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Review

Non-Alcoholic Fermentation of Maize (*Zea mays*) in Sub-Saharan Africa

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Abstract: Maize, together with its fermented products, is fundamental for human nutrition and animal feed globally. Non-alcoholic fermentation of maize using lactic acid bacteria (LAB) is one of the food preservation methods that has been utilised throughout the centuries and has played a vital role in the manufacturing of many fermented beverages consumed these days. However, the coincidence of LAB and yeasts during the spontaneous fermentation of maize-based products is inevitable. The involvement of other microorganisms such as moulds, *Bacillus* species and acetic acid bacteria in the fermentation of maize is important to the characteristics of the final product. Fermented beverages are affordable, have been produced traditionally and are known for their organoleptic properties, as well as their health-promoting compounds. The consumption of non-alcoholic beverages has the prospect of reducing the detrimental health and economic effects of a poor diet. Different fermented maize-based gruels and beverages such as ogi, *mawe*, *banku* and kenkey in West Africa, *togwa* in East Africa, as well as mahewu in South Africa have been documented. The physical and biochemical properties of most of these maize-based fermented products have been investigated and modified by various researchers. Attempts to enhance the nutritional properties of these products rely on supplementation with legumes to supply the insufficient amino acids. The production technology of these products has evolved from traditional to industrial production in recent years.

Keywords: maize; fermentation; lactic acid bacteria; *mahewu*; *ogi*; beverages

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1. Introduction

Cereal grains, such as maize (*Zea mays*), sorghum (*Sorghum vulgare*) and rice (*Oryza sativa*), as well as various minor grains, such as the millets, mainly pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), fonio (*Digitaria exilis-acha* and *D. iburua-iburu)* and teff (*Eragrostis teff*), are of great importance in Africa [1–3]. Cereal grains are estimated to be accountable for about 77% of total calorie intake in most African countries [4]. Moreover, cereal grains are rich sources of carbohydrates, protein, dietary fibre and B complex vitamins, as well as minerals. Whole grains contain principal polyphenolic compounds and have high nutritional properties; therefore, frequent consumption of whole grains has a beneficial influence on health [5,6]. The availability of soluble fibre in cereal grains decreases the glycaemic index of non-alcoholic fermented beverages since fibre slows down their digestion as well as their absorption. Moreover, phytochemicals possess antioxidant potential, thereby scavenging toxic free radicals in the body [7]. The majority of conventional maize-based non-alcoholic beverages are consumed in Africa and largely produced by spontaneous fermentation [4]. Lactic acid bacteria (LAB) predominate during spontaneous fermentation, resulting in a low pH, which prevents the proliferation of pathogenic microorganisms in the beverage, thus improving its shelf life and safety [8].

Generally, the spontaneous fermentation of cereal grains reduces the amounts of carbohydrates and non-digestible poly- and oligosaccharides. Furthermore, the coalescence of amino acids and improvements in the bioavailability of the vitamin B complex might take place [9]. Recently, there has been a significant rise in the number of reports that describe the fermentation process globally, including microorganisms that ferment maize products, especially in Africa and Latin America [10]. The fermentation processes improve cereal grains via different processing steps, through the involvement of endogenous enzymes such as amylases, proteases and phytases, as well as microbial enzymes that come from LAB and yeasts [11]. The majority of the nutrients obtained in cereal grains are utilised by microorganisms and their metabolism is an important factor in the modulation of microbial diversity, as well as the activity of the fermented maize. Moreover, microbiological studies have demonstrated that bacteria and yeast produce various orders of metabolites that are present for all members of the community during spontaneous fermentation [10].

Fermentation is a simple and affordable strategy for improving the nutritional properties of maize-based products and decreasing their antinutritional factors [12]. Fermentation is endorsed as a natural method that preserves and enhances digestibility, eliminates undesirable components, prevents spoilage microorganisms and improves the nutritional value of food and beverages [13]. Fermented products have a desirable shelf life because of the preservative influence of the fermentation process and it also improves palatability and bioavailability, providing acceptable sensory properties that influence flavour, aroma and texture, as well as improving the beneficial health-promoting compounds in food [14,15]. With regards to the most familiar microflora found in fermented maize products, LAB normally generates enzymes that disintegrate polysaccharides or other compounds with high molecular weight, as well as organic acids and compounds such as bacteriocins and hydrogen peroxide that eliminate or decrease the activity of spoilage microorganisms [16]. In addition, LAB increases the free amino acid content and B complex vitamins enhance the bioavailability of minerals such as calcium, iron and zinc because they break down antinutritional factors, as well as producing gas and other volatile compounds that contribute to the organoleptic characteristics of the final product [9].

On the other hand, yeasts supply vitamins and soluble nitrogen as growth factors for LAB and also generate different extracellular enzymes, such as lipases, esterases, amylases and phytases, most of which take part in the development of the flavour and aroma of fermented maize [17]. Yeasts generate a broad range of volatile compounds, such as aldehydes, ketones, alcohols and esters that enhance the sensory properties of the fermented maize product, including contributing to decreasing the proliferation of mould and the germination of spores, as in the matter of ethyl acetate [18]. During the fermentation of maize, as occurs in other non-inoculated fermentations, microbial species compete for substrates, acid tolerance and syntrophic interchange, as well as other physiological characteristics, and these contribute to rapid alterations in the structure of the microbiota [10]. Nevertheless, dough and beverages made from fermented maize have a solid microbial association and interactions among various species that exhibit interdependence can result in the concurrence of some of microorganisms [19].

