Hindawi
Journal of Food Quality
Volume 2024, Article ID 1241614, 32 pages
https://doi.org/10.1155/2024/1241614

Review Article

Diversity of Production Techniques and Microbiology of African Cereal-Based Traditional Fermented Beverages

Felix Kwashie Madilo,[1,2,3] **Angela Parry-Hanson Kunadu**,[2] **Kwaku Tano-Debrah**,[2] **Firibu Kwesi Saalia**,[2] **and Unathi Kolanisi**[3]

[1]*Department of Food Science and Technology, Ho Technical University, Ho, Ghana*
[2]*Department of Food Science and Nutrition, University of Ghana, Accra, Ghana*
[3]*Department of Consumer Science, Faculty of Science and Agriculture, University of Zululand, Richards Bay, South Africa*

Correspondence should be addressed to Felix Kwashie Madilo; felixmadilo@ymail.com and Angela Parry-Hanson Kunadu; apparryhanson@gmail.com

Received 22 August 2023; Revised 12 November 2023; Accepted 26 February 2024; Published 30 March 2024

Academic Editor: Barbara Speranza

Traditional fermented beverages are culturally and socially accepted products for consumption, drinking, entertainment, customary practices, and for religious purposes. The purpose of this review was to identify some cereal-based fermented beverages and determine the differences in their production technologies. There are many unique regional variations in the preparation of each of the identified fermented beverages. They are prepared from raw materials such as maize, millet, rice, and sorghum. Majority of the fermented alcoholic beverages (binuburan, amba beer, sake, dolo, pito, and tchoukoutou) were produced using spontaneous fermentation and industrial fermentation (use of starter cultures) techniques. The various microbial communities associated with the traditional fermentation processes were dominated by *Limosilactobacillus fermentum* and *Lactiplantibacillus plantarum* for Lactic acid bacterial (LAB) species, *Saccharomyces cerevisiae* and *Candida mycoderma* for *Saccharomyces* and *Candida* species (yeasts), respectively; and *Aspergillus aceti* and *Rhizopus stolonifer* for *Aspergillus* and *Rhizopus* species (molds), respectively. *Acetobacter, Pseudomonas, Klebsiella, Weissella, Achromobacter, Flavobacterium, Micrococcus,* and *Bacillus* dominated other microbial genera. The involvement of lactic acid bacteria contributed to the safety and extension of the shelf life of the final products. Most of these beverages were found to be very rich in proteins, carbohydrates, calories, and B-group vitamins including thiamine, folic acid, riboflavin, and nicotinic acid. This article reviewed the available information, such as processing techniques of African traditional beverages, the raw materials used to producing them, and the microorganisms associated with the production processes.

1. Introduction

Traditional fermented foods and beverages are culturally and socially accepted products for several reasons including consumption, entertainment, customary practices, and for religious purposes [1]. Production and drinking of alcoholic and nonalcoholic beverages are widespread interest in enhancing the nutritional significance as well as impacting the pleasure of drinking [2]. Fermented alcoholic and nonalcoholic beverages include a wide range of fermented products including wine and beer [3]. These ethnic alcoholic beverages have a great ceremonial significance among African ethnic groups [4].

Several traditional fermented beverages, both alcoholic and nonalcoholic are produced at the household level in the world. Each fermented beverage has several regional differences in its production process. Therefore, there is a need to identify these beverages with the raw materials used for their production, various variations that exist among their production techniques, the diversity of microbial fermenters that were involved in each of the production techniques of these beverages, and their health benefits.

The majority of these beverages are prepared basically from cereals such as maize, millet, rice, and sorghum. Species of lactic acid bacteria [5] and yeasts [6] are the major microbial fermenters associated with the fermentation of these beverages. They serve to improve the taste, flavor, acidity, digestibility, and texture of both alcoholic and nonalcoholic beverages. The majority of these beverages are high in calories as well as B-group vitamins such as thiamine, folic acid, riboflavin, and nicotinic acid.

This study sought to review the available information such as the processing techniques involved in the production of these beverages, species of the various microorganisms involved in the fermentation processes, taxonomic tools used to identify these microbes, and the nutritional diversity of these traditional fermented beverages in the African countries.

2. Diversity of Traditional Fermented Beverages

Several types of cereal-based traditional fermented beverages are produced and consumed worldwide. Mostly, the preparation and fermentation of these beverages are done spontaneously; hence, they are characterized with different microbial communities. The involvement of this microflora determines the qualities of fermented products [7, 8]. The common processing stages characterizing them include cooking raw materials to gelatinize the starch, adding a source of enzymes to hydrolyze the gelatinized starch into fermentable sugars, and allowing them to go through fermentation [9]. In addition to microorganisms, the raw materials used, the production techniques adopted and the regions or countries where they are produced contribute to the variations. For example, *mahewu* (Zimbabwe) is produced from maize meal and basic ingredient, *ogi* (Nigeria) is manufactured from a three-day soaked maize grain [10]; and *Kwete* (Uganda) produced from a roasted sourdough for its unique golden-brown color and a typical Kwetey flavor [11]. According to Aka et al. [12] and Kouame et al. [13], tchapalo is also produced from two processing steps (i.e., a spontaneous lactic fermentation or backs-lopping is firstly initiated to obtain a sweet wort which is nonalcoholic, followed by alcoholic fermentation). These differences in the production process, microbial communities, raw materials, and the regions of production lead to variations in sensory characteristics and nutritional qualities of final products.

To iron out these differences, the use of defined starters of both lactic acid bacteria and yeasts or their combinations has been suggested [12, 14, 15]. These starters have the potential to rapidly acidify the fermenting products, eliminate or reduce considerable potential spoilage and pathogenic bacteria, improve organoleptic properties and above all, control the fermentation processes [12, 16, 17]. Some of the popular cereal-based traditional fermented beverages that are produced and consumed across the African continent are discussed below.

2.1. Oshikundu. Oshikundu is a popular daily traditional cereal-based fermented and very low alcoholic beverage made from pearl millet and malted sorghum meal produced and consumed in Namibia [18]. The ultimate product of Oshikundu is produced through the processing of raw materials, storage, and traditional milling of malted sorghum and Mahangu meal. In the first step, hot water is added to the Mahangu meal, which is then allowed to cool to room temperature while being stirred occasionally. After that, a malted sorghum meal is added to the mix. The mixture is then blended after adding warm water. Both techniques include the addition of bran, which is optional depending on availability and preference for bran in brewing. The mixture is diluted with water based on the amount of the starting material used and the desired volume of the final product after previously fermented Oshikundu is added. After that, the mixture is then left to ferment spontaneously for one and a half hours [18]. Oshikundu, however, has a very short shelf life of less than six hours [19].

2.2. Finger Millet Slurries. Finger millet fermented slurries are mostly prepared and consumed by the people of Hwedza, Zimbabwe. The products are prepared from four different varieties of finger millet; red variety 1 (RV1), red variety 2 (RV2), white variety 1 (WV1), and white variety 2 (WV2). In short, fermented slurries are made by adding water to an aliquot of millet flour and allowing the entire mixture to ferment for 24 to 36 hours [20]. The presence of foam on the surface of the fermenting slurry indicated a successful fermentation. The fermenting wort is then cooked to make porridge (Figure 1).

2.3. Pito. Pito is an indigenous light brown alcoholic slightly bitter sweet-sour beverage with a fruity flavor made from malted, mashed maize, or sorghum fermentation. Kolawole et al. [21] indicate that the people of northern Nigeria and Ghana are the main producers of pito. Pito is made by soaking cereal millet grains in water for two days. The soaked grains are malted in baskets lined with moistened banana leaves for five days. The malted grains are crushed and cooked with water. After cooling, the mash is filtered through a fine-mesh basket, and the filtrate is left to ferment until it has a somewhat sour flavor. The mixture is then boiled to a concentrate. The cooled concentrate is mixed with a starter from the previous brew and fermented overnight again. Pito is made up of lactic acid, carbohydrates, and amino acids, with a 3% alcohol concentration [21].

2.4. Burukutu. *Burukutu* is a traditional fermented alcoholic beverage mainly by people of Northern Guinea Savannah of Nigeria, but brewed and consumed in other African countries such as Benin and Ghana. The beverage is brewed with varieties of sorghum and/or maize malts [22]. It has an acidic taste due to the action of *Lactobacillus* species in particular, and an opaque color due to suspended solids and yeast components with a thin consistency [23, 24]. Indigenous *burukutu* is produced by steeping sorghum grains in water overnight, washing the soaked grains and draining to remove excess water. The grains are then spread on banana leaves and watered while turning and waiting for germination. The

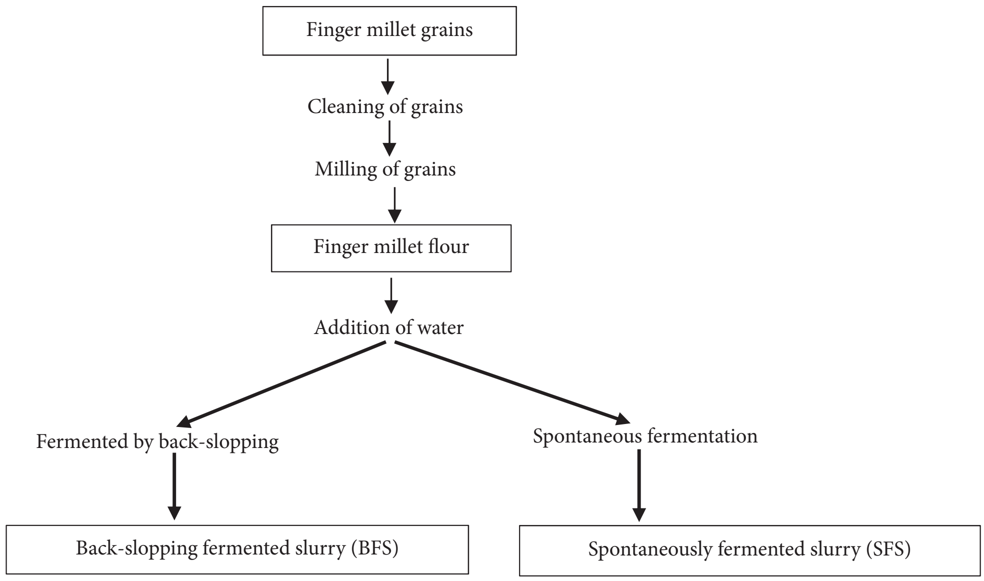

Figure 1: Schematic flowchart for the preparation of fermented slurry (adapted from [20]).

malted grains are then sun dried, grinded, and then mixed with water and boiled for hours. After that, the mixture is allowed to ferment for 48 hours. *Burukutu* is a murky liquid with a vinegary flavor and odor. It has high calories, B vitamins, as well as vital amino acids contents [22].

2.5. Bantu Beer/Kaffir Beer. The Bantu tribe in South Africa produces and consumes Bantu beer (also known as kaffir beer). It is an alcoholic pinkish-brown effervescent beverage with a sour flavor, thin gruel viscous, and an opaque appearance [25]. Malted sorghum or maize grains are used for brewing *Bantu* beer. To speed up the amylolytic activities, the malt is pulverized, slurried to a thin gruel, boiled, and chilled, and a small amount of fresh, uncooked malt is added. The mixture is kept overnight, boiled, and allowed for alcoholic fermentation. More pulverized uncooked malt is added on the third and fourth day and then strained on the fifth day to remove the husks to get the beer ready for consumption [26].

2.6. Amgba. Amgba is a traditional fermented alcoholic beverage of some ethnic groups of Cameroons [27, 28]. It is brewed with either sorghum or millet malt. Two sequential phases of fermentation under ambient conditions are used in the manufacture of amgba. It has lactic acid fermentation and alcohol fermentation stages [29]. Typically, alcoholic fermentation begins by pitching wort with previously brewed or dried yeast obtained from bili bili [30]. The indigenous brewing process has been described by Nanadoum [30] in Figure 2.

