Fermented Millet Technology and Products 12

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Abstract

Millets are small pack of grains with several health benefits and dense nutrients including protein, essential fatty acids, dietary fiber, B-vitamins, and minerals. However, its utilization is still limited to the local consumers due to the lack of convenience food products. Processing technology, such as fermentation, is being used to prepare traditional millet products in Asian and African countries. For millet fermentation, specifically two types of fermentation are used, i.e., lactic acid bacteria fermentation and yeast fermentation that can be spontaneous or nonspontaneous. Fermentation technology is known to improve the nutritional quality of food products though it has some limitations such as contamination with toxic microorganisms, etc. Therefore, the intervention of innovative approaches with the fermentation can make it a safer and better technology. This chapter discusses the effect of the fermentation technology on nutritional composition of the millets, current developments in fermented millet-based products, and the technological advancements explored in the millet fermentation technology.

Keywords

Millets · Fermentation technology · Lactic acid bacteria · Yeast · Product

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12.1 Introduction

Millets are small-seeded grains mainly produced in the arid and semi-arid regions of Africa and Asia. The global production of millets has increased from 28.20 to 31.01 M tonnes from 2015 to 2018 (FAOSTAT 2018). Millets are drought-tolerant crops and hence are of great importance in the present era of climate change, water scarcity, population growth and inflation. The various types of millets that are grown and consumed worldwide include pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), kodo millet (*Paspalum setaceum*), proso millet (*Penicum iliaceum*), foxtail millet (*Setaria italic*), little millet (*Panicum umatrense*), barnyard millet (*Echinochloa esculenta*), and sorghum (*Sorghum bicolor*).

Millets are not only beneficial from the agriculture and economic perspectives but also a boon for human health. These small seeds are a dense nutrient source and can keep several health disorders at bay. They have better nutritional and health-promoting properties than commonly consumed grains such as wheat and milled rice (Parameswaran and Sadasivam 1994), and hence are referred as nutri-cereal. Millets are known to contain substantial amounts of protein, essential fatty acids, dietary fiber, B-vitamins, and minerals such as calcium, iron, zinc, potassium, and magnesium (Rao et al. 2017). They are also rich in health-promoting factors like polyphenols, lignans, phytosterols, phytoestrogens, and phytocyanins. These factors act as antioxidants, immune modulators, detoxifying agents, etc., and hence protect against age-related degenerative diseases like cardiovascular diseases (CVD), diabetes, cancer, metabolic syndrome, Parkinson's disease, etc. (Manach et al. 2005; Scalbert et al. 2005; Chandrasekara and Shahidi 2012). Millets are non-glutinous, and hence are safe for people suffering from gluten allergy and celiac disease. They are non-acid forming, easy to digest, and non-allergenic (Saleh et al. 2013).

There are several millet processing methods, such as thermal processing, mechanical processing, soaking, fermentation, and germination/malting. Among these, fermentation is one of the oldest and widely used methods as millets are known for their prebiotic potential (Amadou et al. 2013; Di Stefano et al. 2017). It is a process dependent on the biological activity of certain microorganisms to release energy from a carbohydrate source to produce a wide range of metabolites such as alcohol, acetic acid, and lactic acid (Ross et al. 2002). Fermentation can be classified based on microorganisms, end product, aeration, phase, starter culture, and substrate feeding method (Fig. 12.1). Fermentation of the millet is commonly done using lactic acid bacteria (LAB) and yeast.

In addition to a convenient processing technique, it is also known to be one of the most popular and crucial processes that considerably lowers the anti-nutrient factors (ANFs) (Tsafrakidou et al. 2020), and hence enhances the overall nutritive value. Several studies have shown that the fermentation of millets might reduce the ANFs present in millets, thereby improving the bioavailability of the nutrients (Table 12.1 and Fig. 12.2). This reduction in ANFs can happen in two ways; either the microbial metabolic activity led to the phytase production or the alteration in the pH during fermentation provides optimum pH for the action of an endogenous enzyme (Samtiya et al. 2020). The breakdown of phytic acid releases the minerals in their

