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

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Traditional fermented beverages are culturally and socially accepted products for consumption, drinking, 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.

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], tcchapol 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
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. *Amsgba.* Amsgba 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 amsgba. 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
been described by Kayodé et al. [31]. The malt of any of the raw materials preferred for the production is milled into a fine 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 h fermentation. Dolo beer is opaque, with a red color, and an alcohol content of 2–4% [34].

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.

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
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.

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.
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.

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

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

### 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.

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

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

<table>
<thead>
<tr>
<th>Products</th>
<th>Defined starters</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sourdough</td>
<td><em>Lactobacillus</em> species including: <em>brevis</em>, <em>hilgardii</em>, <em>sanfranciscensis</em>, <em>farciminis</em>, <em>fermentum</em>, <em>plantarum</em>, <em>amylovorus</em>, <em>reuteri</em>, <em>pointis</em>, <em>panis</em>, <em>alimentarius</em></td>
<td>Palla et al. [176]</td>
</tr>
<tr>
<td>Kimchi</td>
<td><em>Leuconostoc mesenteroides</em>, <em>Lactobacillus plantarum</em>, <em>Weissella kimchi</em> and <em>koreensis</em>, <em>Companilactobacillus kimchi</em> and <em>Lactobacillus sakei</em></td>
<td>Choi et al. [177]; Lee et al. [178]; Muyanja et al. [35]</td>
</tr>
<tr>
<td>Bushera</td>
<td><em>Lactobacillus</em> species such as <em>plantarum</em>, <em>paracasei</em> ssp. <em>paracasei</em>, <em>fermentum</em>, <em>brevis</em>, <em>debrueckii</em> ssp. <em>debrueckii</em> and <em>Streptococcus thermophilus</em></td>
<td>Nuraida et al. [179]</td>
</tr>
<tr>
<td>Pozol</td>
<td><em>Leuconostoc mesenteroides</em>, <em>Lactiplantibacillus plantarum</em>, and <em>W. confused</em>; <em>Lactococcus lactis</em> and <em>raffinolactis</em></td>
<td>Florou-Paneri et al. [180]</td>
</tr>
<tr>
<td>Bread</td>
<td><em>Fructilactobacillus sanfranciscensis</em>, <em>Leuconostoc citreum</em> and <em>Weissella cibaria</em></td>
<td>Alfonzo et al. [181]</td>
</tr>
<tr>
<td>Sato</td>
<td><em>Rhizopus oligosporus</em>, <em>Mucor racemosus</em>, <em>Saccharomyces cerevisiae</em>, <em>Saccharomycopsis fibuligera</em>, and <em>Pichia anomala</em></td>
<td>Gabaza et al. [20]</td>
</tr>
<tr>
<td>Enturire</td>
<td><em>Lactiplantibacillus plantarum</em> MNC 21 combined with <em>Saccharomyces cerevisiae</em> MNC 21Y, and <em>L. plantarum</em> MNC 21 combined with <em>Weissella confusa</em> pH MNC 20 and <em>Saccharomyces cerevisiae</em> MNC 21Y</td>
<td>Mukisa et al. [182]</td>
</tr>
<tr>
<td>Bushera</td>
<td><em>W. confuse</em>, species of (<em>Lactobacillus paracasei</em>, <em>Limosilactobacillus fermentum</em>, <em>Brevilactobacillus brevis</em> and <em>Lactiplantibacillus plantarum</em>)</td>
<td>Muyanja et al. [183]</td>
</tr>
<tr>
<td>Togwa</td>
<td><em>Brevilactobacillus brevis</em>, <em>L. cellobiosus</em>, <em>Limosilactobacillus fermentum</em>, <em>Lactobacillus fermentum</em> and <em>mucosae</em>; <em>W. confuse and kimchi</em>; <em>Pedicoccus acidilactici</em> and <em>pentosaceus</em>; <em>Kluyveromyces marxianus</em>, <em>Pichia anomala</em>; <em>Candida krusei</em> and <em>tropicalis</em></td>
<td>Mugula et al. [184]</td>
</tr>
<tr>
<td>Gowe</td>
<td><em>Lactobacillus fermentum</em>, <em>brevis</em>, and <em>plantarum</em>; <em>Yeast such as S. Cerevisiae</em>, <em>Rhodotorula graminis</em>, <em>Candida krusei</em> and <em>tropicalis</em>, <em>Geotrichum candidum</em>, <em>Geotrichum fermentum</em></td>
<td>Vieira-Dalode et al. [185]</td>
</tr>
<tr>
<td>Ogi</td>
<td><em>Lb. fermentum</em>, <em>Lb. brevis</em>, <em>C. krusei</em>, <em>S. Cerevisiae</em></td>
<td>Omem et al. [186]; Teniola and Odunfa [187]</td>
</tr>
<tr>
<td>Kenkey</td>
<td><em>Lb. fermentum</em></td>
<td>Olsen et al. [188]</td>
</tr>
</tbody>
</table>
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 Lactobacillli (Lactiplantibacillus fermentum, Brevilactobacillus brevis, Lactiplantibacillus plantarum, and delbrueckii), followed by Lactococci, Leuconostoc, and Pediococci with the least being Streptococci (Streptococcus bovis). Lactobacilli 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 with 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, Lactobacillaceae, and Streptococcaceae are the six families defined by Parte [216]. Out of the six families, Enterococcaceae, Leuconostocaceae, Lactobacillaceae, 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, vaccinosterus, 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, Lattlactobacillus 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. kruzei, C. tropicalis, Geotrichum candidum, Hansenula anomala, Klocekera apiculata [122], Pichia membranifaciens, P. ohmeri, Saccharomyces chevalieri, S. uvarum, Kluyveromyces africanus, Torulaspora delbrueckii and Rhodotorula 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. ellipsoides is employed extensively in beverage (wine) production [235]. For beverages produced with maize and millets, Schizosaccharomyces pombe and S. boulardi have been identified as
### Table 5: Microorganisms involved in the fermentation processes of African traditional fermented alcoholic beverages.