2.7. Tchoukoutou. Tchoukoutou is a cereal-based opaque traditional alcoholic beverage produced in Benin and Togo. The principal raw materials include sorghum, millet or maize malts [31]. The process involved in *tchoukoutou* production has

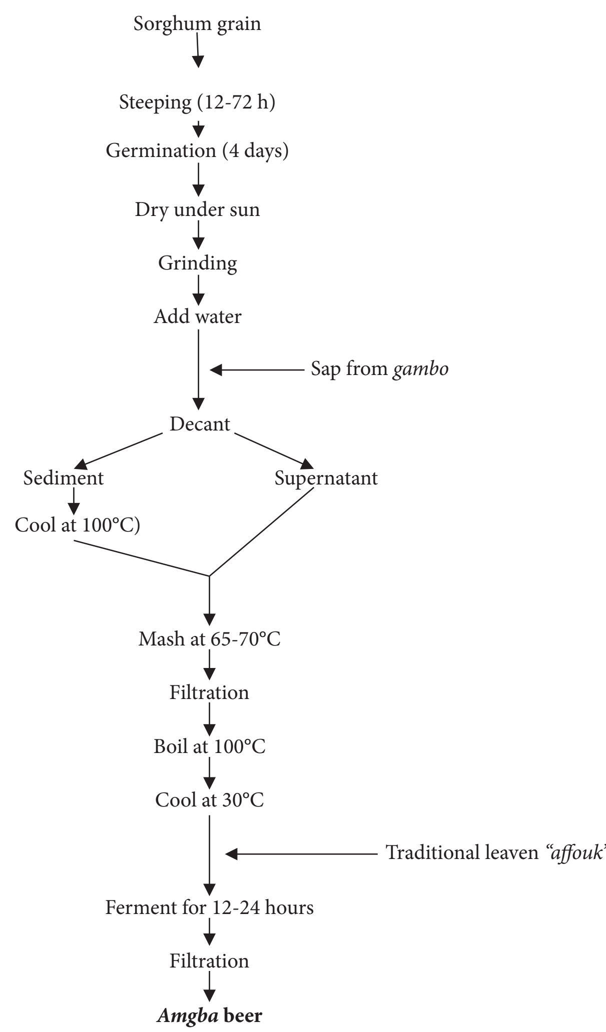

Figure 2: Flow sheet of traditional amgba beer preparation [30].

been described by Kayodé et al. [31]. The malt of any of the raw materials preferred for the production is milled into a fined flour, mixed with water, and left for a few hours for enzymatic action. The mixture is gradually heated and finally boiled. After cooling, kpètè-kpètè is added for fermentation for about 14 h (Figure 3). It has about 4% (v/v) ethanol content (A. [31], and is very rich in iron, solid, and crude protein [32].

2.8. Dolo. Dolo is an important and a popular cereal-based traditional fermented beverage brewed and used in Burkina Faso. The traditional process (Figure 4) is similar to that of *ikigage* beer. Briefly, sorghum malt flour is mixed with water, decanted, and the precipitate is mixed with water and heated to gelatinize the starch, but the supernatant is kept unboiled [33]. After cooling, the previous supernatant is added and heated at 65–70°C for 12–16 h. Cooked wort is chilled and fermented overnight. The cooling wort is injected with a typical leaven to initiate fermentation, which results in dolo beer after 12–24 hours [34] fermentation. *Dolo* beer is opaque, with a red color, and an alcohol content of 2–4% [33].

2.9. Bushera. Bushera is the most widely consumed traditional cereal-based fermented alcoholic beverage in Uganda's Western highlands. Sorghum or millet flour is made by mixing boiling water with germinated sorghum and millet grains. The mixture is then allowed to cool to room temperature. After that, germinated millet or sorghum flour is added, and the mixture is allowed to ferment for 1–6 days at room temperature and *bushera* is ready for consumption [35].

2.10. Ogi. Ogi is a sour, white starchy beverage made from either fermented maize, sorghum, or millet. It is a common cuisine in the West African countries, and it is also used as a weaning food for babies. The traditional method of making *ogi* is soaking corn kernels in water for 1 to 3 days, then wet grinding and filtering to remove the bran, hulls, and germ [36]. The pomace is then retained on the filter and discarded as animal fodder, while the filtrate is then fermented for 48 to 72 hours to produce ogi. Prior to eating, ogi is diluted to an 8–10% solid content and boiled into a pap, or heated and converted into a stiff gel called "agidi" or "eko." [36].

2.11. Mahewu. Mahewu *(amahewu)* is a sour beverage prepared from corn flour that is popular in Africa. According to, mahewu is a fermented millet or sorghum beverage consumed in Zimbabwe. It is made from maize porridge that has been mixed with water. Thereafter, the sorghum, millet malt, or wheat flour is added, and the mixture is allowed to ferment. The natural flora of the malt performs the spontaneous fermentation process at room temperature [37]. Mahewu has a pH of roughly 3.5. It is a daily adult food that is also often used for weaning and as a preferred food for the sick due to its liquid condition and flavor. Traditional mahewu is produced in the same way as industrialized mahewu, with the exception that the latter uses a starting culture [38]. Mahewu is consumed between 24 and 48 h after preparation.

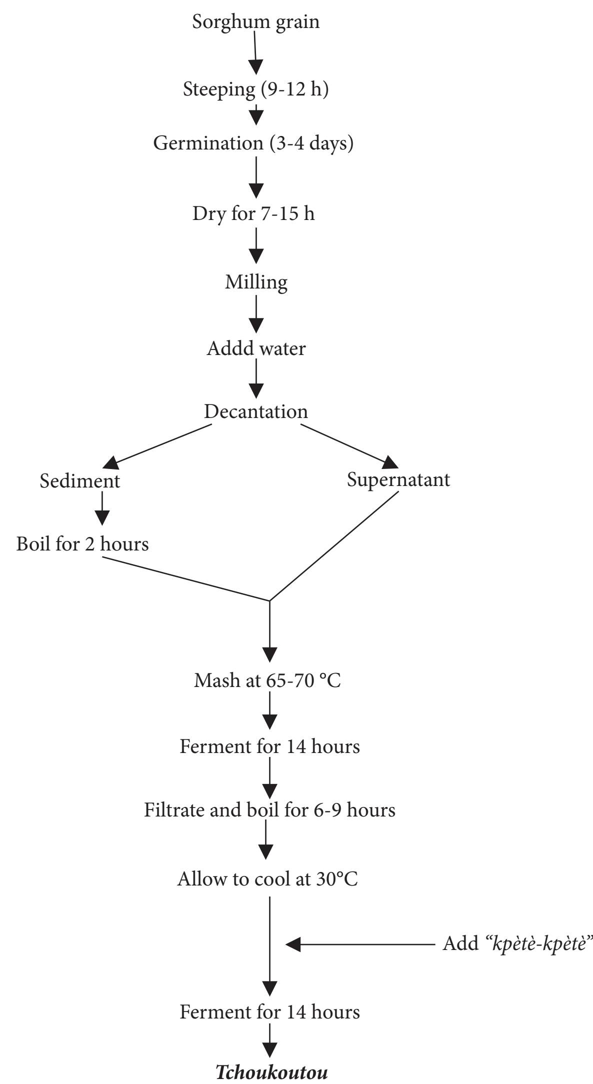

Figure 3: Flow sheet of traditional production processes of tchoukoutou beer [31].

2.12. Kirario. Kirario is a lactic acid-fermented gruel made from maize and millet that is native to Kenya. It is frequently used by the natives as a low-cost meal. Different groups of people including adults who are recovering from circumcision are given as a special beverage. Kirario is traditionally processed by wet milling green maize, then mixing it with dried millet flour and water and grinding it to finer particles. At room temperature, the mixture is left to spontaneously ferment for two days. To produce porridge, the fermented slurry is cooked [39]. Traditional processed kirario has a high acidity level of about 3.0 to 3.5. When proper hygiene protocols are followed, kirario might have a shelf life of about one week or more [39].

2.13. Kunun-Zaki. Kunu-zaki is a native nonalcoholic fermented drink popular in northern Nigeria [40]. It is a millet-based beverage which is consumed within few hours of production [41]. *Kunu* is consumed in place of soft drinks [40]. According to Agarry et al. [4]; fermentation by chance

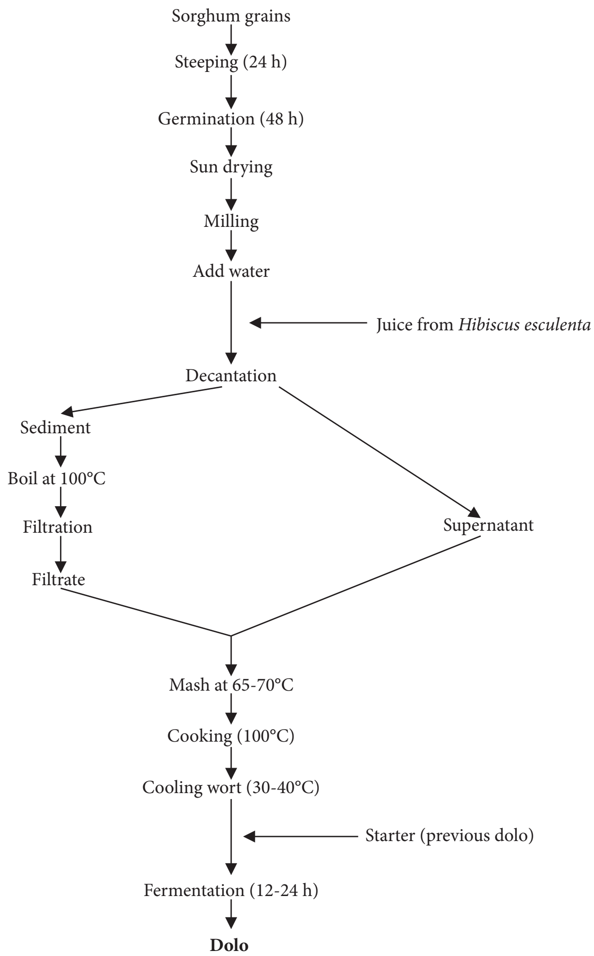

Figure 4: Flow sheet of traditional production processes of traditional dolo beer.

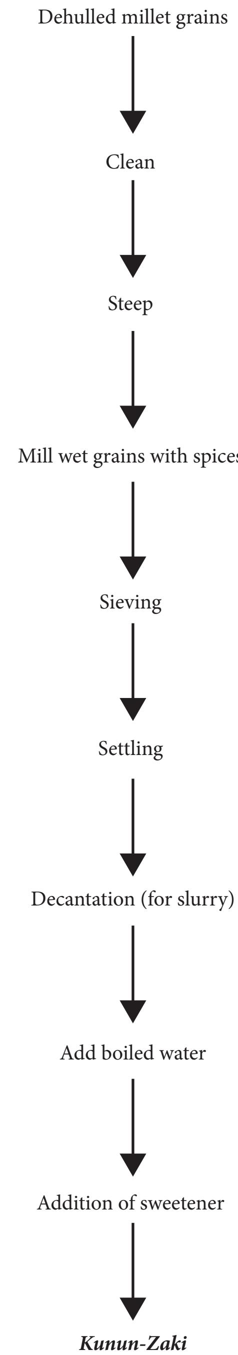

Figure 5: Flowchart for the traditional process of kunun-zaki [4].

inoculation and rudimentary equipment are used in *kunu* production process (Figure 5). It has a short shelf life [2], however, hydrolytic enzymes have been used to increase the nutritional and sensory quality of the product as well as extend the shelf life [42]. According to Umoh et al. [43], *Kunun-zaki* produced through a traditional fermentation technique contains significant levels of spoilage and harmful microbes, which may account for its short shelf life. The beverage contains high amounts of carbohydrates, protein, fat, ash, zinc, calcium, iron, and manganese [44].