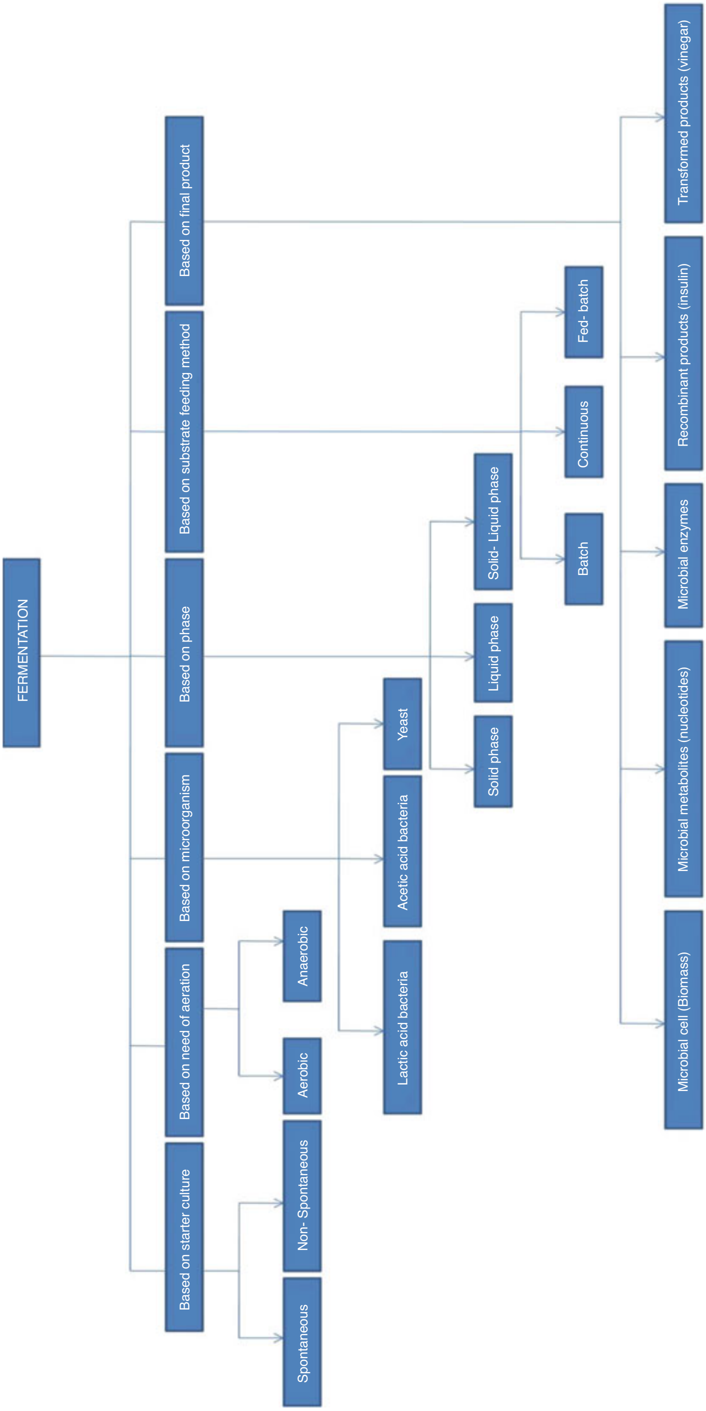

Fig. 12.1 Classification of the fermentation process

Table 12.1 The effect of the fermentation technology on the nutritional profile of millets

