foods resulting from the blend of nutritional habits brought by the Greeks, Nubians, Phoenicians, Egyptians, Arabs, Roman civilizations, and their interactions with those of the original Berber inhabitants.

Olives, produced extensively in northern African countries (Morocco being the largest producer and Tunisia with the widest diversity of olive germplasm), are rarely consumed directly as a natural fruit due to their extreme bitterness but are used instead for the extraction of oil and, to a lesser degree, as table olives (after curing). Indeed, olives are inedible without fermentation that removes bitter phenolic compounds.

Coffee, tea, and cocoa (*Theobroma cacao*) are produced in Africa and consumed worldwide, but largely unperceived by consumers as “fermented” food products. Fermentation of coffee, tea, and cocoa occurs upstream in the food manufacturing process in contrast with milk fermented products, where the finished goods are subject to fermentation and are natural carriers of live microbiota.

The post-harvest processing stage occurs rudimentarily, and cocoa seeds are deliberately fermented for some 7 days, unprocessed green coffee grains for 10–25 days, and in the case of post-fermented teas, fresh tea leaves may be fermented from several months up to several years.

Kombucha, a sweetened fermented black or green tea that is non-alcoholic or low in alcohol content (<0.5%), may have originated from the Manchurian region of China where the drink is traditional but it is now widespread and popular in many African countries.

An alternative substrate to produce kombucha, is *Brassica tournefortii* (Brassicaceae), an annual invasive herb that grows wild in rocky and sandy environments in the Mediterranean regions of North Africa (Figure 12.6). Fermented for about 14 days with a symbiotic culture of several indigenous bacteria (LAB, *Acetobacter* and *Gluconobacter*) and yeasts (*Saccharomyces* spp. and non-*Saccharomyces* spp.), produces a tea beverage.

The production of coffee originates from Ethiopian highlands and, centuries ago, it was reported the production of an alcoholic beverage from fermented ripe coffee (*Coffea arabica*) fruit that also is termed coffee berries. Coffee beans, which are the seeds of the coffee fruit, undergo a fermentation stage that is performed by indigenous bacteria and yeasts present on the surface of coffee berries. Today over 80 bacterial genera have been identified in coffee fermentations, and the yeast population is represented mainly by *Saccharomyces* sp., followed by *Torulaspora delbrueckii*, *Pichia kluyveri*, *Hanseniaspora uvarum*, *Hanseniaspora vineae*, and *Meyerozyma caribbicca*.

Sudan is a particular country that still holds strong traditional values in a rapidly changing world. A special type of wafer-thin pancake or flatbread (*kissra*), which is made from naturally fermented durra sorghum or corn, constitutes the staple diet (Figure 12.7). This is eaten with

FIGURE 12.6 *Brassica tournefortii* on the left. Coffee beans in the middle. Kombucha on the right.

FIGURE 12.7 Typical Sudanese *kissra* making and a full meal with several fermented foods.

FIGURE 12.8 Ripe bananas being prepared for fermentation in Burundi.

various types of condiments for stews (*kawal*), sauces, and soups made from a mixture of dried meat, roots, okra, onions, spices, and peanut butter.

Several food waste products are fermented to produce edible food products in rural Sudan, comprised of bones, hides, and edible insects. Fresh bones are fermented simply by laying them on roofs made of straw or reeds, allowing slow fermentation for weeks or even months into a variety of products, or placing chopped, smaller pieces of bone into fermenting basins.

Several traditional fermented foods and beverages are produced at the household level in Burundi. These comprise cereal and banana-based beverages (*urwarwa, isongo, impeke,* and *kanyanga*) (Figure 12.8), milk products (*urubu, amateregua,* and *amavuta*), and cassava-based fermented foods (*ikivunde, inyange, imikembe,* and *ubswage*).

In most African countries, the unwholesome practice of itinerant or stationary street food vending and consumption represents a growing market, supplying daily ready-to-eat food and beverages and fast takeaway for most urban residents. Although solving major social and economic problems, these activities may result in risks to the health and safety of stakeholders along the value chain.

In few family settings, the eccentric manufacture of some indigenous beverages is as bizarre as to also include car battery fluid, marijuana, magic mushrooms, tobacco, and hallucinogenic herbs in the preparation.

12.5 FERMENTED NON-ALCOHOLIC STARCHY FOODS

Currently, "non-alcoholic" is a regulatory term and the laws regarding it vary across the globe, while in Africa none or little information exists on the extent to which countries are addressing alcohol consumption and alcohol-related harm with a great variation in the strength of alcohol control policies. Elsewhere, there is extensive literature on non-alcoholic fermented beverages from all cereals as they are rich in bioactive compounds and high nutritional values, although deficient in lysine, an essential amino acid. Their phenolic compounds have also strong antioxidant potential and scavenge harmful free radicals.

The market for viable, native-born, and non-alcoholic beverages is constantly growing all over the world. Traditional low-alcoholic fermented beverages and non-alcoholic fermented beverages are vastly consumed in Africa and represent a subgroup of fermented beverages that have received

rather little attention from consumers and scientists alike. Their types and traditional uses in European societies are characterized as "functional" foods based on their probiotic culture content.