2.14. Ting. Ting is a traditional South African and Botswana fermented sorghum beverage. It is known as "*letting*" in South Africa. In preparation, sorghum flour is mixed with warm water to produce a slurry, which is then left to spontaneously ferment in a warm environment for 2-3 days. Alternatively, it can be inoculated with a previously fermented batch of ting. Depending on the starting material, the mixture can be fermented for about 6 to 24 h. While the soured slurry is used to make ting porridges of various consistencies, the soft porridge (motogo) is used for weaning or as breakfast for adults [38].

2.15. Aliha. Aliha is a beverage spontaneously fermented and used by several communities in Ghana. The name *Aliha* was derived from its native origins in the Ewe language of Ketu in Ghana, Volta region. [45]. It is produced using corn malt ("*hali*") as the raw material. The setup is then allowed to ferment which is known as "*aha*," hence, the name (*aliha*). During the production, maize is soaked overnight, and allowed to sun dry (malted). The malts are then ground or milled, mashed, and allowed to boil until no foam is found on the surface. The wort is allowed to ferment for three days after straining, and caramel or burnt sugar is added to obtain the unique brown color and flavor for consumption (Figure 6) [45]. Aliha has to be packaged and refrigerated immediately after production else fermentation continues to a level where it becomes too sour for human consumption [46]. Aliha is regarded as a refreshing drink by the community members, as well as a source of necessary nutrients and certain medicinal properties.

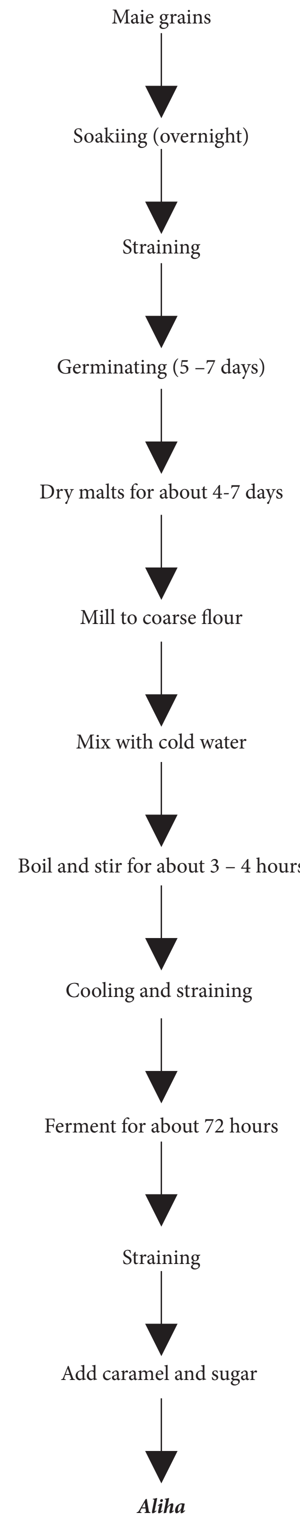

Figure 6: Spontaneous production processing flow of aliha [45].

3. Classification of Traditional Fermented Beverages

Indigenous fermented beverages are consumed all over the world. Their production processes differ from place to place based on several factors including the raw materials used in the production, where the raw materials are cultivated (regions), the production techniques employed, the microbial composition whether exist naturally or added as defined starters and many more. This section of the review would take critical look at the different raw materials and fermentation techniques employed in manufacturing the traditional beverages across the African countries.

3.1. Classification by Raw Materials. The indigenous fermented beverages are unique to those who produce them in a particular geographical location using the raw materials readily available to them. The traditional recipes developed for processing fermented food and beverages are handed down from generation to generation and still considered by both developing and under-developed countries [47]. Most of these indigenous recipes were developed around cereals as the raw materials. However, as modernization and new technologies of food manufacturing begin to manifest, several other raw materials (Table 1) are been used to produce the same beverages probably with better qualities. Cereal utilization started in Neolithic era and still continues to be the most essential source of food worldwide [70]. Cereal-based beverages play many important roles in human life and are considered the major sources of energy for humans [71]. They form key components of human diets for several years and continue to be the main sources of nutrition in both developed, developing, and underdeveloped countries [72]. Like other sources of beverage, cereal-based fermented beverages are used as special vessels for nutrition enhancement [73]. Table 1 presents the common and important cereals that are regularly used for traditional fermented beverages.

3.2. Classification by Fermentation Type

3.2.1. Malted Alcoholic Fermented Beverages. Malting according to MacLeod and Evans [74] and Taylor and Taylor [75] is "a limited controlled germination of grains in moist air, which results in the mobilization of amylases, proteases, and other enzymes which hydrolyze and modify grain components and its structure." The process has been used during the production of food and beverages to develop enzymes needed for fermentation, structural change in the endosperm of the grains into a form that is more readily utilized or extracted in the brewing process, and to develop distinctive malt colors, aromas and flavors [75]. Several African cereal-based alcoholic beverages are produced through malting. During malting processes, hydrolytic enzyme production or activation is maximized leading to the degradation of cell wall and protein solubilization with a minimal starch breakdown [76], an essential component of fermentation.

Table 1: Type of cereals used for the production of African traditional fermented beverages.

Beverage	Raw material	Country	Reference
Aliha	Maize	Ghana	Madilo et al. [45]
Bushera	Sorghum, millet flour	Uganda	Marsh et al. [48]; Aka et al. [49]
Kwete	Maize, millet	Uganda	Enujiugha and Badejo [50]
Malwa	Finger millet	Uganda	Aka et al. [51]
Koko sour water	Cereal (pearl millet)	Ghana	Marsh et al. [48]
Koko	Maize	Ghana	Lei et al. [52]
Pito	Maize, sorghum, maize, sorghum	Ghana, Nigeria	Kolawole et al. [21]; François et al. [53]
Ice-kenkey	Maize	Ghana	Atter et al. [54]
Burukutu	Sorghum	Ghana	Blandino et al. [55]
Mahewu	Maize, sorghum/millet	Zimbabwe	Marsh et al. [48]
Doro	Finger and bulrush millet/sorghum	Zimbabwe	Gadaga et al. [56]; Jane et al. [57]
Mangisi	Millet	Zimbabwe	Aka et al. [49]
Togwa	Maize flour, finger millet malt,	Tanzania	Marsh et al. [48]
Ogi, akamu	Maize, sorghum, millet	Nigeria	Enujiugha and Badejo [58]
Kunun-zaki	Millet, sorghum	Nigeria	Oguntoyinbo et al. [59]; Enujiugha and Badejo [50]
Burukutu	Sorghum	Nigeria	Fadahunsi and Soremekun [60]
Oti-oka	Maize, millet, sorghum	Nigeria	Ogunbanwo and Ogunsanya [61]
Gowe	Sorghum	Benin Republic	Enujiugha and Badejo [58]
Tchoukoutou	Sorghum (and millet or maize)	Benin, Togo	Polycarpe Kayode et al. [62]
Mageu	Maize, wheat south	South Africa	Enujiugha and Badejo [50]
Bantu beer	Sorghum, maize malt	South Africa	Taylor [25]
Umqombothi	Sorghum, maize	South Africa	Shephard et al. [63]
Borde	Maize, finger millet, tef	Ethiopia	Enujiugha and Badejo [58]; Aka et al. [49]
Areki	Millet, sorghum, maize	Ethiopia	Tafere [64]
Keribo	Barley	Ethiopia	Tafere [64]
Tella	Barley, maize, millet, sorghum	Ethiopia	Tafere [64]
Bogobe	Sorghum	Botswana	Blandino et al. [55]
Dolo	Red sorghum	Burkina Faso	Lyumugabe et al. [22]
Bel-saalga	Pearl millet	Burkina Faso	Tou et al. [65]
Amgba	Sorghum (and millet)	Cameroon	Lyumugabe et al. [22]; Aka et al. [51]
Sha	Maize	Cameroon	Abia et al. [66]
Oshikundu	Rice flour + ginger	Namibia	Embashu et al. [18]; Embashu [19]
Oshikundu	Millet, sorghum	Namibia	Mu et al. [67]; Embashu [18]
Bouza	Wheat	Egypt	Blandino et al. [55]
Busa	Rice or millet	Egypt	Blandino et al. [55]
Kishk	Wheat	Egypt	Blandino et al. [55]
Busaa	Maize	Kenya	Katongole [68]; Aka et al. [49]
Tchapalo	Maize	Cote d'Ivoire	Aka et al. [69]; Aka et al. [51]

Meanwhile, the processes involved in the production of malted alcoholic fermented beverages varied from one location to another. However, they are basically produced by subjection of the raw materials (cereals) to malting, mashing, souring, straining, boiling, and fermentation [51]. African malted alcoholic fermented beverages are manufactured by spontaneous fermentation. Spontaneous alcoholic fermentation involves species of LAB and yeasts [77]. It consists of lactic acid fermentation caused by a range of environmental microbes and alcoholic fermentation caused by dried yeast or a fraction of earlier brew [78]. As lactic acid fermentation results in production of nonalcoholic beverages, lactic acid and alcoholic fermentations are set out for alcoholic beverages [79]. According to N'Guessan et al. [80]; whereas lactic acid fermentation is caused by a complex population of environmental microbes as a source of souring taste and storage longevity, alcoholic fermentation is initiated by pitching the wort with a portion of previously fermented brew or dried yeast harvested from the previously fermented beverage. Men are the primary consumers of alcoholic beverages [51, 81]. They are consumed at several social gatherings including festivals, weddings, and funerals [77] in Africa and many developing countries which produce them.

African fermented malted beverages have prolonged shelf-lives due to the production of antimicrobial metabolites (e.g., carbon dioxide, ethanol, and hydrogen peroxide) by LAB; anti-inflammatory, antidiarrheal, antibacterial, antitumor, antispasmodic, laxative, antihemorrhoid, and antioxidant properties [3, 82, 83]. Table 2 presents the list of some malted traditional alcoholic beverages, the raw materials used for their preparations, their alcoholic compositions and fermentation periods.

3.2.2. Malted Nonalcoholic Fermented Beverages. Traditional cereal-based nonalcoholic fermented beverages are also prepared using spontaneous fermentation techniques [77] just like alcoholic fermented beverages. They are prepared from a single or combination of malted barley, maize, millet, oats, rye, sorghum, and wheat [93, 94] as

Table 2: Summary of some African cereal-based malted alcoholic fermented beverages.

Main raw material	Name of beverage	Alcohol content	Fermentation period	Reference
Millet	Boza	Up to 1.5%	24 hours at 15–30°C	Tangüler [84]; Yegin; and Fernandez-Lahore [85]
Pearl millet	Oshikundu	2% or less	1 hour 30 mins	Embashu et al. [18]; Embashu [19]
Rice	Binuburan	18% or less	3-4 days at 35–37°C	Bhalla [86]
Millet	Finger millet slurries	2–4%	24–36 hour	Gabaza et al. [20];
Guinea corn	Burukutu	0.78 g/kg	48 hour at 25–30°C	François et al., [53]; Egemba and Etuk [87]
Maize	Pito	5% and above	2-3 days at 25–30°C	Kolawole et al. [21]
Sorghum/maize	Bantu/kaffir beer	Below 2%	5 days at 30°C	Altay et al. [25, 88]
Sorghum/millet	Amgba beer	4.5–7%	2-3 days at 30°C	Mbaiguinam et al.[30, 89]
Finger millet	Kodo ko jaanr or Chyang	4.8% or less	3-4 d (summer) and 5–7 d (winter)	Thapa and Tamang [90]
Sorghum	Tchoukoutou	4% or less	2-3 days at 30°C	Kayodé et al. [31, 32]
Rice	Sake	15–20%	2-3 d at 10° to 15°C	Yoshizawa and Ishikawa, [91]
Malted red sorghum	Merissa	Up to 6%	N/A	Lyumugabe et al. [22]
Red sorghum	Dolo	2–4%	12–24 h at room temp	Dicko et al. [33]; Nanadoum et al. [34]
Sorghum	Ikigage or Urwagwa	2.2%	12 to 24 h at room temp	Lyumugabe et al. [92];
Sorghum	Bushera	N/A	1–6 d at 27–30°C	Muyanja et al. [35]
Rye, barley	Kvass	1.5% or less	N/A	Marsh et al. [48]
Pearl millet	Oti-oka	1.56%	3 days at 30 C	Ogunbanwo and Ogunsanya [61]

essential sources of dietary proteins [95], energy, carbohydrates, vitamins, minerals, and fibre (arabinoxylan and β–glucan) [77]. They are however deficient in lysine, an essential amino acid [96, 97]. These beverages are drunk by individuals of all ages, particularly youngsters, pregnant women, the sick, and the elderly, and can be used to wean children [49]. They improve lactation in mothers and prevent coronary diseases and cancer.