Raw material	Fermentation conditions	Effect on nutrients	References
Red sorghum, white sorghum, and pearl millet flour	Native microflora at 25 °C for 48 h	Protein digestibility increased by 97.4–98.3%. Phytic acid reduced by 20–21%.	Onyango et al. (2013)
Pearl millet flour	Native microflora at room temperature for 72 h	Protein content increased by 117.96%. Tannin reduced by 31.53%. Phytate reduced by 48.78%.	Ojokoh and Bello (2014)
Finger millet grains	*Lactobacillus salivarius* subsp. *salivarius* (LMG 9477T) at 30 °C for 48 h	Tryptophan increased by 17.8%, lysine increased by 7.1%, and phenylalanine decreased by 3.3%.	Mbithi-Mwikya et al. (2000)
Pearl millet flour	Native microflora at 30 °C for 24 h	Reduction in phytic acid by 51.9%.	Osman (2011)
Pearl millet	*Lactobacillus plantarum* at 37 °C for 96 h	Increase in protein content from 8.73% to 20.21% and reduction in fat content from 10.39% to 0.64%. Reduction in phytates from 1.78% to 0.09% and tannins from 2.80% to 1.40%.	Chinenye et al. (2017)
Pearl millet flour	Native microflora at 37 °C for 12 or 24 h	Improved protein digestibility to 93.6%.	Hassan et al. (2006)
Pearl millet slurry	*Lactobacillus acidophilus* (NCDC-16) at 37.8 °C for 12 h	Increase in thiamine from 0.46 to 1.02 mg/100 g, niacin from 1.25 to 2.52 mg/100 g, and total lysine from 2.53 to 6.30 g/100 g. Increase in albumin from 0.45 to 0.72 g/100 g, globulin from 3.75 to 4.34 g/100 g, and glutelin from 1.8 to 2.06 g/100 g. Prolamin decreased from 4.45 to 3.85 g/100 g. Increase in calcium availability from 40.54% to 80.57%, iron from 20.62 to 68.41, and zinc from 36.01% to 77.97%.	Arora et al. (2011)
Dehulled pearl millet flour (standard cultivar and Ugandi variety)	Native microflora at 30 °C for 14 h	Increase in in-vitro protein digestibility by 82% and 84%. Decrease in polyphenols by 59.5% and 30.45% in standard and Ugandi variety, respectively. Decrease in phytic acid by 59.5% and 46.1% in standard and Ugandi variety, respectively.	El Hag et al. (2002)

Sorghum	Baker's yeast fermentation by *Saccharomyces cerevisiae* at 37 °C for 48 h Amylolytic yeast fermentation by *Lipomyces kononenkoae* NRRL Y-11553 at 37 °C for 48 h	Baker's yeast fermentation led to the higher level of increase in protein digestibility. No significant difference in amino acid profile. Amylolytic yeast fermentation reduced phytate content to a higher extent.	Day and Morawicki (2018)
Little millet	Probiotic yeast (*S. boulardii*) for 5 days	Slight increase in contents of protein and phosphorus. Slight decrease in fat and total carbohydrates content. Marked decreased in phytic acid (from 188.95 to 167.56 mg/100 g). No significant change in calcium, magnesium, iron, and zinc.	Pampangouda et al. (2015)
Millet-wheat composite bread	Baker's yeast (*S. cerevisiae*) for 1 h	Three types of breads enriched with millets (composite bread) prepared, namely LAB fermented composite bread, yeast fermented composite bread, and commercially available white bread. The highest vitamin B group and calcium found in the yeast fermented composite bread.	Mythrayee and Pavithra (2017)
Pearl millet flour	*S. cerevisiae* and *S. diastaticus* for 72 h at 27 °C	Decreased protein content and bulk density, least gelation concentration, tannin, and total phenol. Increased fat content, thiamine, total soluble sugar, reducing sugar, water, and oil-absorption capacity.	Rathore and Singh (2018)
Pearl millet fermented gruel	*P. kudriavzeviiin* combination with LAB strains for up to 24 h	Significant increase in the concentration of folate after 2, 4, and 24 h of treatment due to co-fermentation with yeast.	Greppi et al. (2017)
Sorghum-based fermented *Kisra*	*S. cerevisiae* in combination with LAB strains for different intervals (up to 19 h)	The presence of *S. cerevisiae* reduced the fermentation time.	Ali and Mustafa (2008)

(continued)

Table 12.1 (continued)