Fermentation commits to food security, especially in African agro-pastoralist communities. Nevertheless, there is not enough data regarding the dietary role, nutrient composition, health benefits, and other relevant aspects of diverse ethnic non-alcoholic fermented beverages consumed by Africans.

12.6 COMMON AFRICAN FERMENTED ALCOHOLIC BEVERAGES

The production of African alcoholic beverages, usually designated as wines, is handcraft-manufactured by the age-old method of chance inoculation and uncontrolled fermentation; therefore, it is expected there will be variations in the quality and stability of the product and resulting short shelf-life. The distinctive sensorial attributes identified with these beverages are due to mixed culture fermentations, the specific flavor from each fruit substrate, and the outcome secondary metabolites that are yet to be fully elucidated for each beverage. The alcohol content varies a lot, usually between 4% and 41% (*v*/*v*).

12.6.1 Palm Wine

Palm wine, known by numerous names throughout Africa, and also popular in India and South America, is an alcoholic beverage widely consumed in tropical regions, produced from the spontaneously fermented sap of numerous tropical plants of the *Palmae* family (*Cocos nucífera*, *Elaeis guineensis*, *Phoenix dactylifera*, *Nypa fruticans*, *Caryota urens*, *Borassus aethiopum*, and *Raphia hookeri*). The diversity of microorganisms in the natural unfermented palm sap yields the specificity of different palm wines influencing the flavors and aromas of the final product.

12.6.2 Banana Wine

The banana (*Musa acuminata*) alcoholic beverage is common in many countries with different designations (e.g. *mbege* in Tanzania, *tonto* in Uganda, *urwagwa* in Rwanda, *enika* in Mozambique). The process of fermentation sometimes involves adding germinated, dried, and ground sorghum to the diluted banana juice.

12.6.3 Honey Wine

Honey wine (e.g. *tej*, *kuri*) is home processed, but also commercially available where honey is supplemented with sugar before fermentation. The honey wine, common in Cameroon and Ethiopia, is more complex as its preparation involves the addition of herbs, tree barks, and bittering agents from *Rhamnus prinoides* (Gesho). African commercial honey wine (mead) is made using pure cultures of yeasts and they produce aromatic volatile compounds that include alcohols, organic acids, esters, volatile fatty acids, carbonyl compounds, and volatile phenols.

12.6.4 Pineapple Wine

Pineapples (*A. comosus*) are cultivated mainly in Angola, and they have a significant proportion of sugar and acids that make them ideal for wine production. The production of wine involves the fermentation of peeled, sliced, and pressed pineapple. Pineapple wine aroma complexity has been well identified, influencing specific flavors and tastes. Interesting to note is that pineapple peels can be fermented alone, adding sugar, to produce a weaker wine.

12.6.5 Fan Palm Wine

Fan palm (*H. petersiana*) is a common tree species in such areas as Botswana, Namibia, Zimbabwe, Zambia, Tanzania, Angola, Rwanda, Burundi, and many other Sub-Saharan countries. In Botswana, the drink is called *muchema* and in Namibia *omalunga*, but its production is formally forbidden. There is no scientific description of the microbiota, biochemical, and safety profile of fan palm wine, and further research is needed.

12.6.6 Wild Watermelon Wine

The alcoholic beverage traditional beer (*setopoti*) is made from the fresh material or wastes of wild forms of watermelons (*C. lanatus*) with seeds intact. Usually, these are then fermented using moomelo (malt) which metabolizes the sugar in the watermelon into alcohol. It is brewed in semi-arid regions of Botswana, Namibia, South Africa, and Zimbabwe, in a clay pot which is then tightly closed (Figure 12.9). The preparation is then allowed to spontaneously ferment for one to two days undisturbed. After fermentation, the alcoholic beverage is sieved to remove seeds and solids and served as a smooth fermented beverage.

12.6.7 Cashew Apple Wine

While the external nut from the cashew (*A. occidentale*) fruit is traditionally used and even exported, the succulent part has a sweet–sour taste, contains lots of antioxidants, and has five times the vitamin C of an orange. Native to north-eastern Brazil, Portuguese missionaries took it to East Africa and India. An indigenous spirituous liquor (*cana*), known as *feni* in India, is also prepared from crushed cashew apples or coconut palm sap (Figure 12.10).

12.6.8 Marula

The marula plant (*S. birrea*) has three subspecies very common throughout Sub-Saharan Africa. The spontaneous three-day fermentation of their ripe fruits is known by several names as *omagongo* in Namibia, *buganu* in Eswatini, *bojalwa-jwa-morula* in Botswana, *mukumbi* in Zimbabwe, and *ocanhu* in Mozambique (Figure 12.11).