Regulations and laws covering nonalcoholic beverages vary from country to country. For instance, EU regulation no. 1169/2011 states that an alcoholic beverage must have an alcoholic strength of 1.2% and above; in Great Britain, alcoholic content of nonalcoholic beverage should not be more than 0.05%; Germany has a limit of 0.5%; Spain, France, USA, China and Japan set a maximum of 1%; 1.2%; 0.5%, 0.5% [97], and 1% [98], respectively. Additionally, boza has an alcohol content of not more than 1% in Turkey, but up to 7% in Egypt [99]. The variations in alcoholic contents of cereal malted fermented beverages could be due to several factors including microflora compositions [99]. The combination of cereals with legumes, vegetables, fruits and spices can also lead to these variations.

Nonalcoholic cereal-based fermented beverages serve as alternatives to alcoholic beverages and are used to quench thirst, as nutrition-added value, and have cultural significance [100]. Through fermentation, nonalcoholic beverages have enhanced sensory characteristics, chemical properties, and some bioactive compounds and therapeutic agents significant for human health. Table 3 exhibits a few of these beverages, their raw materials, duration of fermentation, and functional compounds. Maize and millet dominated the cereals used as raw materials used for the production of the selected beverages (Table 3). Additionally, the uniqueness of the nonalcoholic beverages depends largely on the selection of the cereals, microbiota involved, fermentation duration and temperature, and other additional food matrices [109–111].

3.3. Classification by Fermentation Techniques. Fermentation is a biotechnology process which makes use of metabolic activities of microflora and their enzymes to breakdown the raw materials into a desired end product. It is a metabolic activity by which energy is given out by partly oxidizing carbohydrates and related compounds without the assistance of an external acceptor [112]. It is an ancient method used to produce fermented foods and beverages across the globe [113]. As an ancient technique, it was used for food preservation and still be used for same purpose since it has the ability to produce organic acids, ethanol and bacteriocins to either eliminate or reduce the pathogenic microflora from the final fermented products [114], hence, making them safe for human consumption.

Again, fermentation is a better and most cost-effective method of producing and storing food for a longer period of time [115, 116]. It has the ability to convert certain chemicals in the raw materials into physiologically active metabolites. For instance, LAB can synthesize phenolic substances such as flavonoids into active metabolites [117] which may enhance the nutrients and organoleptic characteristics of the final products [118]. Fermentation has the potential to eliminate digestive disorders, and reduce phytic stomach acid, and fermentable carbohydrate concentrations such as fermentable oligosaccharides, disaccharides, simple sugars, and polylactic acid, leading to the reduction of gastrointestinal illnesses [119].

Fermentation of foods and beverages could be attained using several techniques. It can be achieved by a spontaneous technique which is also referred to as the wild fermentation technique [120] where the microflora are naturally present in the raw materials, utensils used or the production environment; back-sloping, or defined starter cultures to produce several fermented products like *sauerkraut*, *kimchi*, *kefir*, *kombucha*, and *natto* [121]. Fermentation can also be achieved using either LAB (lactic acid fermentation), *Acetobacter* species (acetic acid fermentation), yeasts (alcoholic fermentation) or *bacillus* species (alkaline fermentation) [122, 123]. This section of the review is set to look at some of these techniques.

3.3.1. Spontaneous Fermentation. Fermentation is a metabolic process in which carbohydrates and other related chemicals are partially oxidized and energy is released in the absence of any external electron acceptors-organic substances created by carbohydrate breakdown [124]. The process usually uses living organisms or enzymes such as bacteria, yeast, or molds to produce a specific product. Traditional fermented foods and beverages have been a staple of the human diet since the dawn of time [125]. Traditional or indigenous fermentation aims at food preservation; to obtain inhibitory metabolites like organic acid, ethanol, and bacteriocins for the overall safety of the final products [126]. Traditional fermentation is classified into four categories which include alcoholic, lactic acid, acetic acid, and alkali fermentations. While lactic acid fermentation is characterized by lactic acid bacteria (e.g., *kimchi*, *sauerkraut*, and *gundruk*); yeasts are heavily involved in the alcoholic fermentation leading to alcohol production (e.g., wines, beers, vodka, whiskey, brandy, and bread); acetic acid fermentation engages acetic acid bacteria which converts alcohol to acetic acid in the presence of oxygen (e.g., vinegar); and *Bacillus* spp. are also majorly used for alkaline fermentation during the fermentation of soybeans, fish, and seeds, mostly called condiments [125].

Generally, fermentation could be achieved through either spontaneous, back-sloping, or the use of starter cultures (industrial process). The competing actions of various microbial populations generally result in spontaneous fermentations. This type of fermentation depends largely on chance inoculation which involves mixed cultures. The microbiota involved in this method are from the raw materials, utensils, and the environment in which these beverages are processed, hence, the quality of the final products is difficult to predict or control, resulting in short shelf-life and quality diversity of the final beverage. Sáez et al. [127] reported that the microbial communities involved in spontaneous fermentation were LAB, enteric, and sporulated bacteria. They added that the dominant microflora

Table 3: Summary of some African cereal-based malted nonalcoholic fermented beverages.

Beverage	Raw material	Fermentation period	Functional compounds	Reference
Aliha	Maize	72 h at ambient temperature	Protein, iron, carbohydrates, ash, fats, calcium, phosphorus	Kwashie Felix et al. [46]
Sobia	Cereal malt	24 h at ambient temperature	Dietary fibre, amino acids, fatty acids, vitamins B1, B2	Gassem [101]
Koko	Millet	2–12 h at ambient temperature	Group B vitamins; dietary fibre	Lei and Jakobsen [102]
Mahewu	Maize	12–24 h at ambient temperature	Sodium, potassium, calcium, iron, zinc; fibre, carbohydrate, group B vitamins	Mugochi et al. [103]; Vasudha and Mishra [37]
Kirario	Green maize and millet	2 d at ambient temperature	Dietary fibres, amino acid, fatty acid, B1, and B2 vitamins	Kunyanga et al. [39]
Kunun-zaki	Millet	8 h at ambient temp	Minerals (Fe, Ca, Mg, and K)	Agarry et al. [4]; Obadina et al. [40]
Mawe (akassa)	Maize	1–3 days	N/A	Hounhouigan et al. [104, 105]
Pozol	Maize	0.5–4 d at ambient temperature	N/A	Wacher et al. [106]; Ampe et al. [107]
Ting	Sorghum	2-3 d/6–24 h at warm temperature	B1, B3, B2, and B6 vitamins; dietary fibres, zinc, copper, maltoses, maltotrioses, glucoses, fructose	Sekwati-Monang, [38]
Malwa	Millet	2–4 days	Dietary fibre, amino acids, fatty acids, vitamins B1, B2	Muyanja et al. [6]; Lyumugabe et al. [92]
Mangisi	Millet sweet-	8 h at ambient temp	N/A	Blandino et al. [55]
Togwa	Maize/millet	24 h at ambient temperature	Amino acids and some minerals (Fe, Ca, Zn, P)	Mugula et al. [108]
Borde	Millet	12 h at ambient temperature	N/A	Enujiugha and Badejo [50]
Gowe´	Maize/millet	6–24 h at ambient temperature	Amino acids and some minerals (Fe, Ca, Zn, P)	Aka et al. [49]
Koko sour water	Maize	12 h at ambient temperature	Group B vitamins; dietary fibre	Aka et al. [51]
Bushera	Sorghum	24 h at ambient temperature	Proteins, minerals, fibre	Muyanja et al. [35]

associated with spontaneous fermentation includes species of LAB such as *Leuconostoc mesenteroides,* Brevilactobacillus *brevis,* and *Lactiplantibacillus plantarum.*

However, the length of spontaneous fermentation can be shortened by inoculation through back-slopping and starters. The use of small quantities of previously fermented raw materials in the new product or raw materials to be fermented is what is referred to as back-sloping [128]. It is a modified form of spontaneous fermentation [129]. It has been used to produce several food products including sauerkraut, sourdough, *koumiss,* and beverages. In contrast, the microbial qualities of these products have not been properly understood [124]. According to Holzapfel [130]; back-slopping fermentation technology has been widely utilized for generations due to its ease of application and high yields, despite the fact that its microbial ecology is unpredictable. Kim and Jazwinski [131] conducted a study in which they evaluated the microbiological, nutritional, physiochemical, and sensory qualities of innovative back-slopped fermented kefir to those of traditional fermented kefir. Kefir yields increased by 50%, and the microbiological, nutritional, and physicochemical features were not substantially different from those of spontaneously fermented kefir except for the amount of *Lactobacillus kefiri* and yeast, percentage carbohydrate, and pH.

3.3.2. Industrial Fermentation. Fermented foods and beverages have been one of the popular consumed foods in recent times [132]. The fermentation methods used have improved over the years to produce food products that are safer, free from synthetic chemicals, and have higher nutritional contents in order to meet the high demands of the consumers [133]. Specific microorganisms with special functional properties are been used to achieve these objectives. The most dominant bacterial general used heavily in industrial fermentation is *Limosilactobacillus* which has the ability to produce lactic acid from carbohydrates. Other bacteria include the acetic acid-producing *Acetobacter* for fruit and vegetable fermentation, and *Bacillus* species which are used for legume fermentation [132]. Food manufacturing industries also use beneficial yeasts such as *Saccharomyces cerevisiae* as they produce several enzymes to biochemically impact flavor and aroma in wine beer and ethanol, and leavening of bread [134].

Again, the effective application of various novel innovations such as co-culture, thermophilic fermentation, molecular tools, genetic engineering, mutant selection, and recombinant DNA technologies has enabled the design and construction of tailor-made defined microbes that outperform those found naturally [132]. Moreover, commercial or industrial processes of fermentation have employed several species of microorganisms to improve the qualities of fermented food and beverages. The most common products produced through the industrial processes includes but are not limited to wine (*Saccharomyces cerevisiae*; [135]; beer (*Saccharomyces cerevisiae, Saccharomyces pastorianus*; [136]; yogurt (*Streptococcus thermophilus, Lactobacillus delbrueckii*; [137]; cheese (*Lactococcus, Limosilactobacillus, Streptococcus* sp.*, Penicillium roqueforti*; [135]; Acidophilus milk (*Lactobacillus acidophilus*; [138]; sauerkraut (*Leuconostoc* sp.*, Brevilactobacillus brevis, Lactiplantibacillus plantarum*; [139]; fish sauce (Lactic acid bacteria (halophilic), *Halobacterium salinarum, Halobacterium cutirubrum, Bacillus* sp.; [140] and fermented meat (*Limosilactobacillus* sp.,*. Micrococcus* sp.*, Staphylococcus* sp. [141].

As a result of industrial fermentation, the production of seasonal beverages, particularly wine and beers, with varying essential tastes and alcohol levels, such as strong beer brewed from caramelized malt in the winter and lighter beers with citrus flavor in the summer [142] are possible. Again, some yeast species are genetically modified to reduce fermentation time, produce desirable organoleptic properties in food and beverages. *Saccharomyces cerevisiae* ML01, in particular, was genetically modified to reduce the generation of biogenic amines, which are harmful compounds produced during wine fermentation [143]. A different recombinant *S. cerevisiae* strain was employed to minimize the development of ethyl carbamate, a carcinogen formed during wine fermentation [144]. Biomolecular approaches are currently being utilized to investigate the fate of bacteria in alcoholic beverages.