Raw material	Fermentation conditions	Effect on nutrients	References
Fermented broom corn millet sour porridge	*S. cerevisiae* versus *L. brevis* and *Acetobacter aceti* for 24 h at 30 °C	*S. cerevisiae* showed the minimum titratable acidity and sensory scores compared with *L. brevis* and *A. aceti*. Mixed-strains fermentation (1:1:1, v/v/v) was found to be the best combination of strains starter.	Wang et al. (2019)
Fermented millet-based *Kunu*	*S. cerevisiae* and *Lactobacillus* species for 48 h at 35 °C versus naturally fermented *Kunu*	*S. cerevisiae* increased the contents of nitrogen (from 0.5 to 0.62 mg/100 ml), calcium (from 1.13 to 7.35 mg/100 ml), magnesium (from 22.99 to 43 mg/100 ml), and potassium (from 50.45 to 60.01 mg/100 ml), but it reduced the contents of sodium (from 30.1 to 21 mg/100 ml) and anti-nutrients (tannin, oxalate, and phytate) compared to natural fermentation. The combination of *S. cerevisiae* and *Lactobacillus* species maximized the contents of nitrogen, calcium, magnesium, potassium and minimized the content of tannin and oxalate content among all samples.	Agboola and Ojo (2018)
Fermented sorghum-Irish potato based gruel (*Ogwo*)	*S. cerevisiae*, *G. candidum*, *Lactobacillus* strains and natural fermentation at 28 °C for 48 h	*S. cerevisiae* significantly reduced the contents of oxalate, phytic acid, tannin, saponin, and flavonoids, but it increased the contents of potassium, magnesium, and phosphorus when compared to the unfermented and naturally fermented sample. *Lactobacillus* strains minimized the content of anti-nutrients (tannin and phytic acid) and maximized the concentration of magnesium, calcium, and manganese compared to other fermented samples.	Adegbehingbe (2015)

Pearl millet	*S. diastaticus* and *S. cerevisiae* at 30 °C for 72 h	Increased starch digestibility (from 17.8% to 38.3% and 35.6% for *S. diastaticus* and *S. cerevisiae*, respectively). Increased protein digestibility (from 51% to 67.6% and 81.6% for *S. diastaticus* and *S. cerevisiae*, respectively).	Khetarpaul and Chauhan (1990a)
Pearl millet	*S. cerevisiae* and *S. diastaticus* at 30 °C for 72 h	Increased the total contents of soluble sugars (from 1.7 to 3.09 and 2.82 g/100 g for *S. diastaticus* and *S. cerevisiae*, respectively) and reducing sugar (from 0.36 to 2.01 and 0.66 g/100 g for *S. diastaticus* and *S. cerevisiae*, respectively). Decrease in the starch content (from 68.5 to 50.4 and 50.2 g/100 g for *S. diastaticus* and *S. cerevisiae*, respectively).	Khetarpaul and Chauhan (1990b)
Pearl millet	*S. diastaticus*, *S. cerevisiae* for 30 °C for 72 h	Significant reduction in phytic acid (from 990 to 585 and 570 mg/100 g for *S. diastaticus* and *S. cerevisiae*, respectively). Significant reduction in polyphenols (from 761 to 641 and 719 mg/100 g for *S. diastaticus* and *S. cerevisiae*, respectively).	Khetarpaul and Chauhan (1989a)
Pearl millet	*S. diastaticus*, *S. cerevisiae* for 20–30 °C for 72 h	Increased thiamine content (from 1.97 to 5.76 and 840 µg/100 g for *S. diastaticus* and *S. cerevisiae*, respectively).	Khetarpaul and Chauhan (1989b)