The most studied cereal gruels produced from maize are *ogi* and *akasa*/*koko* in West Africa, *uji* in Kenya, *mahewu* in southern Africa and *abreh* in Sudan. *Ogi*, a non-alcoholic fermented cereal porridge or gruel which can be produced from maize, sorghum or millet is common in West Africa, serving as an important weaning food for infants [20]. However, other age groups also consume the weaning porridge. *Ogi* is introduced to infants that are about 9 months old by feeding them once a day to supplement breast milk. *Uji* is another non-alcoholic fermented beverage that is manufactured from the suspension of maize, sorghum, millet or cassava flours [1]. The customary way to prepare *uji* usually involves the mixture of flours of either maize and sorghum or millet, or cassava and sorghum or millet. *Uji* is generally used as a breakfast meal or as a refreshing drink throughout the day and it consists of two types, fermented and non-fermented. *Mahewu* (*amahewu*) is one of the types of non-alcoholic traditional fermented sour beverages produced from maize meals and it is consumed mostly in southern Africa, as well as in some Arabian Gulf countries [21]. It is commonly consumed by adults, although it is sometimes utilised as a weaning food for infants. *Mahewu* is known by different names in South Africa, such as '*amahewu*' in Zulu, '*amarehwu*' in Xhosa, '*emahewu*' Swati, '*metogo*' in Southern Sotho (Sepedi), '*machleu*' in Northern Sotho and '*mabundu*' in Venda. However, the beverage is better known as *mahewu* [22,23]. *Mahewu* is mainly produced in southern Africa but it is also associated with traditional LAB-fermented products such as *ogi* and *uji* in Nigeria and Kenya.

2. Structure and Composition of Maize Grains

Maize (*Zea mays* L.) is one of the principal staple cereal grains consumed as part of a daily diet by the majority of people globally, together with wheat and rice [24]. Maize has a high energy value and is utilised as human food, animal feed and fuel; it is very rich in dietary fibre and deficient in protein, with low fat and sodium contents [25,26]. The structural components of the maize kernel consist of four major classes: the endosperm, the germ or embryo, the pericarp and the pedicel and these components have different compositions. The endosperm (about 85%) is the largest component of the maize kernel, followed by the germ and pericarp, with 10% and 6%, respectively. The endosperm predominantly consists of starch (70–73%) and low amounts of protein (8–10%) [27]. This makes maize a good substrate for fermentation because of starch, which is embedded in a protein matrix. Floury and horny are two types of endosperm in maize kernels. Floury endosperm has starch granules that are loosely packed and bound to the central fissure, whereas horny endosperm contains smaller starch granules that are tightly packed around the periphery. The fat content is high in the germ and is around 33%; protein is also very high (19%), along with minerals [28].

In terms of nutrition, the protein of maize lacks essential amino acids, such as lysine and tryptophan [29]. Moreover, maize contains different bioactive compounds, such as phenolic acids, flavonoids, anthocyanins and carotenoids, that are important in promoting health and disease prevention. Most of these bioactive compounds are agglomerated in the pericarp, aleurone layers and germ, and the endosperm contains small amounts [30]. Moreover, the pericarp has higher amounts of anthocyanin pigments, whereas the aleurone layer has low amounts.

In general, the fermentation of maize consists of four stages, whereby grains are cleaned, soaked in water overnight to soften them, grinding them while still wet, and then ferment spontaneously [10]. Maize grains are modified during the fermentation processes through several steps, in which endogenous and microbial enzymes are involved [11]. Moreover, environmental factors, such as temperature, pH, the quantity of inoculum and the fermentation period, determine the members of the maize microbiota, which are part of a complex association [10].

3. Lactic Acid Fermentation in Food and Beverages

Lactic acid bacteria are non-spore formers, forming a group of Gram-positive, anaerobic, rod- or coccus-shaped bacteria, which generate lactic acid due to carbohydrate metabolism, and lactic acid is one of the principal products of fermentation [31]. Most strains of LAB grow at pH levels between 4.0 and 4.5, whereas others grow at pH 3.2 and 9.6 [9,32]. LAB uses three main pathways to produce fermented foods, as well as developing their flavour, and this includes the fermentation of sugars (glycolysis) and the breakdown of fat and proteins (lipolysis and proteolysis) [33]. Fermentation by LAB is a habitual strategy of producing traditional food in Africa and it is the least expensive process. The fermentation of LAB is spontaneous via the activity of microorganisms available in the surrounding environment and linked to the raw materials [34]. Maize porridge and gruels, dairy products and alcoholic and non-alcoholic beverages are some of the examples of traditional fermented food in Africa, whereby LAB are utilised in the fermentation process [22]. Lactic acid-fermented gruel and porridge have gained attraction, owing to their potential action against microorganisms, their enhanced nutritional and sensory properties and their probiotic ability [35]. Microorganisms that are involved in LAB fermentation include *Lactobacillus* spp., such as *Lactobacillus brevis*, *Lactobacillus plantarum*, *Lactobacillus bulgaricus*, *Streptococcus thermophiles*, *Leuconostoc mesenteroides*, *Pediocccus cerevisiae*, *Streptococcus lactis*, *Bifidobacterium bifidus* and others.