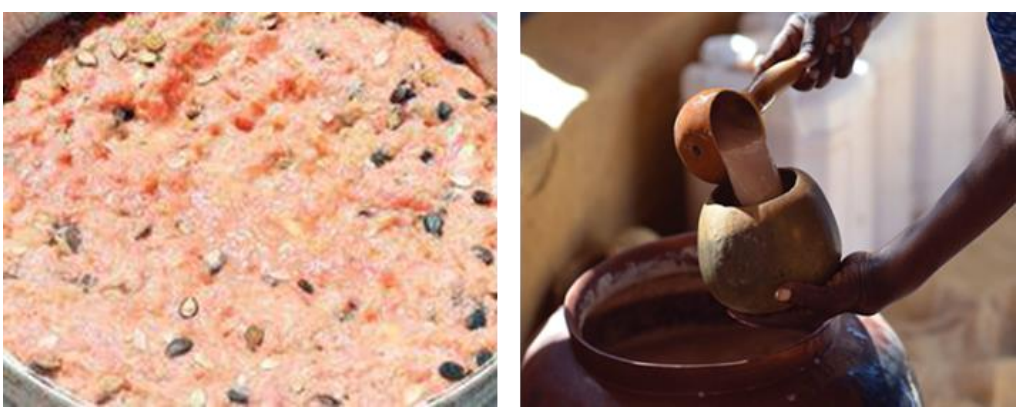

FIGURE 12.9 Preparation of wild water mellon wine.

FIGURE 12.10 Cashew apple fruit on the left with the unique external seed and women preparing cashew fruit wine in Guiné-Bissau.

FIGURE 12.11 Traditional preparation of amarula drink ("ocanhu") in Mozambique.

12.6.9 Other Mixed Brews

Several alcoholic beverages resulting from the fermentation of mixed cereals and fruits are well known. *Kachasu* (*nipa*, *lukutu*, or *tototo*) is like *waragi* of Uganda and *chang'aa* of Kenya. It is usually brewed using maize meal, but bulrush (*Cyperus papyrus*) or finger millet meal (*Eleusine coracana*)**,** various fruits such baobab (*A. digitata)*, masau/maçanica (*Z. mauritiana*), tambarind (*Tamarindus indica)* and banana peels may be used as alternative sources of soluble carbohydrates (Figure 12.12).

Fermented foods and beverages are more popular than ever before, while research into the health benefits of fermented foods is relatively new. Not all fermented foods contain live organisms; beer and wine, for example, sometimes undergo steps that remove the organisms, and other fermented foods like bread are heat-treated and the organisms are inactivated.

Traditional and modern dietary practices utilize fermented foods and beverages, contributing significantly to the food chain value and belonging to a category of foods called "functional foods" (e.g. probiotics, prebiotics, stanols, and sterols) by having an additional characteristic, i.e. health-promotion or disease prevention effect.

Traditional fermentation exhibits an exceptionally precious cultural patrimony in most African countries. Many fermented foods serve as main course meals, beverages, and popular food condiments. Those which serve as main meals and beverages are usually products of carbohydrate-rich raw materials. Some of the most essential ones in this group include "*gari*" from cassava, "*ogi*" and "*amahewu*" from maize, and "*kaffir*" beer from sorghum. *Amasi* is predominantly an outcome of spontaneous milk fermentation and *amahewu* is manufactured by spontaneous fermentation of cooked maize or sorghum meal over a one to three-day period, both non-alcoholic drinks.

12.7 SOME AFRICAN FERMENTED ANIMAL PRODUCTS

Milk is a major source of energy and nutrients, but can also be a vehicle for zoonotic foodborne diseases when raw milk is used with inadequate hygiene conditions. Pathogens (e.g. *Streptococcus infantarius* subsp. *infantarius*) may lead to spoilage and reduce food safety and security. Fermentation done carefully can help mitigate the impact of poor handling and storage conditions by enhancing shelf life and food safety.

Milk from cows, camels, and does is important in some pastoral civilizations of Africa. There is an extraordinary range of local products and by-products where tradition, culture, and environmental conditions and constraints play a crucial role in the diversity of end products. Generally, there is scarce hygiene in milk production and processing, giving rise to careless fermentations that shorten shelf life, leading to spoilage and hazards to human health.

In North Africa, the diet is limited to foods of animal origin as opposed to vegetable foods, mainly cereals, and a variety of centuries-old dairy products are known and still highly appreciated by consumers. The most popular of them are *jben*, *lben*, and *smen* (Figure 12.13), and they are being increasingly marketed throughout the region in informal markets.

In Algeria, *smen/dhan* is a cultural butter product made by empirical methods, used as taste and aroma enhancers on several dishes, which is a long-duration traditional and spontaneously fermented butter made from various sources of whole raw milk. Artisanal cheese from fermented milk is named *klila*.

In South Africa, small-scale local farmers, using just raw milk, produce well-matured hard cheese *karoo crumble*, while in Sudan, Somalia, Ethiopia, and Kenya camel milk has potential but has not been fully explored.

FIGURE 12.12 Images of masau (*Ziziphus mauritiana*), tambarind (*Tamarindus indica*), millet (*Cenchrus americanus*), bulrush (*Scirpoides holoschoenus*), monkey orange msala (*Strychnos spinosa*), and baobab (*Adansonia digitata*) fruit.