3.3.3. Fermentation by Starter Cultures. Starter cultures are active and desirable microflora isolated from previously fermented products (food and beverages) and is intentionally added to the new raw materials at a high number to improve upon the qualities desired by the consumers in the fermented products [145]. They are purely used in manufacturing fermented food and beverages [146]. They could be single or combined pure cultures (defined as microorganisms) that are added to a raw or pasteurized product to start and accelerate its fermentation process [147]. They initiate and carry out the desired fermentation essentials in manufacturing food and beverages [148]. Their metabolic activities have desired effects on the final fermented products [149].

Lactic acid bacterial starters produce lactic acids which lead to a rapid decrease in the pH of the raw materials leading to assuring the safety of the final product. Moreover, the bacteriocins they produce also cause stability of the microbial content of the final products [150]. The starter cultures are normally seeded into the products to be fermented and are allowed to multiply under controlled conditions, which thereafter, impart the characteristic features such as acidity (pH), aroma, consistency, and flavor of the resultant products. During the process of inoculation, bacteria break down lactic acid in the substrates, resulting in increased acidity which imparts preservative effects, improving the nutritive and digestive qualities of the final products. Some of the well-known defined starter cultures that are used commercially for the production of fermented food and beverages includes the strains of *Limosilactobacillus* spp., *Bifidobacterium* spp., and *Propionibacterium* spp. *Lactobacillus acidophilus*, *Lacticaseibacillus casei, Limosilactobacillus reuteri, Lacticaseibacillus rhamnosus* and

Lactiplantibacillus plantarum [151–153]. According to Holzapfel [154], several researchers have reported that *Brevilactobacillus brevis, Limosilactobacillus fermentum Lactiplantibacillus plantarum, Limosilactobacillus reuteri, Pediococcus pentosaceus* and *P. acidilactici* used as pure starter cultures either singly or in combinations show improved performance in lactic acid-fermented cereal and vegetable products in African countries [155–159]. However, Oyewole [160], Jespersen [161], Obilie et al. [162], and Dzogbefia et al. [163] also reported *Candida krusei, Candida tropicalis, Pichia saitoi, Pichia anomala, Saccharomyces cerevisiae, Zygosaccharomyces florentinus* and *Zygosaccharomyces* spp. as mold and yeast cultures used in fermentation of cassava tissues. Holzapfel [154] also revealed that yeast species such as *Saccharomyces, Candida, Torula,* and *Hansenula*, considered as starters improved the performance of food products produced by plant-based materials containing fermentable sugars. The lactic acid fungi produce alcohol to prevent bacterial and mold infection and improve storage qualities.

Furthermore, the starter cultures' primary and most important function is to hydrolyze carbohydrates and produce lactic acid in the final products. Coagulation, moisture ejection, texture formation, and flavor development are all secondary impacts of acid production. The lactic acid produced increases the coagulation of milk, strengthens the curd, and protects the finished product from infection. The enzymes of lactic acid bacteria starters also help the flavor development of cheeses during the ripening process by the activities of glycolysis, proteolysis, and lipolysis [164]. Again, the starters aid in pleasant taste, offer protection against potential pathogens and spoilage-causing microbes thereby extending the product's shelf life. Fermentative activities of LAB and yeasts during fermentation are thought to increase the quality, flavor, hygiene, and safety of fermented foods and beverages. Holzapfel [130] indicated that West Africa's cereal-based fermented foods and beverages are produced by spontaneous fermentation and on small industrial scales, hence, have varying quality and microbial stability. Therefore, the use of a preparation containing a large amount of known variable microflora is recommended to promote rapid acidification of the raw materials leading to final products with consistent quality and also preventing the growth and proliferation of spoilage and pathogenic bacteria, thereby prolonging the shelf life of the final products [58, 165].

Again, M'hir et al. [145] have it that though some *Enterococcus* species and strains are considered as pathogens, most of them contribute significantly to the improvement of the organoleptic properties of food and beverages. They play important roles in the ripening of dairy products, mostly through proteolytic and lipolytic activities, exopolysaccharide production, and citrate breakdown, hence, giving a unique taste and flavor to the final products [166, 167]. The pH, color, titratable acidity, alcohol content, and some organoleptic characteristics of "*Pito*" produced by the use of starter preparations can be compared favorably to that produced using spontaneous fermentation techniques [168].

Additionally, LAB strains selected as starter cultures are able to proliferate during sourdough fermentation, acidify the dough and inhibit microbial pathogens [169]. According to Gallagher et al. [170], LAB starters such as *E. faecium* strains in particular, exhibited a functional role in the fermentation of *Hussuwa* through bacteriocin and other antimicrobial compounds production against *Listeria innocua, L. monocytogenes,* and *Staphylococcus aureus.* Moreover, they are also able to ferment indigestible oligosaccharides, leading to an improved nutritional quality of sorghum final products [169]. *E. faecalis* combined with *Leuconostoc mesenteroides* as starters are able to produce sufficient lactic acid, leaven the batter, and form a unique flavor in *idli* [32]. It was also reported that the bacteriocin and other antimicrobial compounds produced by LAB starter strains such as *faecium* ST62BZ and *faecium* BFE 900 isolated from *boza* were active against a number of food-borne pathogens including *Pseudomonas* spp., *Escherichia coli*, and *Klebsiella pneumoniae* [171]. The enterocins produced by *Enterococci* starter cultures promote inhibitory activity towards spoilage or food-borne pathogens such as *Listeria* spp. and *Clostridium* spp. [172, 173]. Their activities towards pathogens such as *Escherichia coli* and *Vibrio cholerae* have also been brought to light by Javed et al. [173], Khan et al. [174], and Vijayendra et al. [175]. Moreover, some of the defined starters used successfully in producing specific food products are summarized in Table 4. From the table, *Limosilactobacillus fermentum* and *Lactiplantibacillus plantarum* dominated the lactic acid bacterial starters, while *Saccharomyces cerevisiae* dominated the yeast starters considered for the fermentation of the selected beverages.

4. Microbiology of Cereal-Based Traditional Fermented Beverages

The fermentation of the majority of cereal-based traditional fermented foods and beverages is spontaneous, hence, involves different species of microflora [189]. The association of different communities of microorganisms makes the production process difficult to control, standardize, safe and resulting in variable-end products. The qualities of the final fermented food and beverages are largely determined by the microbial properties involved in the fermentation process. Different production techniques, the raw materials employed, and hygiene and sanitation practices employed during production also contribute significantly to the microflora communities of the traditional fermented beverages. However, the acidity of the fermenting products increases when LAB dominates the initial stage through to the final stage of the fermentation, thereby eliminating the food spoilage and pathogenic microbiota and leading to the safety of the products [190].

4.1. Microbiota Associated with Cereal-Based Traditional Fermented Beverages. The fermentation processes of traditionally fermented food and beverages involve the hydrolysis of organic compounds into acids or alcohol through enzymatic actions of various microorganisms such as bacteria,

Table 4: Starter cultures used in fermenting some cereal-based traditional fermented products.

Products	Defined starters	References
Sourdough	*Lactobacillus species including; brevis, hilgardii, sanfranciscensis, farciminis, fermentum, plantarum, amylovorus, reuteri, pontis, panis, alimentarius*	Palla et al. [176]
Kimchi	*Leuconostoc mesenteroides, Lactobacillus plantarum, Weissella kimchi and koreensis, Companilactobacillus kimchi and Lactobacillus sakei*	Choi et al. [177]; Lee et al. [178]; Muyanja et al. [35]
Bushera	*Lactobacillus species such as plantarum, paracasei* ssp. *paracasei, fermentum, brevis, delbrueckii* ssp. *delbrueckii and Streptococcus thermophilus*	Nuraida et al. [179]
Pozol	*Leuconostoc mesenteroides, Lactiplantibacillus plantarum, and W. confuses; Lactococcus lactis and raffinolactis*	Florou-Paneri et al. [180]
Bread	*Fructilactobacillus sanfranciscensis, Leuconostoc citreum and Weissella cibaria*	Alfonzo et al. [181]
Sato	*Rhizopus oligosporus, Mucor racemosus, Saccharomyces cerevisiae, Saccharomycopsis fibuligera, and Pichia anomala*	Gabaza et al. [20]
Enturire	*Lactiplantibacillus plantarum* MNC 21 combined with *Saccharomyces cerevisiae* MNC 21Y, and *L. plantarum* MNC 21 combined with *Weissella confusa* pH MNC 20 and *Saccharomyces cerevisiae* MNC 21Y	Mukisa et al. [182]
Bushera	*W. confuse, species of* (*Lacticaseibacillus paracasei, Limosilactobacillus fermentum, Brevilactobacillus brevis and Lactiplantibacillus plantarum*)	Muyanja et al. [183]
Togwa	*Brevilactobacillus brevis, L. cellobiosus, Limosilactobacillus fermentum,* (*Lactiplantibacillus plantarum*), *and Pediococcus pentosaceus, Candida* (*pelliculosa and tropicalis*), *and Saccharomyces cerevisiae*	Mugula et al. [184]
Gowe	*Lactobacillus fermentum and mucosae; W. confusa and kimchi; Pediococcus acidilactici and pentosaceus; Kluyveromyces marxianus, Pichia anomala; Candida krusei and tropicalis*	Vieira-Dalode et al. [185]
Ogi	*Lactobacillus fermentum, brevis, and plantarum; Yeast such as S. Cerevisiae, Rhodotorula graminis, Candida krusei and tropicalis, Geotrichum candidum, Geotrichum fermentum*	Omemu et al. [186]; Teniola and Odunfa [187]
Kenkey	*Lb. fermentum, Lb. brevis, C. krusei, S. Cerevisiae*	Olsen et al. [188]

yeasts, and molds [191]. The quality of the fermented products depends largely on the community of microbiota involved in the fermentation processes [7]. Which means the differences in the final-fermented products are as a result of the variations in the microbial community associated with the fermentation process. Tables 5 and 6 present the microbial communities associated with traditional fermented alcoholic and nonalcoholic beverages.

Furthermore, Tables 5 and 6 reveal that bacteria, yeasts, and molds were the major microbial compositions of the selected traditional beverages. The lactic acid bacteria were dominated *Lactobacilli* (*Lactiplantibacillus fermentum*, *Brevilactobacillus brevis*, *Lactiplantibacillus plantarum*, and *delbrueckii*), followed by *Lactococci, Leuconostoc,* and *Pediococci* with the least being *Streptococci* (*Streptococcus bovis*). *Lactobacillus* and other LAB species are known and are very important in food technology. Zalán et al. [213] reported that LAB in cheese, yoghurt/fresh dairy products industries, and production of probiotics represent a market of 55 billion Euros, 25 billion Euros, and 20 billion Euros, respectively. Again, while *Saccharomyces cerevisiae* and *Candida mycoderma* dominated *Saccharomyces* and *Candida* species (yeasts) respectively; *Aspergillus aceti* and *Rhizopus stolonifer* dominated *Aspergillus* and *Rhizopus* species (molds) respectively. Other microbial dominants found to be associated with the selected local fermented beverages include *Acetobacter, Pseudomonas, Klebsiella, Weissella, Achromobacter, Flavobacterium, Micrococcus*, and *Bacillus*.