Table 1 shows the genera of LAB involved in cereal fermentation. A study carried out by Byaruhunga [36] demonstrated that LAB-fermented beverages with pH 4.0 inhibit the proliferation of *Bacillus cereus* and other pathogens. The mechanism by which LAB-fermented beverages prevent pathogens is based on the influence of pH, although other inhibitory factors such as the generation of bacteriocins and low redox potential by LAB might be involved in the prevention of *B. cereus* [37].

Table 1. Genera of lactic acid bacteria (LAB) involved in cereal fermentation.

Genera of LAB	Cell Form	Catalase Activity	Gram (±) Reaction
Lactobacillus	Rods (Bacilli; cocobacilli)	−	+
Streptococcus	Spheres in chains (Cocci)	−	+
Pediococcus	Spheres in tetrads (Cocci)	−	+
Lactococcus	Cocci	−	+
Leuconostoc	Spheres in chains (Cocci)	−	+
Bifidobacterium	Branched rods	−	+
Carnobacterium	Cocci	−	+
Enterococcus	Cocci	−	+
Sporolactobacillus	Rod	−	+
Lactosphaera	Cocci	−	+
Oenococcus	Cocci	−	+
Vagocuccus	Cocci	−	+
Aerococcus	Cocci	−	+
Weisella	Cocci	−	+

Source [38,39]. − Negative catalase activity, + Gram positive.

Moreover, LAB provide preservative and detoxifying effects on beverages. Frequent utilisation of LAB-fermented food and beverages helps in boosting the immune system and strengthening the body in the fight against infections by pathogenic microorganisms. Fermentation by LAB provides the consumer with broadly different types of flavour, aroma and texture [22]. In addition, LAB fermentation improves the nutritional, safety and quality characteristics and the acceptability of different types of cereal based-food and beverages [9,40].

Lactic acid bacteria fermentation of beverages is also known to provide various important therapeutic benefits to consumers, such as anti-carcinogenic properties [41]. Moreover, LAB fermentation detoxifies natural toxic chemicals such as cyanogenic glycosides and mycotoxins. The therapeutic benefits related to LAB include the prevention of some types of intestinal infections, improved tolerance to beverages with lactose and the potential inhibition of cancer initiation [42,43]. The survival of LAB fermentation throughout the centuries in Africa has been attributed to these benefits, as it has served as a technology for the household to boost food safety, provide low-cost food preservation methods and contribute to an increase in the nutritional composition as well as the digestibility of raw materials [34]. Therefore, LAB fermentation is of substantial economic importance in Africa, while also promoting human health.

4. Types of Non-Alcoholic Maize-Fermented Gruels and Beverages in Sub-Saharan Africa

Table 2 shows various types of fermented non-alcoholic maize-based gruels and beverages in sub-Saharan Africa. Some of them are commercially available, whereas others are generally produced at the household level, using traditional processes for individual consumption. Most of these traditionally produced non-alcoholic beverages are regarded as functional foods and wholesome food products [8,44] The consumption of functional beverages is on the rise globally and this is attributed to their shelf life/stability, high nutrient values, ease of transport and storage, as well as their convenient packaging [45]. Moreover, the beverages are suitable for consumption by vegetarians and lactose-intolerant individuals. Non-alcoholic fermented beverages are affordable, and traditional methods are utilised during their preparation to maintain good hygiene practices, as well as the quality of the product [9].

Table 2. Fermented non-alcoholic maize-based gruels and beverages in sub-Saharan Africa.

Product	Region	Countries	Substrate	Microorganisms	References
Mahewu	Southern Africa	South Africa, Botswana and Zimbabwe	Maize, water	*Lactococcus lactis subsp. lactis*	[46]
Incwancwa	Southern Africa	South Africa	Maize, water	*Lactobacillus* species	[47]
Ogi (Akamu)	West Africa	Nigeria, Ghana	Maize, Sorghum, millet, water	*Lactobacillus* species, Aerobacter and yeasts	[48]
Togwa	East Africa	Tanzania	Maize, finger millet malt, water	*Lactobacillus* species, *Issatchenkia orientalis* and *Saccharomyes cerevisiae*	[49]
Borde (shamita)	East Africa	Ethiopia	Maize, wheat, barley, water	Lactobacillus species, *Enterobacteriaceae*	[50,51]
Munkoyo	Southern Africa	Zambia	Maize, *Rhynchosia heterophylla* root extract, water	*Lactobacillus plantarum*, *Weissella confusa*, *Lactococcus lactis* and *Enterococcus italicus*	[52,53]
Uji	East Africa	Kenya, Uganda	Maize, Sorghum, millet, water	*Leuconostoc mesenteriodes*, *Lactobacillus platarum*, *Pediococcus acidilactici* and *P. pentosaceus*	[1,9]
Kunu	West Africa	Nigeria, Cameroon, Niger	Maize, sorghum, millet, water	*Bacillus subtilis*, *Micrococcus* sp., *Staphylococcus Aureus*	[54–56]

4.1. *Mahewu*

In Southern Africa, maize is the principal raw material for *mahewu* production, a beverage which has little or no alcohol and a pH around 3.5, and which is favoured by black Africans [36]. *Mahewu* is traditionally prepared as shown in Figure 1, whereby one part of the maize meal is added to nine parts of boiling water. The mixture is cooked for ten to fifteen min, allowed to cool and then kept in the fermentation container. Starch gelatinisation occurs as a result of cooking maize and the swelling of the starch granules. Moreover, starch components such as amylase leach out and there is also an increase in the viscosity of the porridge, as well as a high risk of enzymatic digestion [36,42]. The addition of wheat flour (5% (*w/w*) of the maize meal used) at this stage is very important, since it aids as an inoculum source.