FIGURE 12.13 Milk and butter *smen*.

In Egypt where some 70% of milk production is used to manufacture cheese, its consumption is significantly higher than in the other countries of North Africa, while there are more diversified and elaborated cheese types, among which brined cheeses are the most dominant. White and salty *domiati* cheese is made by combining camel with cow and sometimes buffalo's milk with or without the addition of a starter culture.

In Cape Verde, distinct types of cheese are produced according to different islands of the archipelago. Local goat cheese from raw milk from the Planalto Norte region, produced in difficult harsh environmental conditions from grazing animals, is sold as fresh cheese or, less frequently, as ripened cheese.

In Nigeria, *wara* is an unripened cheese or a milk curd achieved by adding a coagulant to fresh milk with no aging or pressing process. It is not a product of fermentation and not being a cheese, is highly perishable, and does not last more than two to three days.

In Ghana and other West African countries, *nunu* produced from raw milk is a spontaneously fermented yogurt-like dairy product consumed as a basic food product.

In Senegal, fermented milk product *(lait caillé*), is prepared in wooden bowls (*lahals*) with a bacterial biofilm to steer the fermentation process.

Fermentation has been used as a natural flavor-enhancing tool process, usually the result of microbial enzyme interactions (e.g. proteinase, amylase, mannase, cellulase, and catalase) with plant enzymes and their activities on vegetable proteins of legumes or oil seeds.

Traditional fermented proteins from oilseeds generate tasty food condiments rich in polypeptides. These include *iru/dawa/sumbala* from African locust bean (*P. biglobosa*); *ugba* from alkaline fermentation of African oil bean seeds (*P. macrophylla*) and *ogiri* from melon seeds (*Cucumeropsis mannii*) among others. All are known to be good sources of proteins and vitamins. These fermented condiments can assist consumers regarding the supply of antioxidants, polypeptides, organoleptic, and probiotic characteristics, and antibiotic activity.

Worldwide, the usage and design of fermentation processes have experienced notable improvement in recent years. Despite the increased scientific interest in African traditional fermented foods and beverages, the age-old techniques used for their production in Africa have not improved as a result.

The importance of fermented foods in the nutrition of Africans is now better appreciated, as a result of which efforts are now being made to industrialize some of the processing in some cases

even through studying the microbiome of African fermented foods using high-throughput DNA sequencing techniques.

12.7.1 Non-dairy African Fermented Products

The fermentation of milk proteins has been well described for many years. However, only some 11 fermented meat products are made in Africa, mainly in Sudan. In *heirta*, for instance, all offal plus muscle meat is chopped, added to milk, and fermented twice. The product is used to make a sauce for *aceda* stiff porridge from Sudan.

Miriss is prepared by fermentation of visceral fat. The fat is kneaded with a quantity of an ash preparation, *combu*, and fermented for up to six days. The product is very white and extremely foul-smelling.

At least three fermented products are made from fresh bones and meat scrapings. *Beirta* is prepared from he-goat meat. *Dodery*, for example, is prepared from marrow-impregnated joint bone endings. These are chopped, sun-dried, and pounded into a paste which is mixed with *combu* and fermented for up to five days. *Um-tibey* is best prepared from gazelle's meat and rumen.

In Cape Town, South Africa, despite the recent (2022) success of a novel green innovative precision fermentation technology on cellular agriculture using microorganisms as a blueprint to create animal-free milk recombinant proteins, identical to those found in cow's milk, one cannot expect a replacement of indigenous fermented foods.

12.7.2 Fish Products

Africans have many different fermented fish products all of them raising safety questions. The Nile Valley probably has a greater variety of fermented fish products than other regions of Africa. Sudan has at least four distinct such products. *Kejeik* represents the common, dry, split fish of Africa. *Fesseilch* is fermented whole fish made of a particular species and is known also in Egypt. However, *mindeshi*, a fish paste, and *terkin*, a fish sauce paste, appear not to be known in other parts of Africa. However, these fermented fish products could also be a source of nematode parasites and heavy metals if poorly processed.

12.8 POPULAR AFRICAN TRADITIONAL FERMENTED FOODS AND BEVERAGES

Fermented products can play an important role by contributing to the livelihoods of rural and peri-urban dwellers alike, through enhanced food security, and income generation via a valuable small-scale enterprise option. The strong link between fermented foods and food shortages is revealed by the fact that when a family becomes rich several fermented foods are no longer prepared. Cereal grains account for more than 60% of food materials used in the preparation of indigenous fermented foods in Africa.

Traditional beverages are drinks that are indigenous to a particular area and have been developed by the natives of that area themselves using techniques that are ancient and from locally available and home-grown raw materials. A consortium of yeasts and bacteria is known to carry out fermentation and contribute to the unique sensorial properties of fermented beverages.