<table>
<thead>
<tr>
<th>Beverage</th>
<th>Microorganisms/taxonomic tool</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>Pito (maize/sorghum)</td>
<td>L. fermentum, Candida spp. Lactococcus delbrueckii, Pediococcus acidilactici, Lactobacillus lactis, and Leuconostoc lactis (cultural, morphological, and biochemical characterization)</td>
<td>Sanni et al. [192]</td>
</tr>
<tr>
<td>Bantu beer (maize/sorghum)</td>
<td>Saccharomyces cerevisiae, Candida spp., L. plantarum, L. fermentum, L. brevis</td>
<td>Dirar [194]</td>
</tr>
<tr>
<td>Amgba (sorghum and millets)</td>
<td>Cryptococcus albicus var albicus, C. melibiosica, Debaryomyces hansenii var hansenii, Dekkera bruxellensis, Rodotorula mucilaginosa and Torulaspora delbrueckii, Saccharomyces cerevisiae, lactic acid bacteria (PCR/RFLP, partial sequencing of 16S of rDNA) Saccharomyces fibuligera, Rhizopus spp., Mucor spp., Pediococcus pentosaceus and anomala, L. bifermens, Mucor circinelloides, Rhizopus chinensis and stolonifer, Saccharomyces cerevisiae, Candida glabrata. (Cultural, MBC) Amylomyces rouxii, Rhizopus oryzae, Endomycopsis fibuligera, S. cerevisiae, Enterococcus facalis, P. pentosaceus (biochemical tests, API 50 CHL)</td>
<td>Nanadoum et al. [30]</td>
</tr>
<tr>
<td>Kodo ko jaanr (millet, barley)</td>
<td></td>
<td>Prakash Tamang and Thapa [195]</td>
</tr>
<tr>
<td>Bhaati jaanr (rice)</td>
<td></td>
<td>Nout [196]</td>
</tr>
<tr>
<td>Tchoukoutou (sorghum, millet, maize)</td>
<td>Rhizopus, Mucor, Aspergillus spp., acetic acid bacteria, lactic acid bacteria, bacilli, Saccharomyces, Candida, Hansenula spp. Saccharomyces fibuligera, Rhodotorula glutinis, Debaromyces Hansenii, Candida parapsilosis, Trichosporon fennicum, and LAB including Leuconostoc spp. (cultural, morphological and biochemical characterization)</td>
<td>Prakash et al. [31, 197]</td>
</tr>
<tr>
<td>Merissa (sorghum or millet)</td>
<td></td>
<td>Sanni et al. [192]; Jespersen [161]</td>
</tr>
<tr>
<td>Chibuku (sorghum)</td>
<td></td>
<td>Sanni et al. [192]; Jespersen [161]</td>
</tr>
<tr>
<td>Beverage</td>
<td>Microorganisms/taxonomic tool</td>
<td>Reference</td>
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<tr>
<td><strong>Dolo (sorghum)</strong></td>
<td>Saccharomyces cerevisae, Candida inconspicua, Issatchenka 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)</td>
<td>Jespersen [161]; Sawadogo-Lingani et a. [36, 199]</td>
</tr>
<tr>
<td><strong>Tchapalo (sorghum)</strong></td>
<td>Leuconostoc mesenteroides subsp. mesenteroides, Leuconostoc mesenteroides subsp. dextranicum, Weissella confusa, and L. plantarum (API 50 CHL and ID 3 2C)</td>
<td>Sanni et al. [192]; Muyanja et al. [35]</td>
</tr>
<tr>
<td>Ogi (maize, sorghum, millet)</td>
<td>Cryptococcus albidius var albidius, Candida melibiosica, Debaryomyces hansenii var hansenii, Dekkera bruxellensis, Rhodotorula mucilaginosa, Tordilagora delbrueckii(S), S. cerevisiae and S. paradoxus (PCR/RFLP, partial sequencing of 26S of rDNA and sequences) (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. corynformis, 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)</td>
<td>Nanadoum et al. [34]</td>
</tr>
<tr>
<td>Bili bili (maize, sorghum, millet)</td>
<td>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 fuarius. (API 50 CHL and API 20E media.sequences)</td>
<td>Nanadoum et al. [34]</td>
</tr>
<tr>
<td>Boza (millet, maize, wheat, and rice)</td>
<td>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 fuarius. (API 50 CHL and API 20E media.sequences)</td>
<td>Heperkana et al. [201]; Hancioglu and Karapinar. [202]; Tamer et al. [203]; Botes et al. [204]</td>
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</tbody>
</table>
Table 5: Continued.