The natural microflora of the malt is responsible for the spontaneous fermentation of *mahewu* at ambient temperatures (20–30 °C), and this can be stored in a cool place for 20–25 days [42]. *Lactococcus lactis* subsp. *lactis* is the principal microflora during the spontaneous fermentation of non-alcoholic beverages such as *mahewu*. Currently, *mahewu* is produced on an industrial scale in South Africa, either as a liquid or powdered product, and powdered *mahewu* is sold as a pre-cooked ready-mix. Schweigart and Fellingham [46] evaluated the utilisation of different LAB as starter cultures in the fermentation of *mahewu* and concluded that the utilisation of *Lactobacillus delbruckii* and *L. bulgaricus* produces the most desirable commercial *mahewu* and at the same time inhibits the proliferation of other spoilage microorganisms.

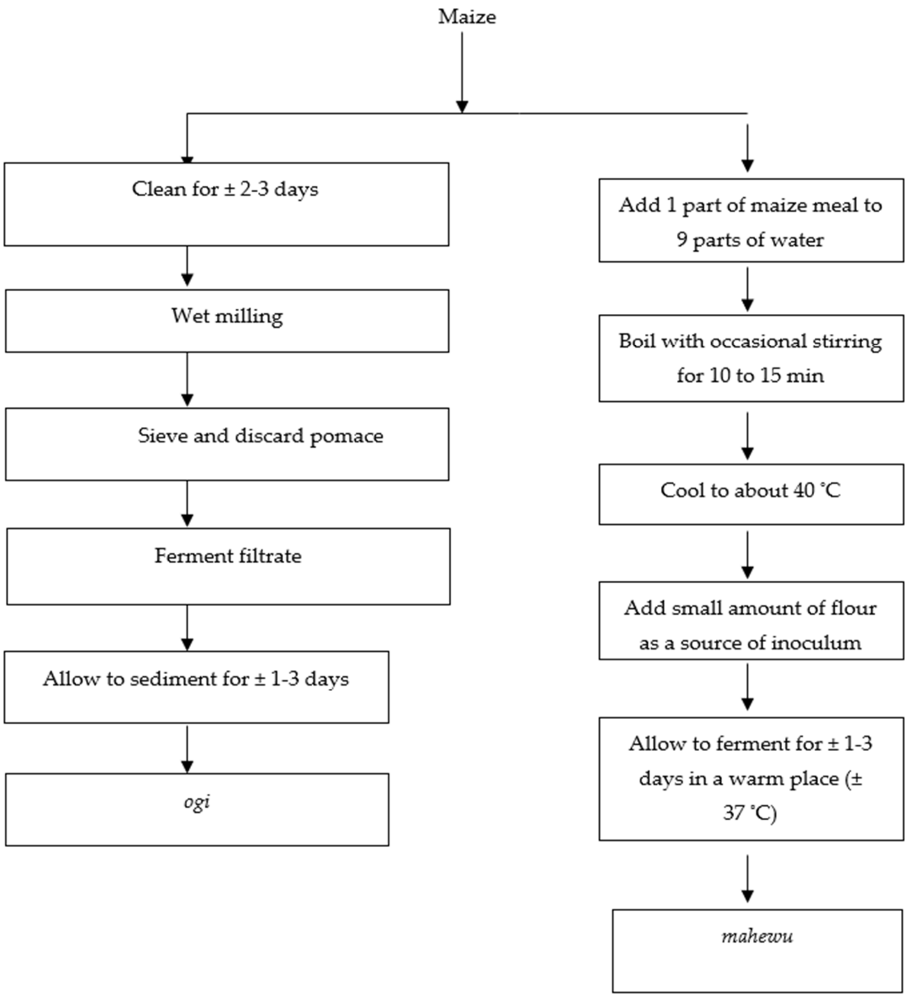

Figure 1. Flow diagram for the production of home-made *mahewu* and *ogi* [4,42].

Moreover, Van Noort and Spence [57] combined different starter cultures such as acid and non-acid producing bacteria and yeast to produce acceptable *mahewu* at room temperature (20–30 °C). Different strategies to fortify *mahewu*, such as the utilisation of fresh and sour milk, soya flour, whey protein and others, have been recommended. The consumption of *mahewu* in South Africa is seasonal and peak sales take place from October to March (summer months). A decline in sales and consumption (50–60%) of *mahewu* usually takes place during winter, with May to June regarded as the worst months.

4.2. *Ogi*

The latest statistics indicated that the total market for *mahewu* in 1984 was around 146 million litres, of which around 97 million litres were packaged and 49 million litres were transported in bulk. The annual per capita consumption of commercial *mahewu* by South African black adults is estimated to be between 12–14 L [58].