Fermented plant foods may be classified as (i) those made from cereal grains (e.g. maize, sorghum, millet, rice, wheat), such as *kenkey, mahewu, ogi*, and *injera*; (ii) those made from pulses, nuts, and other seeds, such as the African locust bean tree *dawadawa*; (Figure 12.14); (iii) those from tubers (cassava, aroids, potatoes), such as *gari* and *farinha mandioca;* (iv) those from fruits

FIGURE 12.14 The multipurpose dawadawa tree, known as the African locust bean tree (*Parkia biglobosa* and *Parkia filicoidea*).

and vegetables, such as *gundruk* (fermented leaf spinaches) and *chakalaka*; and (v) beverages derived from fruit wastes (pineapple peel wastes). Fruit vinegar and pickled fruit (lemon, lime, and mango) are also common.

The fermented locust bean seed is used to prepare condiments to flavor soups and stews, commonly called *netetu*, *afinti*, *iru*, *dawadawa*, *ogiri*, *farroba*, or *soumbala*. Although the seeds and fruit pulp are popular because of their culinary uses, the other parts of the tree such as the bark, roots, and stems all have significant medicinal roles in African traditional medicine. They are often used to treat diabetes, malaria, diarrhea, wounds, and dental caries.

Data on the profile of microorganisms involved in spontaneous fermentation of non-grain-based alcoholic beverages as compared to grain (maize, sorghum, millet, rice, wheat)-based alcoholic beverages in the Sub-Saharan Africa region is scarce.

In the Sub-Saharan region, non-grain-based alcoholic beverages are produced from inexpensive substrates such as wild or cultivated fruits, tree saps, roots, and tubers whereas grain-based alcoholic beverages are made from cassava, small grains, maize, sorghum, and millet.

Sorghum beers are considered both an energy-boosting food and an alcoholic drink, consumed extensively in various ceremonies. Commonly named opaque beers throughout Africa, sorghum malt beers are produced in most countries with different designations. In Cameroon, it's called *amgba*; in Burkina Faso, *dolo*; in Zimbabwe, *doro*, *chibuku*, and *chikokivana* are produced as an ardent spirit from a blend of coarse mealie meal and millet malt; in Rwanda, *ikagage*; in Tanzania, *mtama* and *togwa* are produced from sorghum, maize, and Panicum grass; in Nigeria and Ghana, *burukutu* and *pito*; in Ethiopia, *borde* is made from maize, barley, or wheat and their malts; in Sudan, *merissa;* in Chad, *bilibili;* in Ivory Coast, Togo, and Benin, *tchapalo*; in South Africa, *kaffir*. In Uganda, *obushera* refers to a group of traditionally fermented or unfermented alcoholic or non-alcoholic sorghum beverages and *bushera* from millet.

Nigeria produces over 900 million liters of sorghum beer annually. One of these cereal-based alcoholic beverages, *chibuku*, another sorghum-based beer, has made it to the commercial markets in Botswana, Zimbabwe, and South Africa. In Mozambique, a cassava-based beer lager is commercially produced in the north (Figure 12.15).

Kawal, a strong-smelling fermented product made of the leaves of a wild and reputedly toxic African legume (*Senna obtusifolia*), is believed to have helped people endure and survive famines in South Sudan and Chad.

In Sub-Saharan Africa, fermented alcoholic beverages are produced from various inexpensive local raw materials such as palm sap, *marula* fruit, and *Grewia flava* wild berries' *mogwana* and *khadi*.

FIGURE 12.15 Commercially cassava beer is produced in Mozambique, brand name *Impala*. *Chibuku* sorghum beer is made in several countries. *Burukutu* preparation in Nigeria.

FIGURE 12.16 Palm wine created from the sap of various species of palm trees; hibiscus wine.

The non-cereal beverages vary across Africa, based on sugarcane, watermelons, banana, cassava, palm sap, pineapple, and others. In Ethiopia, an affordable wine (*tej*) is home-produced from a blend of honey and sugar as fermentable substrates. In Rwanda and The Democratic Republic of Congo, an artisanal banana beer (*urwaga*) is homemade or commercially produced from the fermentation of the *M. acuminata* variety. Palm wine, traditionally produced or commercially pasteurized, is known by several local names, with *malafu* being a common designation.

In Ghana, sorrel drink (*sobolo*) is an immune booster drink naturally high in antioxidants made from *Hibiscus sabdariffa* extract, while *asaana/elewonyo* is a refreshing tisane made from hibiscus, maize, and caramelized sugar (Figure 12.16). The seeds of this plant are widely used in alkaline fermentation to produce food condiments popularly known as *bikalga* (Burkina Faso), *dawadawa botso* (Niger), *datou* (Mali), *furundu* (Sudan), and *mbuja* (Cameroon).

12.9 EXAMPLES OF UNDESIRABLE EFFECTS OF FERMENTED PRODUCTS

Often, emphasis is made on the beneficial aspect of fermented food products. However, some of the microbiota used in the fermentation of foods and beverages may become harmful under certain undesirable conditions and pose a serious food safety challenge. Post-fermentation contamination of products may also affect the hygiene of the products thereby becoming disruptive to health and deleterious to life.