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

Note. MBC, morphological and biochemical characterization.
<table>
<thead>
<tr>
<th>Beverage</th>
<th>Microorganisms/taxonomic tools</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koko/akassa</td>
<td><em>Lactobacillus fermentum</em>, (Lb. cellobiosus, Lb. brevis, Lb. curvatus, Lb. buchneri, and Weissella confusa), pediococci and yeasts such as Candida krusei, Candida kefyr, Candida glabrata, Saccharomyces cerevisiae</td>
<td>Nout [32]</td>
</tr>
<tr>
<td>Togwa</td>
<td><em>L. fermentum</em>, <em>L. cellobiosus</em>, <em>P. pentosaceus</em>, <em>W. confusa</em> <em>Issatchenkia orientalis</em>, <em>C. pelliculosa</em>, <em>C. tropicalis</em>. (biochemical tests, API tests)</td>
<td>Vasudha and Mishra [37]; Mugula et al. [108]</td>
</tr>
<tr>
<td>Amazake</td>
<td><em>Lactobacillus</em> spp.</td>
<td></td>
</tr>
<tr>
<td>Mahewu (amahewu)</td>
<td><em>Lactococcus lactis</em> subsp. <em>lactis</em>, <em>Lactobacillus</em>, <em>Streptococcus</em>, <em>Enterococcus</em> (cultural, morphological, and biochemical characterization)</td>
<td>Blandino et al. [55]; Gadaga et al. [207];</td>
</tr>
<tr>
<td>Kunnu zaki</td>
<td><em>Lactobacillus fermentum</em> and <em>Lactobacillus leichmannii</em>, <em>Leuconostoc</em> spp., <em>Lactococcus</em> spp.</td>
<td>Akoma et al. [208]; Agarry et al. [4]</td>
</tr>
<tr>
<td>Mageu</td>
<td><em>Sacccharomyces cerevisiae</em>, <em>Issatchenkia orientalis</em>, <em>Pichia fabianii</em>, <em>Aureobasidium pullulans</em>, <em>Candida glabrata</em>, <em>Pichia ciferri</em>, <em>Saccharomycopsis fibuligera</em>, <em>Hanseniaspora opuntiae</em>, <em>Zygoascus helenium</em>, <em>Cryptococcus flavus</em>, <em>Cryptococcus magnus</em>, <em>Candida parapsilosis</em>, <em>Candida pyralidae</em> and <em>Rhodotorula mucilaginosa</em>, <em>Lactobacillus agilis</em>, <em>L. minor</em>, <em>L. Confuses</em> and <em>L. fructosus</em>, <em>L. Minor</em>, <em>L. divergens</em>, <em>L. agilis</em> and <em>L. plantarum</em>, <em>L. bifermantans</em>, <em>L. divergens</em>, <em>L. fermentum</em>, <em>L. hilgardii</em>, <em>L. minor</em>, <em>Streptococcus</em> spp.</td>
<td>Nyanga et al. [209]; Fleet [210]</td>
</tr>
<tr>
<td>Pozol</td>
<td><em>Streptococcus</em>, <em>L. fermentum</em>, <em>L. plantarum</em>, <em>L. casei</em>, <em>L. delbrueckii</em> <em>Streptococcus bovis</em>, <em>S. macdonlicus</em>, <em>L. lactis</em>, and <em>Enterococcus sulfureus</em>. (Cultural, morphological, and biochemical characterization, RT-PCR)</td>
<td>Muyanja et al. [6]</td>
</tr>
<tr>
<td>Malwa</td>