The traditional production of *ogi*, as shown in Figure 1, includes steeping of maize kernels in water for 24 to 72 h and, thereafter, the bran, hulls and germ are removed via wet milling [59]. Sieves are used to keep the pomace, which is later used as animal feed, and the filtrate is fermented for 48–72 h to produce *ogi*, which has a sour taste and a white starchy residue. The traditional marketing of *ogi* as a wet cake involves wrapping it with leaves or transparent polythene bags. The gelatinised *ogi*, which is known as pap, is generally utilised as a traditional weaning food for infants and adults use it as a meal for breakfast [60]. The shelf life of fermented *ogi* by traditional methods is estimated to be about 40 days [46], and has been improved to a semi-industrial scale [15]. Different authors have reported on the traditional and industrialised methods for *ogi* production; Odunfa et al. [61] used mutants as a starter culture and the lysine content increased threefold. Various efforts have been utilised to modify the nutritional value of *ogi* by adding substrates that are rich in protein, and ingredients such as sugar, condensed or powdered milk are normally added to *ogi*, depending on the taste [48,62].

The texture of *ogi* porridge is very smooth, possibly close to hot blancmange and its sour taste is similar to that of yoghurt. The colour of the cereal grain utilised provides the colour of *ogi*—reddish-brown for sorghum, creamy for maize, and dirty grey for millet [63]. *Ogi* is a typical example of the non-alcoholic fermentation of cereal grains, which has been improved up to a semi-industrial scale [11]. The fermentation of *ogi* is spontaneous but can also be instigated, and *Lactobacillus plantarum* is the principal microorganism that produces lactic acid. In addition, maize starch is hydrolysed by *Corynebacterium* into organic acids, whereas *Saccharomyces cerevisiae* as well as *Candida mycoderma* are important for the development of flavour [22].

4.3. Uji

Uji is traditionally prepared from a viscous mixture of maize, millet, sorghum or cassava flours in warm water, either using a single four or a mixture of these flours. The raw materials used to produce *uji* are mostly formulated at home or in small-scale processing plants using elemental equipment and technology [64]. The mixture (30% *w/v* solid) is fermented for 24–72 h at ambient temperature or nearby fire and water is added to dilute the mixture to 8–10% *w/v* solids, boiled, sweetened and served when is still hot [65]. The dry matter content of traditional *uji* ranges from 6–10 g/100 mL and is too low to be of any nutritional importance [66]. Therefore, various attempts have been made to produce related beverages that have a dry matter content that is 2–3 times higher but still having the original attractive viscosity [1].

The fermentation of *uji* is spontaneous and the predominant microorganism is *Lactobacillus plantarum* and is responsible for its sour taste, as well as high levels of lactic acid. There are also other homo-fermentative and heterofermantative microorganisms, such as *Pediococcus acidilactici*, *Lactobacillus paracasei* ssp. *paracasei*, *Lactobacillus fermentum*, *Lactobacillus buchneri* and others [12,67]. The acidic flavour of *uji* determines its acceptance by consumers and aroma compounds produced during fermentation make it more appetising, thereby improving its consumption. The major non-volatile compound in *uji* is lactic acid, which results from the dominance and metabolic activities of LAB [65,67].

4.4. Togwa

Togwa is a sweet and sour non-alcoholic beverage that is directly used as a weaning food or diluted for use as a refreshment. It is a common beverage in Tanzanian rural households and it is prepared from the suspension of maize, sorghum and finger millet flours, and cassava flour is used at times. The substrates chosen are boiled, cooled and fermented for about 12 h to form a porridge, and this is diluted to make a drink [68]. Uncontrolled spontaneous fermentation is used and this results in *togwa* of alterable quality. The consumption of *togwa* has declined and is now linked to low-income groups. Unhygienic production methods and poor shelf life are the principal factors contributing to the decline in popularity of *togwe* amongst the Tanzanian population [69].

4.5. Borde

Borde is cloudy and bubbling, its colour is white-grey to brown, and it displays thick viscosity and a sweet-sour taste. It is a low-alcohol or non-alcoholic fermented beverage, common in western and southern parts of Ethiopia. The fermentation is spontaneous, and it is produced from different local available cereal grains, such as maize, sorghum or millet, using traditional methods [50]. One type of grain or a mixture of cereal grains is used to prepare adjunct and malt forms. The beverage produced is consumed by children and adults within a day, while fermenting, because of its poor keeping quality. The preparation of *borde* is labour-intensive and it is often consumed by poor households, mostly in rural areas, since it is a low-cost meal [70].

4.6. Munkoya

Munkoyo is a traditional maize-based non-alcoholic fermented beverage, commonly produced in Zambia and the Democratic Republic of Congo [71]. *Munkoyo* is prepared using maize grit, maize meal and *Rhynchosia insignis* or *Rynchosia heterophylla* root [52]. The local people in the above-mentioned countries generally call the root *munkoyo*. The *munkoyo* root is tuber-like, fibrous and it is debarked, beaten into fibrous strands, sun-dried and stored uncovered before use [72]. Thin or thick porridge is used to produce the *munkoyo* beverage. The extract or root of *munkoya* is incorporated into the warm porridge and allowed to spontaneously ferment at ambient temperatures for 24 to 48 h via LAB and yeast [73]. *Munkoyo* is the most popular traditional beverage prepared at the household level using traditional methods and it is consumed while intently fermenting. The beverage is used as a major breakfast, weaning, or complementary food for infants and is consumed during ceremonies such as marriage ceremonies and funerals [52].