12.9.1 Mycotoxins in Indigenous Fermented Foods and Beverages

Most home-produced and processed grains and peanuts from which traditional beverages are made across the continent are frequently and excessively contaminated with different mycotoxins caused by poor farming, handling, post-harvesting, and storage practices that portray the region. Mycotoxins are non-toxic before metabolism, but after ingestion, they are metabolized to both toxic and non-toxic compounds, such as Cytochrome P450 enzymes.

There are many transcripts on the array and abundance of mycotoxins in the sources used in traditional beverage processing, nonetheless, few reports have analyzed mycotoxins in the final fermented products themselves.

The suggestion of making use of microorganisms to eliminate mycotoxins emerged long ago. Biological decontamination using microorganisms has revealed new opportunities. Mycotoxins are fungal metabolites commonly occurring in food, which pose a health risk to the consumer. The main fungi that infect cereals, roots, and tubers belong to *Aspergillus, Penicillium, Fusarium, Alternaria, or Claviceps* genera, they are associated with the production of mycotoxins (aflatoxins, fumonisins, zearalenone, and deoxynivalenol), aflatoxins, ochratoxin A, and patulin being the main risks in tropical crops.

Many countries have regulations specifying the maximum allowed concentration of mycotoxins, but there are no regulations requiring measures to reduce contamination. Only detoxification methods on feeds, but not in foods, have obtained a positive EFSA (European Food Safety Authority) scientific opinion and may be used. Sorghum, unlike other cereals, does not have yet legislation that regulates the maximum content of mycotoxins in grains for its commercialization.

Two main methods of microbial decontamination are identified in the literature: adsorption to the cell wall compounds (peptidoglycan, glucomannan, D-glucan) and biotransformation to less toxic or non-toxic compounds, thanks to the expression of appropriate enzymes. Atoxigenic strain-based biological control is a natural, nontoxic technology that uses the ability of native atoxigenic strains of *Aspergillus flavus* (one of the fungi that produce aflatoxin) to naturally outcompete their relatives, aflatoxin producers.

However, the levels of mycotoxin contamination in the raw materials should still not exceed the accepted levels established in international Regulations. For example, fumonisin esterase, which can degrade fumonisin mycotoxins and is produced by a genetically modified *Komagataella pastoris* yeast strain, has been approved by the EU but only for animal use. Therefore, in Africa, only good agricultural and manufacturing practices can help control the presence of mycotoxins as food contamination, and these are not common disciplines.

The risk of mycotoxin exposure continues in developing countries due to a lack of food security, poverty, and malnutrition. The occurrence of mycotoxin contamination in food is more prevalent in tropical and subtropical countries resulting in acute and chronic mycotoxicoses in humans and animals. Yeasts, especially *S. cerevisiae* and *Pichia kudriavzevii,* and LAB occur as part of the natural microbial population in spontaneous food fermentation and as starter cultures in the food and beverage industry.

Cooking and fermentation do little to reduce potential mycotoxin content, however, yeasts and LAB have immense potential as tools in tackling the problem of fungi and mycotoxins in cereal-based foods and beverages. The yeast *Saccharomyces boulardii, a* strain of *S. cerevisiae,* classified as a probiotic agent, has been used successfully in the treatment or prevention of mycotoxin activity. The question remains on the toxicity of products of enzymatic degradation and undesired effects of fermentation with non-native microorganisms on the quality of the final product.

The presence of uncertain microorganisms hinders the monitoring of the fermentation process, leading to finished products of variable quality. Some unwanted toxic contaminants and

metabolites of the microbes are released into the food base during fermentation. Despite some progress, mycotoxins, bacterial toxins, biogenic amines, and cyanogen glycosides still frequently occur as toxic compounds in fermented foods and beverages.

Research is scarce while extension services and smallholders' family farmers do not have adequate knowledge of the specific substrates and type of the microbiota *inocula*. Therefore, the final fermented product quality at the household level remains unknown and difficult to be standardized.

Literature abounds on the microbiology of traditionally fermented foods and beverages, and mixed fermentation resulting in the production of diverse products. This microbiota has the enzyme complement to produce beneficial vitamins and amino acids for the host.

These foods have an important role in the African diet and can contribute to food security by increasing the availability of cheap, nutritious food and supporting livelihoods. However, the presence of foodborne pathogens and antibiotic-resistant bacteria in may constitute a health risk to consumers.

Furthermore, mixing different traditional and modern styles of eating and drinking, namely the use and abuse of diet sodas raises new hazards through the consumption of aspartame with an impact on several neurodegenerative diseases, including autism.

Methanol is found naturally in certain fruits and vegetables and the ingestion of as little as one to two teaspoons of this easily absorbed will cause death. Sugar will produce a very small amount of methanol, which is produced more from grains and their husks and organic fibers. It is also found naturally in trace amounts in fruit juice and distilled spirits such as whisky, wine, and beer. It may also be produced as an unintended by-product during the fermentation process.

Nevertheless, several hazards may occur through pathogenic contamination or the yield of methanol, which may impact health. The incidence of methanol contamination of traditionally fermented beverages is increasing globally resulting in the death of several people. Methanol is produced during fermentation by the hydrolysis of naturally occurring pectin in traditionally fermented beverages and can be linked to the activities of pectinase-producing yeast, fungi, and bacteria.