<td><em>Lactobacillus</em> spp., <em>Lactobacillus</em>, <em>coliforms</em>, <em>Enterobacter aerogenes</em>, <em>E. sakazakii</em>, <em>E. cloacae</em>, <em>Serratia liquefaciens</em>, <em>Saccharomyces cerevisiae</em>, <em>Candida tropicalis</em>, <em>C. ciferri</em>, <em>C. guilliermondii</em>, <em>C. lipolyla</em>, <em>Kloeckera japonica</em>, <em>Rhodotorula rubra</em>, <em>Penicillium</em> spp. API 50 CHL system, API 20 system, API 20C AUX system, <em>Leuconostoc mesenteroides</em> spp., <em>mesenteroides/detranticum</em>, <em>Leuconostoc citreum</em>, <em>Lactococcus lactis</em> spp. <em>lactis</em>, <em>Lactobacillus raffinolactis</em>, <em>Lactobacillus plantarum</em>, <em>Lactobacillus brevis</em>, <em>Lactobacillus collnoides</em>, and <em>Lactobacillus coprophilus</em> (API 50 CH strips, API 50 CHL medium)</td>
<td>Mavhungu [211]</td>
</tr>
<tr>
<td>Sobia</td>
<td><em>Lactobacillus</em> spp., <em>Lactobacillus</em>, <em>coliforms</em>, <em>Enterobacter aerogenes</em>, <em>E. sakazakii</em>, <em>E. cloacae</em>, <em>Serratia liquefaciens</em>, <em>Saccharomyces cerevisiae</em>, <em>Candida tropicalis</em>, <em>C. ciferri</em>, <em>C. guilliermondii</em>, <em>C. lipolyla</em>, <em>Kloeckera japonica</em>, <em>Rhodotorula rubra</em>, <em>Penicillium</em> spp. API 50 CHL system, API 20 system, API 20C AUX system, <em>Leuconostoc mesenteroides</em> spp., <em>mesenteroides/detranticum</em>, <em>Leuconostoc citreum</em>, <em>Lactococcus lactis</em> spp. <em>lactis</em>, <em>Lactobacillus raffinolactis</em>, <em>Lactobacillus plantarum</em>, <em>Lactobacillus brevis</em>, <em>Lactobacillus collnoides</em>, and <em>Lactobacillus coprophilus</em> (API 50 CH strips, API 50 CHL medium)</td>
<td>Mavhungu [211]</td>
</tr>
</tbody>
</table>
the most dominant yeasts in the fermentation of the substrates [236]. While Saccharomyces cerevisiae var. carlsbergensis 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. trachypermus, 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 Penicillium species are involved in cheese ripening and flavor development. While Ceratozystis species are important in fruit flavor synthesis, Penicillium is the causative 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 “Igikage,” a traditionally 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 lipoiytica 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, 265]. 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 IL3l1, 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, 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, carbohy- drate, 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 [5]. 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 microorganisms 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 spontaneously 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 alilha, mahewu, kunun-zaki, ting, borde, and bushera were traditional fermented nonalcoholic beverage. The fermentation of these beverages was achieved through spontaneous fermentation (buruku, mahewu, sake, kirario, mawe, ikegaye, and ikivunde), back-slopping (amba beer, tchoukoutou, and dolo), and the use of industrial techniques (pito, Bantu beer, and Bhaati jaan). 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. delbruecki; 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.

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