5. Nutritional Characteristics and Health Benefits of Maize-Based Non-Alcoholic Fermented Beverages

The perception that the consumption of traditional non-alcoholic fermented gruels or beverages is related to health benefits is ubiquitous and is influenced by their ability to prevent disease and to ensure well-being and healthy living at all ages, as well as their good taste [74,75]. Maize, like all other cereal grains, contains anti-nutritional factors such as phytic acid, polyphenols, and tannins that negatively affect the bioavailability and digestibility of carbohydrates and proteins. This is attributed to these antinutritional factors forming a complex with the inhibition of enzymes and minerals [76]. Phytic acid is an important phosphorus storage compound in most cereal grains, accounting for more than 70% of the total phosphorus [77]. It has a strong capacity to bind metal ions such as iron, zinc and calcium, which results in very insoluble salts with poor bioavailability of minerals [78]. Spontaneous fermentation of non-alcoholic beverages furnishes the ideal pH conditions for enzymes to break down the phytate, which increases the levels of soluble iron, zinc and calcium [79]. The reduction of the phytate content in fermented beverages is attributed to the action of phytases that catalyse the alteration of phytate to inorganic orthophosphate, and the sequence of myoinositols decreases the phosphoric esters of phytate. Lopez et al. [80] also observed that the fermentation of maize causes minerals to be more bioavailable, as well as causing the liberation of phosphorus from phytate. Moreover, the spontaneous fermentation of maize results in a reduction in the amount of carbohydrates and some non-digestible poly- and oligosaccharides [44].

Maize is a rich source of vitamin B complexes, such as folic acid, riboflavin, thiamine, pantothenic acid and pyridoxine; they are water-soluble and available in the aleurone layer of the kernel. A deficiency of B vitamin complexes impairs the utilisation of macronutrients. For example, thiamine and vitamin B_6 deficiencies negatively influence the metabolism of carbohydrates and amino acids [81]. Moreover, a deficiency of B vitamin complexes might also hamper the metabolism of other micronutrients, such as vitamin B_6, and the production of endogenous nicotinamide adenine dinucleotide through the kynurenine pathway [82]. Spontaneous fermentation improves the nutritional characteristics of beverages by enhancing riboflavin, niacin and thiamine, as well as the protein content, due to the activity of LAB [83]. Therefore, LAB are being explored to enhance the amounts of riboflavin in fermented foods since they can produce B-vitamin complexes during the fermentation process [84].

Maize-based non-alcoholic fermented beverages are rich in sources of nutrients, such as vitamins, minerals, dietary fibre and bioactive compounds which might protect against oxidative stress, hyperglycaemia and inflammation diseases [85]. Non-alcoholic fermented beverages are associated with many capabilities and some corroborative health claims and actions on digestive, endocrine, cardiovascular, immune and nervous levels [86].

The strong relationship between LAB content and the enhancement of gastrointestinal health is contemplated to be accountable for perceived health effects [65]. The availability of various important components in maize-based fermented non-alcoholic beverages provides different health benefits, as shown in Figure 2.

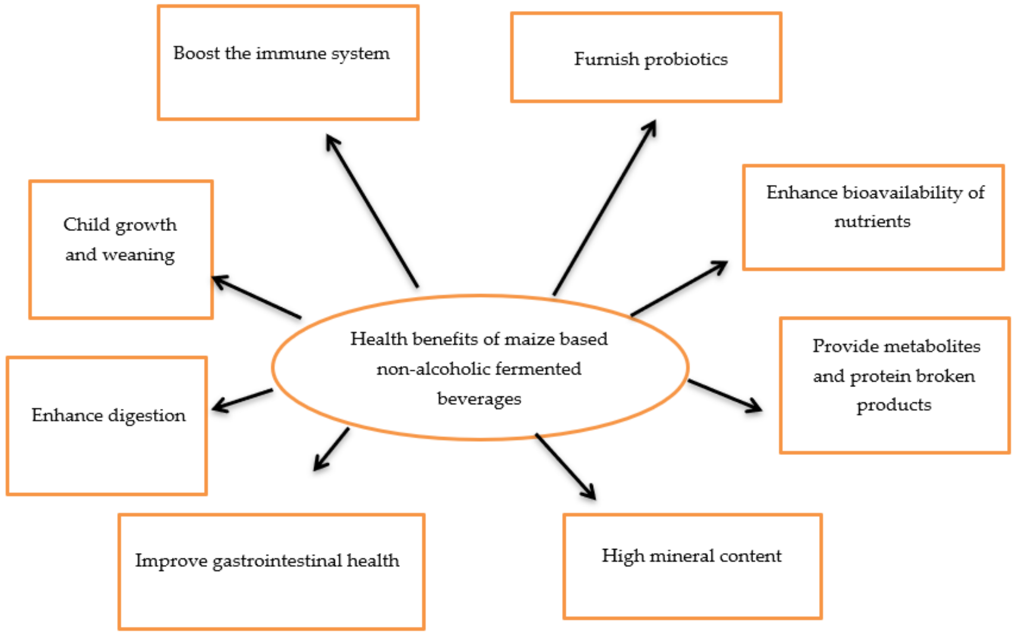

Figure 2. Health benefits of maize-based non-alcoholic fermented beverages.