In addition to alcoholic drinks and accidental poisoning, another source of methanol is aspartame, which is used in over 6000 products, is a popular synthetic non-nutritive sweetener in diet sodas, and is nevertheless considered to be a potential carcinogenic. Acceptable Daily Intake (ADI) for aspartame of 40 mg/kg body weight was established in the early 80s.

Upon ingestion, aspartame is broken, converted, and oxidized into formaldehyde in various tissues. Aspartame (Figure 12.17) is fully broken down in the gut into aspartic acid and phenylalanine, which are absorbed and enter the body. In addition, the methyl group from the modified phenylalanine is released in the gut to form methanol.

Besides the exogenous methanol, there is endogenous metabolic methanol since in normal, healthy individuals, methanol and its short-lived oxidized metabolites, formaldehyde, and formic acid occur as a result of fermentation by gut bacteria and metabolic processes involving S-adenosyl-L-methionine.

These metabolites are associated with metabolic acidosis, visual dysfunction, and neurological symptoms. Regardless of the source, low levels of methanol in the body are maintained by physiological and metabolic clearance mechanisms, avoiding cell hypoxia.

During ripening, pectin in fruits is broken down by pectin methyl esterase resulting in the formation of methanol. Cases of methanol contamination have been reported in most traditional beverages at trace levels. Concentrations of 6–27 mg/l in beer and 10–220 mg/l in spirits are not harmful. There is however need for research to focus on other possible sources of methanol in locally traditionally fermented beverages.

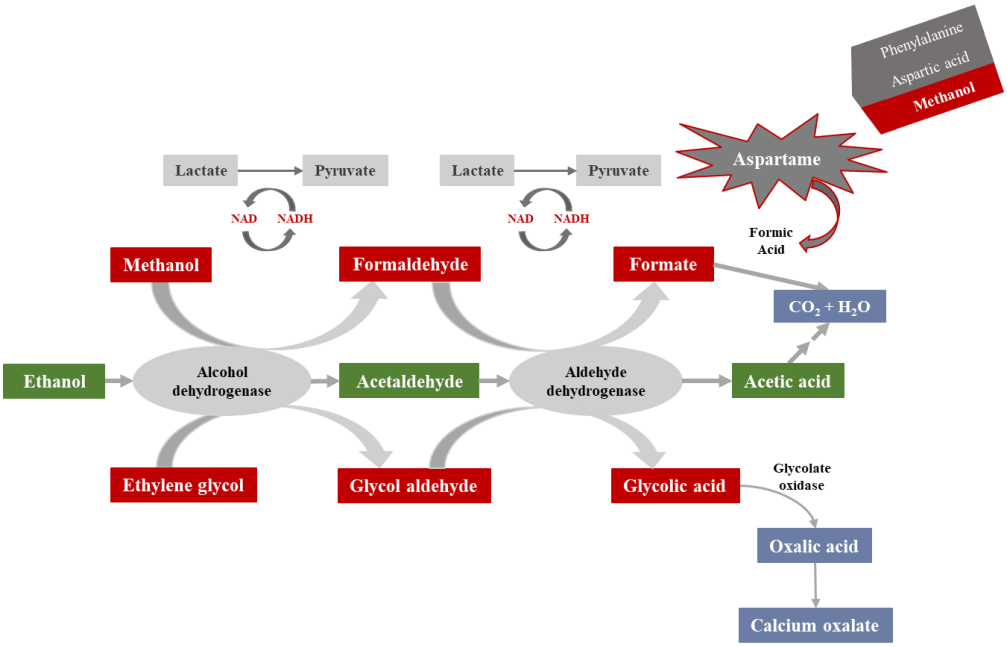

FIGURE 12.17 Aspartame, a well-known artificial sweetener of sodas, candy, chewing gum, and energy drinks, is a synthetic chemical composed of the amino acids phenylalanine and aspartic acid, with a methyl ester. The methanol produced by the metabolism of aspartame is absorbed and quickly converted into formaldehyde and then completely oxidized to formic acid. The acceptable daily intake (ADI) for aspartame is 40 mg/kg of body weight. Ethanol, drinking alcohol, is mainly produced from maize fermentation. Ethylene glycol, used as anti-freeze, if ingested is rapidly absorbed from the gastrointestinal tract and slowly absorbed through the skin or lungs.

In Mozambique, after a funeral, at least 75 people died and 235 suffered from severe intoxication after consuming traditional *pombe* (Swahili for "beer"), a type of traditional East African beverage made from malted sorghum, millet, maize, and sugar. The compound is boiled two or three times in huge pots, strained, when wanted clear, through a bag of matting, and allowed to ferment: after the third day, it becomes as sour as vinegar.

It was originally suggested that crocodile bile was used as the lethal toxin in the brew. However, the cause was identified as being contamination by the bacterium *Burkholderia gladioli* (previously named *Pseudomonas marginata*) which produces bongkrekic acid. This is implicated in outbreaks of food-borne illness involving also coconut- and corn-based products in other countries such as Indonesia and China. It is responsible to produce a lesser-known mitochondrial toxin and alter cellular apoptosis.