4.1.1. Lactic Acid Bacteria (LAB). Lactic acid bacteria are classified according to their morphology, glucose fermentation potentials, temperature tolerance, lactic acid synthesis, ability to thrive at high salt concentrations, and acid or alkaline tolerance [214, 215]. *Aerococcaceae, Carnobacteriaceae, Enterococcaceae, Leuconostocaceae, Lactobacillacea,* and *Streptococcaceae* are the six families defined by Parte [216]. Out of the six families, *Enterococcaceae, Leuconostocaceae, Lactobacillacea,* and *Streptococcaceae* account for the majority of the genera and species involved in fermentation. The LAB genera in the other two families are more closely linked to food deterioration. Among the four families, seven genera such as *Enterococcus, Oenococcus, and Leuconostoc, Lactobacillus, Pediococcus, Lactococcus,* and *Streptococcus* from each of the four families, respectively, were associated with food and beverage fermentation [216]. Studies have established that the appearance of microorganisms, particularly LAB in fermented food and beverages depend largely on their geographical locations [217]. Fujimoto et al. [218] isolated *Lactobacillus* species such as *brevis, alimentarius, pentosus, vaccinostercus, sanfranciscensis,* and *sakei* from fermented wheat and corn sourdough; Fujimoto et al. [218] and Liu et al. [219] reported species of *Lactobacillus, Pediococcus,* and *Leuconostoc* in wheat sourdough. While Liu et al. [219] and Zhao et al. [220] identified 217 strains of *Lactiplantibacillus plantarum, Lacticaseibacillus. pantheris, L. raffinolactis, Leu. mesenteroides, Leuconostoc citreum, Leu. pseudomesenteroides, Weissella viridescens,* and *Lactococcus lactis* from wheat sourdough from Ya'an city of China, Zhang et al. [221] and Yan et al. [222] reported *Lactobacillus* spp., *L. brevis, Latilactobacillus curvatus, L. lactis* ssp. *lactis, Lactococcus lactis* ssp. *lactis*, *E. casseliflavus, E. durans, E. faecium, S. constellatus*, and *S. equinus* as the predominant LAB species in corn and rye sourdoughs.

The LABs are safe microbes playing very important roles in food fermentation and preservation through natural fermentation or added as defined starters [223]. The preservative ability of LAB is actually as a result of antimicrobial compounds production which include hydrogen peroxide, ethanol, diacetyl, γ-aminobutyric acid, propionic acid, benzoic acid, fatty acids, bacteriocins, and bacteriocin-like inhibitory substances [224]. Again, these compounds are produced to prevent the development of undesirable microbes thereby improving the shelf life and the overall safety of the final beverage [225]. The organic compounds produced could also improve food and beverage functionalities [226, 227].

4.1.2. Fungi. Fungi are a broad group of microorganisms that live in a variety of environments, including soil, plant parts, water, food, and beverage sources [228–230]. Temperature, pH, moisture, degree of aeration, and the amount and kind of nutrients are all elements that influence their growth and distribution [231]. Fungi are a family of yeast and molds naturally found in fermented food and beverages or added as defined starter cultures.

(1) Yeasts. Yeasts are considered to be the primary spoilage microbes. The various spoilage-causing yeast genera that are found in low-alcoholic and nonalcoholic beverages include *Zygosaccharomyces bailii, Saccharomyces, Brettanomyces, Hanseniaspora, Hansenula,* and *Pichia.* Several researchers have also identified *Schizosaccharomyces pombe, S. japonicus, Candida castellii, C. fructus, C. intermedia, C. krusei, C. tropicalis, Geotrichum candidum, Hansenula anomala, Kloeckera apiculata* [122], *Pichia membranifaciens, P. ohmeri, Saccharomyces chevalieri, S. uvarum, Kluyveromyces africanus, Torulaspora delbrueckii* and *Rhodutorula graminis* as the predominant species associated with most of the African fermented beverages [114, 232, 233].

Like bacteria, yeasts have advantageous and disadvantageous effects in food fermentations. They can be applied in the production of ethanol, single-cell protein (SCP), feeds, industrial enzymes, and metabolites [114]. During the fermentation of traditional food and beverages, they ferment carbohydrates leading to the formation of alcohols and other aroma compounds [114]. Yeasts like *Pichia* are seen as food spoilage organisms while *Candida* spp. is utilized for single-cell protein production [234]. The most beneficial yeast in terms of desirable food fermentations are from the family of *Saccharomyces*, especially *S. cerevisiae* which is widely associated with bread making and alcohol in wine fermentations. *Saccharomyces cerevisiae* var. *ellipsoideus* is employed extensively in beverage (wine) production [235]. For beverages produced with maize and millets, *Schizosaccharomyces pombe* and *S. boulderi* have been identified as

Table 5: Microorganisms involved in the fermentation processes of African traditional fermented alcoholic beverages.

Beverage	Microorganisms/taxonomic tool	Reference
Burukutu (sorghum)	*Aspergillus aceti*, *A. hansenii*, *A. pasteurianus*, *L.plantarum*, *L.brevis*, *L. fermentum; S. cerevisiae*, *B. licheniformis*, *Flavobacterium* spp., *Candida mycoderma*, *Hansenula anomala*, *S. diastaticus*, *and L. fermentum.* (API 50 CHL and 16S rRNA gene sequencing)	Sanni et al. [192]; Lyumugabe et al. [22]; Eze, et al. [193]; and Kolawole et al. [21]
Pito (maize/sorghum)	*Acetobacter aceti*, *Aspergillus hansenii*, *A. pasteurianus*, *Flavobacterium* spp., *Lactobacillus plantarum*, and *Lb. brevis, Saccharomyces cerevisiae*, *A. aceti, L. buchneri, Micrococcus varians, B. licheniformis L. fermentum, Candida* spp. *Lactococcus delbrueckii, Pediococcus. acidilactici, Lactobacillus lactis, and Leuconostoc lactis* (cultural, morphological, and biochemical characterization)	Sanni et al. [192]
Bantu beer (maize/sorghum)	*Saccharomyces cerevisiae*, *Candida* spp., *L. plantarum*, *L. fermentum*, *L. brevis*	Dirar [194]
Amgba (sorghum and millets)	*Cryptococcus albidius* var *albidius*, *C. melibiosica*, *Debaryomyces hansenii* var *hansenii*, *Dekkera bruxelensis*, *Rodotorula mucilaginosa* and *Torulaspora delbrueckii, Saccharomyces cerevisiae*, lactic acid bacteria (PCR/RFLP, partial sequencing of 26S of rDNA)	Nanadoum et al. [30]
Kodo ko jaanr (millets, barley)	*Saccharomycopsis fibuligera*, *Rhizopus* spp., *Mucor* spp., *Pediococcus pentosaceus and anomala, L. bifermentans, Mucor circinelloides, Rhizopus chinensis and stolonifer, Saccharomyces cerevisiae, Candida glabrata.* (Cultural, MBC)	Prakash Tamang and Thapa [195]
Bhaati jaanr (rice)	*Amylomyces rouxii, Rhizopus oryzae, Endomycopsis fibuligera, S. cerevisiae*, *Enterococcus faecalis, P. pentosaceus* (biochemical tests, API 50 CHL)	Nout [196]
Tchoukoutou (sorghum, millet, maize)	*Rhizopus, Mucor, Aspergillus* spp., *acetic acid bacteria, lactic acid bacteria, bacilli, Saccharomyces, Candida, Hansenula* spp.	Prakash et al. [31, 197]
Bouza (buza) (Wheat, maize, millet, sorghum)	*Saccharomycopsis fibuligera*, *Rhodotorula glutinis*, *Debaromyces hansenii*, *Candida parapsilosis*, *Trichosporon fennicum*, and LAB including *Leuconostoc* spp. (cultural, morphological and biochemical characterization)	Adegoke et al., [198];
Merissa (sorghum or millet)	*Lactococcus lactis, Aspergillus aceti*, *Aspergillus hansenii*, *Aspergillus pasteurianus*, *L. plantarum*, *L. fermentum*, *L. brevis*, *L. lactis*, *L. delbrueckii*, *Alcaligenes*, *Saccharomyces cerevisiae*, *Micrococcus* spp. *Candida* spp. *Bacillus licheniformis*, *Flavobacterium* spp., *Candida mycoderma*, *Hansenula anomala*, *Saccharomyces diastaticus*, *Bacillus* spp. *Rhodotorula* spp. *Pediococcus acidilactici* (API 50 CHL, ITS-PCR/RFLP, (PFGE), 16S rRNA gene sequencing. MALDI-TOF)	Sanni et al. [192]; Jespersen [161]
Chibuku (sorghum)	*Lactococcus lactis, Aspergillus aceti*, *Aspergillus hansenii*, *Aspergillus pasteurianus*, *L. plantarum*, *L. fermentum*, *L. brevis*, *L. lactis*, *L. delbrueckii*, *Alcaligenes*, *Saccharomyces cerevisiae*, *Micrococcus* spp. *Candida* spp., *Bacillus licheniformis*, *Flavobacterium* spp., *Candida mycoderma*, *Hansenula anomala*, *Saccharomyces diastaticus*, *Bacillus* spp. *Rhodotorula* spp. *Pediococcus acidilactici* (PCR-DGGE, PCR-RFLP, API 20 C kit, ABI 3130 genetic analyzer, API 50 CHL system)	Sanni et al. [192]; Jespersen [161]

Table 5: Continued.

Beverage	Microorganisms/taxonomic tool	Reference
Dolo (sorghum)	*Saccharomyces cerevisae*, *Candida inconspicua*, *Issatchenkia orientalis*, *Candida magnolia*, *Candida humilis*, *L. fermentum*, *Lactobacillus buchneri*, *Lactobacillus* sp., *Aspergillus niger*, *Fusarium* sp. and *Aspergillus* sp. (API 20 C kit, PCR -sequencing, ABI 3130 genetic analyzer, API 50 CHL system)	Jespersen [161]; Sawadogo-Lingani et a. [36, 199]
Ikigage (sorghum)	*Aspergillus aceti*, *Aspergillus hansenii*, *Aspergillus pasteurianus*, *L. plantarum*, *L. fermentum*, *L. brevis*, *Alcaligenes*, *Saccharomyces cerevisiae*, *Micrococcus* spp., *Candida* spp., *Bacillus licheniformis*, *Flavobacterium* spp., *Candida mycoderma*, *Hansenula anomala*, *Saccharomyces diastaticus*, *Bacillus* spp. *Rhodotorula* spp.	Lyumugabe, et al. [92]
Tchapalo (sorghum)	*L. fermentum, L. brevis, L. plantarum, L. paracasei* subsp. *paracasei and L. delbrueckii* subsp. *delbrueckii; Lactococcus lactis* subsp. *lactis, Leuconostoc mesenteroides* subsp. *mesenteroides, Leuconostoc mesenteroides* subsp. *dextranicun, Weissella confusa, and L. plantarum* (API 50 CHL and ID 32C)	Sanni et al. [192]; Muyanja et al. [35]
Bushera (sorghum, millet)	*Lactobacillus plantarum, Corynebacterium, Aerobacter, Candida mycoderma, Saccharomyces cerevisiae, Rhodotorula, Cephalosporium, Fusarium, Aspergillus, Penicillium, L. plantarum Corynebacterium, S. cerevisiae, Candida mycoderma. L. fermentum biotypecellobiosus, L. brevis,, L. curvatus, L. buchneri, L. delbrueckii* subsp. *bulgaricus, L. helveticus, L. pantheris, L. vaccinostercus, L. bifermentans, L. nantensis, Candida humicola, C. krusei, Geotrichum* spp., *Cryptococcus* spp., *Trichosporon* spp., *C. krusei, Clavispora lusitaniae, S. cerevisiae.* (API kit, PCR-DGGE and partial 26S rRNA gene sequencing, 16S clone library and PCR-DGGE)	Oguntoyinbo et al. [59]; Greppi et al. [200]
Ogi (maize, sorghum, millet)	*Cryptococcus albidius* var *albidius, Candida melibiosica, Debaryomyces hansenii* var *hansenii, Dekkera bruxellensis, Rhodotorula mucilaginosa, Torulaspora delbrueckii* (5). *S. cerevisiae and S. paradoxus* (PCR/RFLP, partial sequencing of 26S of rDNA and sequences)	Nanadoum et al. [34]
Bili bili (maize, sorghum, millet)	(*S. cerevisiae, S. carlsbergensis, C. tropicalis, C. pararugosa, C. diversa, C. boidinii, C. lactiscondes, C. lambica, C. norvegica, C. inconspicua, Pi. fermentans, Pi. norvegensis, R. mucilaginosa, R. araucariae and T. delbrueckii*) *and lactic acid bacteria, L. confusus, L. fermentum, L. plantarum, L. coryniformis, Lb. sanfrancisco, L. coprophilus, L. paracasei* subsp. *paracasei, L. brevis, L. acidophilus, L. rhamnosus, Leu. mesenteroides, Leu.oenos, Leu. raffinolactis, Lc. lactis, W. confusa* (RAPD PCR, partial 16S rRNA gene sequencing, API 50 CHL and API ZYM galleries)	Nanadoum et al. [34]
Boza (millet, maize, wheat, and rice)	*Lactobacillus plantarum, Lactococcus lactis* ssp. *lactis, Lactobacillus delbrueckii* ssp. *delbrueckii, L. fermentum, Lb. pentosus, and L. curvatus* ssp. *curvatus, Enterobacter cloacae, E. sakazakii, Pseudomonas luteola, P. aeruginosa, and Serratia ficaria.* (API 50 CH/CHL and API 20E media.sequences)	Heperkana et al. [201]; Hancıoğlu and Karapınar, [202]; Tamer et al. [203]; Botes et al. [204]

Table 5: Continued.