The consumption of these beverages has been demonstrated to improve liver functioning, as well as the amounts of lactobacilli and bifidobacteria in the intestinal microbiota [87].

Non-alcoholic fermented beverages are regarded as important, since they serve as valuable tools for probiotics that play an indispensable role in human health. Probiotics provide many beneficial functions, such as the promotion of the microbiota that inhabit the organism in a way that ensures an ideal balance between foodborne microorganisms and the bacteria that are imperative for the normal functioning of the organism [88,89]. They also improve the effectiveness of the immune system and vitamin and mineral absorption, and invigorate the production of organic and amino acids [90,91]. Moreover, probiotic bacteria such as *Lactobacillus* and *Bifidobacteria* spp., which are available in cereal-based beverages, are natural producers of vitamin B complexes [92].

6. Preservative Effects, Safety and Risk Factors of Maize Based Non-Alcoholic Fermented Beverages

The organic acids, such as lactic, butyric and acetic acid, etc., generated during the fermentation process improve the shelf life and stability of beverages by decreasing the pH to below 3. The undissociated forms of acetic and lactic acids at reduced pH have a suppressive ability over a broad variety of pathogenic microorganisms. This prevents the proliferation and survival of pathogenic and spoilage microorganisms, such as *Escherichia coli*, salmonella and shigella, in the beverages [42,44]. Lactic acid bacteria can generate antibiotics and bacteriocins that inhibit spoilage and pathogenic microorganisms [13]. Moreover, LAB can produce an array of other antimicrobial metabolites, such as ethanol from the hetero-fermentative pathway; carbon dioxide and hydrogen peroxide, generated during aerobic growth; and diacetyl, which also improve the preservative effects of the beverages [93,94]. Some LAB isolated from cereal-based beverages have antibacterial properties against *Staphylococcus aureus*, *Escherichia coli*, *Lactobacillus innocua*, *Bacillus cereus* and *Pseudomonas aeruginosa* [95,96].

The major challenge of maize-based non-alcoholic fermented beverages is their short shelf life (3–5 days), which is attributed to over-souring or an off flavour generated by the continued activities of microbes after production. Yeasts that belong to *Pichia* spp. are the most dominant microorganisms causing the spoilage of beverages such as *mahewu*, as well as *Acetobacter liquefaciens*. These spoilage microorganisms convert lactic acid into acetic acid, which leads to off odours and discolouration of the beverage [97]. Other spoilage microorganisms, such as *Acetobacter hansenii*, *Acetobacter pasteurianus*, *Alcaligenes*, etc., also generate acetic acid and volatile off flavours, rendering the taste and smell of the beverages unacceptable to consumers [98,99]. Moreover, the use of uncontrolled conditions, mainly temperature, might also contribute to the growth of spoilage bacteria that convert lactic acid to an unacceptable end product, which negatively affects the sensory properties of beverages [100].

The challenges of food safety which arise in spontaneously non-alcoholic fermented maize-based beverages might be partially attributed to the wide variety of microbes that cause undesirable competition among the fermenting microbes, which leads to the generation of toxic by-products that affect the safety of the beverages [101]. Most of these beverages are produced at home, usually under poor hygienic conditions and with the use of dirty equipment. Microorganisms might originate mainly from raw materials, utensils and tap water used during the mixing process [102]. Some pathogenic microorganisms that are prone to contaminate maize-based beverages include *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus* spp., *Proteus* species, *Rhizopus stolonifer*, *Aspergillus flavus* and *Aspergillus niger* [103,104]. The availability of these pathogens and mycotoxins in these beverages pose a threat to consumer's health and financial losses for brewers [22]. The health risk related to the consumption of maize-based fermented beverages could be attributed to the presence of harmful minerals, such as lead, mercury, arsenic and cadmium, that have harmful effects on consumers' health. High concentrations of lead in beverages may cause food poisoning in humans [50]. Like other cereal grains, maize has antinutritional factors that can interconnect with proteins, vitamins and minerals to form stable complexes and thus limiting their bioavailability. It has been reported that antinutritional factors cause malnutrition and decreased growth rates, since they promote poor digestibility of protein and also restrict the bioavailability of minerals [44].

7. Current and Future Research on Maize-Based Non-Alcoholic Fermented Beverages

Further research is needed in the supplementation or fortification of non-alcoholic fermented cereal gruels and beverages. This is as a result of different studies (Table 3) indicating that fortification or supplementation of non-alcoholic fermented beverages with protein and other plant sources is beneficial and can be a feasible and sustainable project if produced on a commercial scale using suitable technology. This technology, among others, needs to be further upgraded in order to boost food safety and the shelf life/stability of beverages even in rural-based settings. Different methods have been proposed to increase the manufacturing, convenience, attainability and consumption of non-alcoholic beverages that are rich in phytochemicals. This involves supplementing cereal flours with non-gluten flours or powders such as legumes and pseudocereals such as amaranths, fruits, vegetables and herbs to enhance the quality characteristics of beverages [10,105]. Furthermore, the fortification of cereal flours with legume flour can enhance protein quality. Phytochemicals available in fruits and vegetables could be an excellent source of probiotics, prebiotics, and synbiotics such as in non-alcoholic fermented cereal beverages [106,107].