In Nigeria, recent findings have shown that Ochratoxin A has been detected in a non-alcoholic cereal-based fermented beverage (*kunun-zaki*), which also showed contamination by high counts of spoilage and pathogenic microorganisms (*Bacillus*) which may be responsible for its short shelf-life. In Nigeria, in 2015, a total of 89 persons died following the consumption of locally produced ethanol beverage, containing 16.3% methanol, called *kaikai/ogogoro/apeteshi* or illicit gin. *Kaikai* is produced mostly from the sap of raffia palm and oil palm and to a lesser extent from other palms such as date palm, and nipa palm. *S. cerevisiae* has been used as a catalyst for the

production of ethanol for thousands of years. But recent studies have shown that there are different strains of *S. cerevisiae* involved in traditional ethanol fermentation in Africa.

In Kenya, alcohol-related deaths are common, with hundreds of people dying every year from poisoned liquor often sold in the brewer's home, others blinded, after drinking illegal alcohol laced with methanol. The drink is often known locally as *changaa* or *kumi kumi*.

In Cameroon, consumers who can no longer afford to buy good-quality whiskies now purchase fake, locally brewed alcoholic drinks which are dangerous to their health. Many people have developed liver problems and died from consuming fake whiskies, namely during the pandemic.

Despite the low prevalence of classical risk factors such as heavy drinking and tobacco smoking, there is evidence that significant levels of ethanol and acetaldehyde were produced during fermented milk *mursik* production in Kenya. This may justify the high incidence of esophageal squamous cell cancer in Africa even in young people (<30 years of age) due to their carcinogenic potential.

The microbiota in fermented products impacts the organoleptic profile, the physicochemical characteristics as well as human health. Microbiota can also release from the food matrix toxic compounds, the most notorious being decarboxylation products of amino acids (e.g. biogenic amines, histamine, tyramine, and putrescine, by decarboxylation of histidine, tyrosine, and ornithine, respectively) and mycotoxins.

12.9.2 Antimicrobial Resistance

The existence of antimicrobial resistance (AMR) in the environment, a growing public health concern, has been well documented although transmission routes of antimicrobial agents and genes across different ecosystems remain obscure. Multidrug-resistant bacteria is a natural phenomenon and has been identified in unexpected extreme weather sites such as the Sahara Desert and both Poles. In Africa, most countries have not established AMR surveillance systems.

During fermentation, bacteria multiply significantly, and various genes, including AMR genes, can be exchanged by bacteria during horizontal gene transfer processes. If any of those bacteria harbor AMR genes, the number of bacteria with resistance genes could be increased in the final products (e.g. fermented dairy products) and lead to critical health considerations.

Microorganisms present in each traditional fermented product, where the starting culture strains of fermented foods are not monitored, could act as resistance superbugs since several reports indicate that fermented produce could be considered as vehicles of antibiotic-resistant bacteria and, thus, AMR genes (e.g. *poxtA* gene) may be horizontally transferred to other bacteria including pathogens and commensals through the food.

12.10 CONCLUSIONS

Africa is well-known for its exotic traditionally fermented food and beverages produced using a wide range of raw materials, microorganisms, and fermentation processes. These artisanal practices need rejuvenation following traditional forms of art practice or craft making. But until these fermentation practices come under new improved safety and risk control they will remain beyond any official compliance with national regulatory standards. There also is a lack of appropriate surveillance programs that can supply information on consumption patterns and a lack of epidemiological data, which are necessary to properly evaluate the link between fermented products and health.

Indigenous crops and fruits constitute an important part of human diets in many Sub-Saharan African countries, particularly in rural areas and during droughts. To promote and expand the utilization of these products when fermented, knowledge of their nutritional composition is essential.

Despite the high potential of these heritage-fermented foods and beverages, only limited and outdated data on basic nutrient composition exist on raw indigenous foods. Traditional methods of manufacture should take advantage of technical progress to assure a reasonable margin of health benefit, and at the same time conserve the authenticity and origin(s) of these products, trying to transfer these ancestral technologies to small and medium industrial scales.

Notwithstanding scientific advances, our knowledge of the effects of fermented foods and beverages, and the precise associations of their microbiota on human health remains incompletely understood. Again, fermentation-dependent biomarkers have not yet been well documented.

While African indigenous fermented products offer a vast genetic potential of undiscovered microbiota strains that possess valuable technical characteristics, these fermented outcomes may also serve as vehicles of pathogenic and antibiotic-resistant bacteria and genetic determinants. Significant research and data gaps exist regarding the microbiological safety of these food products, which warrant urgent attention.

The restrictions and inconsistencies in the current portfolio of evidence imply that no absolute conclusions can yet be depicted on the potential health benefits of traditional fermented products although it may be expected that the microbiomes of fermented foods will acquire a leading role in future nutrition and therapeutics.

In summary, there is very scarce preclinical and clinical confirmation for the validity of most traditional fermented foods and beverages in gastrointestinal health and disease.

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