Beverage	Microorganisms/taxonomic tool	Reference
Oshikundu (millet, sorghum)	*Lactococcus, Weissella, Leuconostoc, Aeromonas, Enterococcus, Pseudomonas, Lactobacillus, and Acinetobacter* (Rep-PCR and 16S rRNA)	Embashu et al. [18]
Finger millet slurries (millet)	*Leuconostoc lactis, Lc. mesenteroides, L. plantarum, L. brevis, W. viridescens, E. casseliflavus, E. faecium, E. mundtii, E. durans, Pediococcus acidilactici and yeast species* (ISR-PCR fingerprinting, RAPD-PCR, 16S–23S ISR, RAPD-M13 and 16S rRNA)	Gabaza et al. [20]

Note. MBC, morphological and biochemical characterization.

Table 6: Microorganisms fermenting African traditional fermented nonalcoholic beverages.

Beverage	Microorganisms/taxonomic tools	Reference
Koko/akassa	*Lactobacillus fermentum*, (*Lb. cellobiosus, Lb. brevis, Lb. curvatus, Lb. buchneri,* and *Weissella confusa*), *pediococci and yeasts such as Candida krusei, Candida kefyr, Candida glabrata, Saccharomyces cerevisiae*	Nout [32]
Ben-saalga	*Lb. fermentum, Lb. plantarum, and Pediococcus pentosaceus Lb. plantarum*	Sifer et al. [205]
Togwa	*Lactobacillus* spp., *Saccharomyces cerevisiae, Candida* spp. *L. plantarum, L. brevis, L. fermentum, L. cellobiosus, P. pentosaceus, W. confusa Issatchenkia orientalis, C. pelliculosa, C. tropicalis.* (biochemical tests, API tests)	Vasudha and Mishra [37]; Mugula et al. [108]
Amazake	*Aspergillus* spp.	Yamamoto et al. [206]
Mahewu (amahewu)	*Lactococcus lactis* subsp. *lactis, Lactobacillus, Streptococcus, Enterococcus* (cultural, morphological, and biochemical characterization)	Blandino et al. [55]; Gadaga et al. [207];
Kunnu zaki	*Lactobacillus fermentum and Lactobacillus leichmannii, Leuconostoc* spp., *Lactococcus* spp.	Akoma et al. [208]; Agarry et al. [4]
Mageu	*Saccharomyces cerevisiae, Issatchenkia orientalis, Pichia fabianii, Aureobasidium pullulans, Candida glabrata, Pichia ciferrii, Saccharomycopsis fibuligera, Hanseniaspora opuntiae, Zygoascus hellenicus, Cryptococcus flavus, Cryptococcus magnus, Candida parapsilosis, Candida pyralidae and Rhodotorula mucilaginosa, Lactobacillus agilis, L. minor, L. Confuses and L. fructosus. L. Minor, L. divergens L. agilis and L. plantarum, L. bifermentans, L. divergens, L. fermentum, L. hilgardii, L. minor, Streptococcus* spp.	Nyanga et al. [209]; Fleet [210]
Pozol	*Streptococcus, L. fermentum, L. plantarum, L. casei, L. delbrueckii Streptococcus bovis, S. macedonicus, L. lactis,* and *Enterococcus sulfureus.* (Cultural, morphological, and biochemical characterization, RT-PCR)	Muyanja et al. [6]
Malwa	*Lactobacillus* spp., *Lactococcus, coliforms*	Muyanja et al. [6]
Sobia	*Lactobacillus cellobiosus, L. buchneri, L. plantarum, L. brevis, L. delbrueckii. delbrueckii, Leuconostoc lactis, Pediococcus pentosaceus, Klebsiella pneumonia, Enterobacter aerogenes, E. sakazakii, E. cloacae, Serratia liquefaciens, Saccharomyces cerevisiae, Candida tropicalis, C. ciferrii, C. guilliermondii, C. lipolytica, Kloeckera japonica, Rhodotorula rubra, Penicillium* spp. API 50 CHL system, API 20 system, API 20C AUX system	Mavhungu [211]
Kirario	*Leuconostoc mesenteroides* ssp., *mesenteroides/detranicum, Leuconostoc citreum, Lactococcus lactis* ssp. *lactis, Lactococcus raffinolactis, Lactobacillus plantarum, Lactobacillus brevis, Lactobacillus collinoides,* and *Lactobacillus coprophilus* (API 50 CH strips, API 50 CHL medium)	Kunyanga [212]
Ting	*Lactobacillus pentosaceus, Lact. plantarum, Lact. pentosaceus, Lact. cellobisus, Leuconostoc mesenteroides, Lact. collinoides, Lact. brevis, Lact. fermentum,* and *Lact. curvatus* (PAGE, API 50CHL medium and API 50CH strips)	Mavhungu [211]

the most dominant yeasts in the fermentation of the substrates [236]. While *Saccharomyces cerevisiae* var. *carlbergenisis* is associated with beer production, *Schizosaccharomyces pombe* has been found to degrade malic acid into ethanol and carbon dioxide and has been used successfully to lower the acidity in the grape and plum musts [237].

(2) Molds. Molds are white, delicate, fluffy, cottony masses suspended in alcoholic and nonalcoholic beverages. Their spores cannot grow in carbonated beverages but can survive. The most beverage contaminating molds found to be associated with alcoholic and nonalcoholic beverages are *Aspergillus ochraceus, A. tamarii, A. flavus, Byssochlamys nivea, B. fulva, Paecilomyces variotii, Neosartorya fischeri, Eupenicillium brefeldianum, Phialophora mustea, Talaromyces flavus, T. trachyspermus,* and *T. aurantiacum.* Others include *Penicillium notatum, P. roqueforti, Rhizopus, Fusarium,* and *Cladosporium* spp. [232, 233].

Molds are equally essential microorganisms in food processing, preservation, and spoilage. The majority of the species have the ability to produce enzymes of commercial importance such as pectinase by *Aspergillus niger* [238]. *Aspergillus* species have been linked to the generation of citric acid from waste materials such as apple pomace [238, 239]. These species are frequently responsible for undesired changes in foods that lead to spoiling, whereas *Penicillum* species are involved in cheese ripening and flavor development. While *Ceratocystis* species are important in fruit flavor synthesis, *Penicillium* is the causal agent for toxin formation such as patulin [240].

4.1.3. Pathogenic and Spoilage Microorganisms. Beverages have high water activity and are often rich in nutrients including vitamins and minerals so they are highly susceptible to microbial contamination and spoilage. Potential microbes that can contaminate foods and beverages could include species of bacteria and fungi. Bacterial species could be *E. coli, Salmonella, Shigella,* and *Staphylococcus* [241], while fungal contaminants could be several species of *Aspergillus* and *Saccharomyces* [242]. These spoilage microbes are well reported to be identified with fermented food and beverages [243, 244]. Microbial analysis of "Ikigage," a traditional fermented beverage of Rwanda revealed several species of spoilage microbes including lactic acid bacteria, *E. coli, fecal streptococci, Staphylococcus aureus*, yeast, and molds [92]. In "pito," Minamo et al. [245] reported *Staphylococcus aureus*, *E. coli, B. subtilis, Streptococcus* species, *Proteus* species, *Rhizopus stolonifer, Aspergillus flavus, Aspergillus niger, Saccharomyces cerevisiae*, and *Mucor* species as the predominant spoilage microorganisms contaminated the beverage. Their presence in the beverage was as a result of improper handling during the production [245]. Even in the acid environment, yeasts could contaminate foods and beverages leading to spoilage by producing film, causing color changes and off-flavor [88]. *Candida krusei, Candida pelliculosa*, and *Candida lipolytica* were the main causes of *shalgam* beverage spoilage [88]. *E. coli* [246] and *Salmonella typhi* [247] were also recorded as the major spoilage bacteria in shalgam.

Pathogens are disease-causing organisms found in food. They may include bacteria, viruses, and parasites and have the potential to cause illnesses and even death [248]. *E. coli* 0157:H7, *Salmonella enterica, Listeria monocytogenes, Yersinia enterocolitica,* and *Staphylococcus aureus* were found to be the most predominant food pathogens contaminating several beverages [249–253]. The traditional techniques of production and marketing by the local producers or traders expose the beverage to pathogenic and spoilage microbes. Specifically, species of pathogenic microbes such as *E. coli, S. typhimurium, S. aureus, L. monocytogenes C. albicans,* and other *Enterobacteriaceae* were found to be associated with several fermented beverages [254, 255].

Again, several factors could make food and beverages liable to microbial contamination and spoilage. Food and beverages are easily contaminated by spoilage microorganisms during the production process, by the production environment, raw materials for production, water and other additives, processing equipment, poor hygienic handling, packaging materials, and storage conditions [256–258]. It is however required that food handlers must observe strict hygiene protocols in the food value chain, particularly, during food preparations.

5. Quality Issues of Cereal-Based Traditional Fermented Beverages

Traditional cereal-based fermented foods and beverages have been produced and consumed since the inception of civilization [259]. Traditional foods and beverages produced through fermentation serve several purposes. However, it was majorly and currently used for preservation and safety through the production of inhibitory metabolites by microbial communities associated with the fermentation process [260]. When LAB and yeasts are added as starters or dominate the spontaneous fermentation process, bacteriocins, and other organic acids are produced to eliminate the pathogenic and spoilage organisms to ensure the safety of the final products [125]. There have been several concerns about food safety due to microbial contaminations leading to outbreaks of food-borne illnesses. LABs are capable of acidifying fermented products and are also able to produce acetic aroma compounds, bacteriocins, enzymes, and exopolysaccharides when considered for controlled fermentation as one of the natural surest ways of addressing all safety issues regarding fermented products [125, 261]. Therefore, this section is to review all the safety issues concerning the fermented beverages.

5.1. Microbiological Safety Issues. Factors not limited to the use of different raw materials, production techniques, microbial community, and fermentation conditions have greatly influenced the final traditional fermented beverages. However, consumers are currently aware of maintaining strong immune systems to avoid diseases and are seriously searching for food products which could assist them maintain their health status and preventing health-related problems [100]. There are different types of traditional fermented beverages produced and used worldwide, particularly in Africa. The fermentation of these beverages is spontaneously done which involves diverse microbial communities (bacteria, yeasts, and molds) thereby determining the qualities of the final beverages [7]. The diversity of microbial communities in cereal-based fermented alcoholic and nonalcoholic beverages in Africa are summarized in Tables 5 and 6, respectively. For this reason, the safety of traditional fermented beverages raises so much concerns.

However, the initial development of the acidifying bacteria plays a key role of regulating the microbial communities in the beverage. The involvement of species of LAB either by natural process or added as starters prevents the growth and existence of microbial pathogens in the final beverage [262, 263]. The food pathogens that are aerobes and facultative anaerobes and ferment simple sugars can grow at pH between 4.3 and 9, but combining growth factors such as pH and water activity can prevent the growth of food-borne pathogens [190] to ensure the safety of the products. Moreover, the major problems observed with the production of traditional fermented beverages include unhygienic processing environments coupled with highly variable production techniques. Since the soaking and the malting parameters vary within and between processors [45], the grains can easily be infected by fungi with aflatoxin contamination potentials (aflatoxins) [264].