Bioactive compounds, such as phenolic acid, flavonoids, anthocyanin and carotenoids, dietary fibre, vitamins and minerals, fatty acids and probiotics, can be added into maize-based beverages. The availability of nutrients and bioactive components presents the possibility of utilising food as a precious tool in preventing diseases, especially in the early stages [7,108]. However, the incorporation of functional ingredients might negatively impact the flavour and aroma of beverages and therefore the inclusion of flavour enhancers and natural or artificial sweeteners are also encouraged to improve the flavour and aroma [109]. Vegetables, such as carrots, tomatoes, beetroot, cabbage, mushroom, etc., might also be added during the manufacturing of non-alcoholic fermented beverages because they provide nutrients, as well as additional fermentable substrates, and act as prebiotics in the beverages [110]. Traditional processes such as LAB fermentation and malting have been advocated in order to produce non-alcoholic fermented beverages with improved contents of polyphenolic compounds [111].

Strains that produce antimicrobials such as bacteriocins might work as natural preservatives and assist in producing a more natural product, whereas successive fermentation with yeast, preceded by bacteria, might bestow maize-based beverages with suitable physicochemical properties [112]. Recently, emerging technologies such as nanotechnology are being evaluated in improving the nutritional properties and functionality of non-alcoholic fermented beverages. Innovations and modifications to guarantee the viability of maize-based fermented products should be an ongoing process.

Table 3. Effects of ingredients on the nutritional and quality properties of maize-based non-alcoholic fermented beverages.

Product	Ingredients	Effect	References
Mahewu	Aloe vera powder	Increased titratable acidity and reduced pH	[113]
	Moringa oleifera powder	Increased ash and fat contents, dietary fibre and selected mineral elements	[114]
	Bambara groundnut flour	Increased protein and crude fibre contents, essential amino acids and titratable acidity Reduced phytate content and pH	[115]
	Provitamin A biofortified maize meal	Retained provitamin A High sensory acceptability	[116]
	Bambara groundnut flour (raw, germinated and roasted)	Increased protein and lysine contents Increased protein digestibility Improved colour, aroma and taste	[117]
	Watermelon pulp powder	Increased protein, ash, titratable acidity, vitamin C and total carotenoid contents	[118]
Ogi	Okra seed flour	Increased proximate composition (moisture, ash, protein and fat contents) and minerals (iron, calcium and potassium)	[119]
	Defatted and roasted okra seed meal	Increased ash, protein and fat contents Higher viscosity and sensory scores for colour and taste	[120]
	Pigeon pea flour	Increased protein content and dietary fibre, B complex vitamins and essential amino acids Reduced anti-nutritional factors	[121]
	Whey	Increased protein, ash and fat contents and essential amino acids	[122]
	Groundnut seed powder	Increased protein, ash and fat contents	[123]

Other areas that can be investigated to increase the utilisation of maize-based fermented products include the use of whole maize grains, since they furnish desirable health benefits, as well as beneficial components in the products compared to products from processed grains [124,125]. Whole cereal grains contain nutrients such as vitamins, unsaturated fatty acids, dietary fibre and polyphenolic compounds with antioxidant properties that are likely to be cardioprotective.

Traditional technologies such as LAB fermentation and malting have been advocated in order to manufacture maize-based non-alcoholic beverages that have high amounts of functional bioactive compounds [112]. As mentioned earlier, LAB fermentation reduces phytates, thereby improving the absorption of iron, calcium, and other minerals. To guarantee the safety of maize-based beverages, there is a need to improve the quality of raw materials, especially in rural-based settings, as well as awareness and training in relation to food hygiene and safety. Small- and medium-scale production should integrate pre-requisite programmes, such as good manufacturing practices, and they should receive assistance to implement hazard analysis critical control point (HACCP) principles. This will make most of these beverages able to enter into the international market, since the products will be certified as safe for human consumption.

8. Conclusions

Non-alcoholic maize fermentation is beneficial with regards to food safety, quality and shelf life. Therefore, communities need to be educated about the benefits of consuming non-alcoholic fermented maize gruels and beverages. Although beverages such as *ogi* and *mahewu* have received some advances in terms of product development, through fortification and the establishment of starter cultures, there is still a need for further scientific investigations of this group of traditional foods. However, studies on the fortification or supplementation of maize-based non-alcoholic beverages are in their preliminary stages, and they look promising. The main challenge for both researchers and the beverage industry is to produce non-alcoholic beverages on a large scale without affecting the distinctive flavours, as well as other properties related to the original products. Nevertheless, ongoing research and the improvement of technologies are vital in order to better develop non-alcoholic fermented beverages and also to assure their safety. There are many benefits of improving fermented beverages via biotechnological processes, since LAB fermentation leads to a phytic acid reduction, which contributes to the increased absorption of minerals such as iron, zinc, calcium and others. Current and future studies should concentrate on producing new non-alcoholic fermented beverages that are fortified or supplemented with products such as underutilised legumes, indigenous fruits and vegetables and herbs, aimed at addressing particular health conditions.

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