Nonetheless, to ensure that traditional fermented beverages are safe by all standards, several studies have been conducted to keenly select microorganisms with probiotic potential as starter cultures for control fermentation [259, 265]. Examination of enterocin-producing *Enterococcus faecium* YT52 pose low or no risk to the health of the consumers; hence, it could be used as starters to inhibit the growth of food pathogens, thereby making the spontaneous fermented products safe for consumption [100]. To buttress this point, Arslan-Tontul and Erbas [266] used *Enterococcus faecium* YT52 to completely prevent the growth of *Listeria monocytogenes* and *Bacillus cereus.* The LAB strains such as *Lactiplantibacillus plantarum* IL4l1, *L. plantarum* A1MM10, *Lactococcus lactis* IL5l1, *Leuconostoc lactis* A1MS3, *Lc. pseudomesenteroides* IL5l2 and *Pediococcus pentosaceus* S0l10 were also used to inhibit the growth of several species of *Enterobacteriaceae* in Atole *agrio*, a traditional Mexican fermented beverage [267]. Studies have published the effectiveness of low pH caused by LAB against food pathogens [262, 267]. *Lactococcus lactis* A1MS3 and *P. pentosaceus* S0l10 were used to ferment *Atole agrio* and a plant-based fermented food, respectively, due to their strong antimicrobial properties against *Enterobacteriaceae* [267, 268].

Furthermore, due to proven probiotic effects and disease prevention abilities of the traditional fermented beverages, they are receiving much attentions by both researchers and consumers [269]. These health benefits are strongly linked to high probiotic microbial contents in the fermented beverages. As a result of the presence of probiotic LAB, the traditional fermented beverages have the potentials to improve gastrointestinal health status of the consumers [48]. Consumption of these beverages improves liver function, levels of *Lactobacilli* and *bifidobacteria* in the intestinal microbiota, a balanced gut microbiota, and the avoidance of bacterial translocation, which leads to a reduction in nosocomial infections [269]. They also have the potentials to remove antinutrient compounds, mycotoxins, endogenous toxins and cyanogenic compounds and enhance bioavailability making these beverages safe for consumption [270]. Moreover, due to the presence of the varieties of lactic acid bacteria metabolites, the consumption of these beverages confers bactericidal, bacteriolytic, and bacteriostatic properties, resulting in therapeutic effects at a digestive level. These antimicrobial compounds found in the fermented beverages exhibited activities against several species of bacteria including pathogenic yeasts and molds [269, 271].

5.2. Nutritional Issues. The nutritional properties of cereal-based traditional fermented beverages depend largely on the raw materials and other ingredients used in the production [272]. They then reported carbohydrates, protein, potassium, magnesium, and phosphorus as the key nutritional contents of *amahewu*. Similar studies by Fadahunsi and Soremekun [60], Olusanya et al. [273], and Qaku et al. [274] identified improved proximate and mineral compositions in maize and sorghum-fortified *amahewu*. Varying the production processes such as the periods of soaking, fermentation times, and terminating fermentation at different pH values revealed different nutritional compositions of *amahewu* [274]. According to Fernandes et al. [275], Mckevith [276] and Brennan and Cleary [277] cereals are the major sources of macronutrients and minerals, phytochemicals, and antioxidants in cereal-based fermented beverages. These beverages are able to exert probiotic effects due to the water-soluble fibre in the raw materials [277]. They are excellent media for the transportation of nutrients and bioactive compounds into the human body (the consumer) [278]. Vitamins B & E and many minerals (Ca, Mg, Mg, Fe, and Zn) are required for proper functioning of the body and are found in cereals [279].

Additionally, apart from improved digestibility, functional and sensory properties, fermentation is largely used for nutritional enhancement, particularly in cereal-based fermented products [269, 280–282]. Most African-fermented beverages are basically fermented and produced from cereals [109]. Traditional fermented beverages are important to the human body because they play key roles in human health and for their nutritional, nutraceutical, and pharmaceutical properties [125, 263, 283, 284]. Consumption of cereal-based fermented beverages improves the bioavailability of both macro and micronutrients [109]. They are rich sources of vitamins of all kinds, fibre, flavonoids, phenolic compounds, antioxidants, omega-3 fatty acids, amino acids, and biopeptides [285].

Again, the proximate composition of *borde* includes high amounts of ash, fat, protein, and carbohydrate [286]; *tej* and *grawa* contain equally high amounts of protein, carbohydrate, fat, and few minerals [287]. *Mabisi* and *Munkoyo*

(Zambia) have high values of vitamins B1, B2, B3, calcium, protein, and zinc [288].

Furthermore, cereal grains are essential in transporting organs for nutrients and bioactive compounds into the bodies of consumers and also facilitate the availability of these compounds. These bioactive compounds are phytochemicals (phytoestrogens, phenolic compounds, flavonoids, and carotenoids), dietary fibre, vitamins, fatty acids, probiotics, and minerals which are readily available in cereal-based fermented beverages and essential compounds for disease control [100].

Furthermore, LAB in fermented cereal-based meals and beverages release various B vitamins, including niacin (B3), pantothenic acid (B5), folic acid (B9), as well as vitamins B1, B2, B6, and B12 [3]. Folates, for example, prevent neural tube abnormalities in infants and protect against cardiovascular disease and various malignancies by acting as co-factors in metabolic events [3]. Hence, the consumption of fermented beverages is of great important to human.

5.3. Sensory Issues. The purpose of fermentation is not only to preserve, and improve the nutritional values of the products, and make the products safe for consumption but rather also to enhance the organoleptic qualities of the final products desired by the consumers. The sensory characteristics of fermented beverages are equally important as the nutritional values are essential from the consumers' point of view since they determine whether or not the consumers will patronize a particular food product despite their nutritional values [272].

For instance, consumers reject *amahewu* enriched with *Aloe vera* leaf powder due to its bitterness [271]. Despite the nutritional compositions of *amahewu* fortified with *Moringa oleifera* leaf powder, it was poorly rated by the sensory panelists as compared to the conventional *amahewu* [273]. Again, Awobusuyi and Siwela [289] and Awobusuyi et al. [290] discovered that adding processed bambara groundnut flour to *amahewu* manufactured from provitamin A biofortified maize and white maize samples enhanced sensory characteristics when compared to *amahewu* made without bambara groundnut flour. Oyeyinka and Oyeyinka [291] added that in the move to improve the nutritional properties of fermented food and beverages, the organoleptic characteristics must be highly upheld. The characteristics of traditional fermented food and beverages including organoleptic properties are impacted by a number of factors not limited to production technologies and metabolic reactions of microbiota associated with the products [292].

Moreover, during cereal fermentation, different microbial metabolites such as lactic, acetic, oleic, and linoleic acids, esters, higher alcohols and aldehydes, ethyl acetate, and diacetyl are synthesized which were identified to have had a significant influence on the shelf-life and the sensorial properties of fermented products [293]. The color, flavor, aroma, appearance, taste, and texture differ from beverage to beverage depending on the raw materials or qualities of the raw materials involved and are essential for their acceptability [294]. For instance, the sensory properties such as taste, aroma and color of *gowe* (a sorghum-based beverage) fermented with only *Limosilactobacillus fermentum* and in combination with *Kluyveromyces marxianus* rated far higher than the spontaneous fermented *gowe* [295]. The aroma and taste of *Brevilactobacillus brevis* and *Saccharomyces cerevisiae* fermented *obushera* were more acceptable than the naturally fermented *obushera* [296]. However, there was no significant difference in the aroma, texture, color and appearance of *ogi* fermented with *Lactiplantibacillus plantarum, Kluyveromyces marxianus* singly and spontaneously fermented *ogi* [297]. Similarly, the sensory panelists also rated the taste and flavor of spontaneously fermented *akamu* and *L. plantarum* fermented *akamu* above *akamu* fermented with both *Lactiplantibacillus plantarum* and *Kluyveromyces marxianus* [297]. These incidences might be as a result of over fermentation leading to over acidification.

Salmeron [93] indicated that volatile compounds produced by microbial communities involved in fermentation have considerable impacts on the sensory properties of food products. He therefore concluded in his report that the starter organism used during the fermentation affected the aroma profile of the grains significantly, but each grain substrate has a unique aroma profile. Again, the organic compounds such as aroma and flavor synthesized after barley and malt substrates which were fermented by single starters of *L. acidophilus*, *Limosilactobacillus reuteri, and Lactiplantibacillus plantarum* were uniquely enhanced for each of them as compared to the spontaneously fermented substrates [93]. Hence, the amount and the types of organic compounds produced by the microbial communities involved in the fermentation together with the types of raw materials used and the duration of fermentation determine the organoleptic qualities of the final traditional fermented beverages.

6. Conclusion

Despite the fact that the same raw materials are used during the production of traditional fermented beverages, the preparation varies significantly from ethnic group to ethnic group. The review of these beverages revealed maize, millet, and rice were the major cereals used as the raw materials for the production of these traditional beverages. *Binuburan, amgba beer, tchoukoutou, sake, dolo*, and *pito* were identified as the major alcoholic traditional fermented beverage; while *aliha, mahewu, kunun-zaki, ting, borde,* and *bushera* were traditional fermented nonalcoholic beverage. The fermentation of these beverages was achieved through spontaneous fermentation (*burukutu, mahewu, sake, kirario, mawe, ikegage,* and *ikivunde*), back-slopping (*amba beer, tchoukoutou,* and *dolo*), and the use of industrial techniques (*pito, Bantu beer,* and *Bhaati Jaanr*). Moreover, the dominant microbial species typical of the traditional fermented beverages identified in this review so far were *Limosilactobacillus fermentum, Brevilactobacillus brevis, Lactiplantibacillus plantarum, L. delbrueckii*; *Lactococcus* (*Lact. lactis, Lact. curvatus,* and *Lact. pantheris*), *Leuconostoc* (*Leuc. mesenteroides* and *Leuc. paracasei*); and *Pediococcus* (*P. pentosaceus, P. acidilactici*); fungi (*Saccharomyces,* *Candida, Aspergillus,* and *Rhizopus* spp.); and other bacterial species (*Acetobacter, Pseudomonas, Klebsiella, Weissella, Achromobacter, Flavobacterium, Micrococcus,* and *Bacillus* spp.).

However, the nutritional composition of these beverages cannot be overemphasized. They were found to have sensory properties such as good taste, flavor, acidity, digestibility, and texture in both alcoholic and nonalcoholic beverages. Most of these beverages were found to be rich in calories, and B-group vitamins including thiamine, folic acid, riboflavin, and nicotinic acid. However, due to microbial quality issues associated with spontaneously fermented beverages, defined starter cultures or industrial processing techniques are recommended for the production of these beverages, since they improve the microbial, sensory, and nutritional qualities of the final products [298, 299].

Data Availability

The data used for the findings of this study are included in the article.

Additional Points

Highlights. (1) The major production technique used was spontaneous fermentation. (2) The dominant raw materials identified for the production were maize and millet. (3) LAB and fungi were the major microbiota involved in the fermentation. (4) These beverages are rich in proteins, carbohydrates, calories, and B-group vitamins.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

FKM designed the topic and wrote the manuscript. APHK, KTD, and FKS approved the topic, supervised, and reviewed the manuscript. FKM, APHK, and KU formatted and revised the manuscript.

Acknowledgments

The authors acknowledge the research skills they received from The World Academy of Science (TWAS) at the University of Zululand, South Africa. We also acknowledge the financial supports from the University of Ghana Research Funds (UGRF) and Pan-African Doctoral Academy (PADA) under the "Building a New Generation of Academics in Africa (BANGA-Africa)" University of Ghana chapter.

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