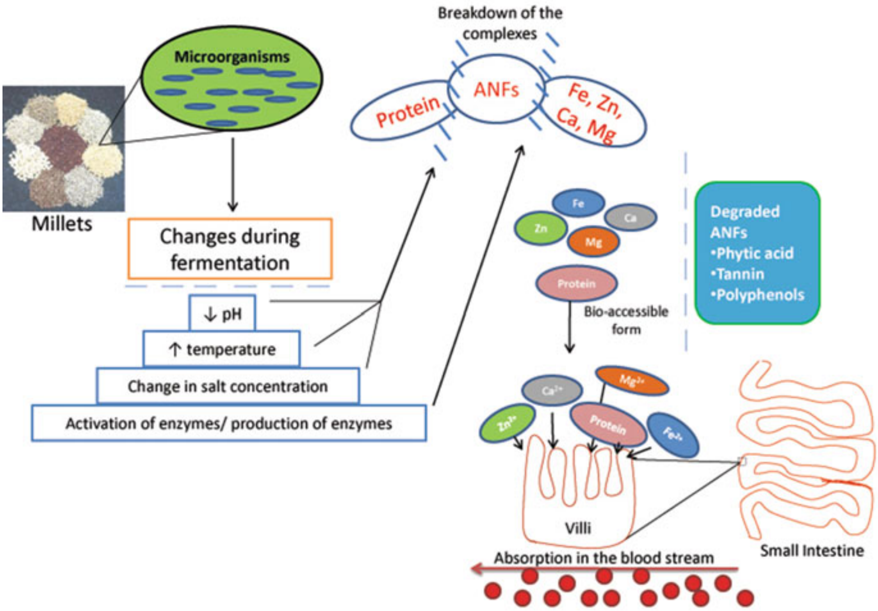

Fig. 12.2 Changes during the fermentation process

readily absorbable form, thereby increasing their bioavailability (Samtiya et al. 2020). The breakdown of phytic acid increases protein digestibility as well (Melini et al. 2019). Fermentation conditions like pH, temperature, and ionic strength can directly or indirectly influence protein digestibility (Joye 2019). Lactic acid fermentation may also induce favorable conditions for the interaction of starch and protein, thereby decreasing glycemic index (Melini et al. 2019). Furthermore, the microbial metabolism during fermentation produces more essential nutrients, such as thiamine, folate, riboflavin, vitamin C, and vitamin E, which are of great importance to human health (Kohajdova 2017).

Fermentation technology may be used for the development of probiotic or synbiotic fermented foods from millet. Such products may have some beneficial effects on some of the pathological conditions as diarrhea (Lei et al. 2006).

12.2 Lactic Acid Fermentation of Millets

Lactic acid bacteria (LAB) represent a ubiquitous and heterogeneous species with typical characteristics of lactic acid production by metabolizing sugar and creating acidic conditions with a pH of 3.5 (Fig. 12.3) (Charlier et al. 2009; Ghaffar et al. 2014). LAB fermentation ability is mainly associated with dairy products, but nowadays, its potential in cereal fermentation is being attempted. However, the

Fig. 12.3 Breakdown of sugar during LAB fermentation (Ghaffar et al. 2014)

Fig. 12.4 Fermented millet-based products: (**a**) *Dosa* (**b**) *Idli* (**c**) Curd

nutritionally fastidious nature of LAB for specific amino acids, B-vitamins, and other growth factors has made it an appropriate choice for millet fermentation.

LAB fermentation of the millets has been shown to enhance vitamin B and K, lysine, folate, and micronutrients in the fermented products (Tamene et al. 2019). One of the advantages of LAB fermentation is higher mineral bio-accessibility due to the reduction in pH. The use of LAB for the fermentation of millets has a long tradition that can be observed in some of the traditional fermented food such as *Idli*, *Dosa*, and *Ambli* in the Asian subcontinent (Rawat et al. 2018) and *Ben saalga*, *Uji*, *Mangisi*, etc., in African subcontinents (Amadou et al. 2011). These traditional products are the result of spontaneous or natural fermentation where native microorganisms metabolize the substrate (Fig. 12.4).

At present, LAB fermentation technique is being explored for the development of products, such as curd, yogurt, *Rabadi*, fermented milk, and other fermented beverages, from millets (Table 12.2). For the development of fermented millet products, processes like germination, fermentation, malting, etc., are used individually or in combination. For example, the millets are first germinated to extract milk, which is further fermented to develop curd. Sheela et al. (2018) demonstrated that the germination process directly influences the millet milk yield and subsequently, the curd yield. Currently, millets such as foxtail, proso, kodo, barnyard, and little millet have been explored to produce fermented milk. Among the millets, foxtail and proso millets had the highest extraction yield (Sheela et al. 2018).

A millet yogurt with acceptable organoleptic characteristics has been developed with the combination of millet milk (15%) and dairy milk with 6 h fermenting (Miaomiao 2007). Fermented millet sprout beverage has been developed using a combination of pearl millet (23.9%), finger millet (30%), and sorghum (21.1%) with

Table 12.2 LAB fermentation for the development of the millet products

Product	Fermentation conditions	Product characteristics	References
Fermented millet sprout milk beverage from sorghum, pearl millet, and finger millet	Millets were germinated for 48 h followed by grinding and filtration. The milk was fermented by 2% LAB culture for 12 h at 37 °C	• Sedimentation rate—0.7 ml • Viscosity—156.5 cP • Whey off—0.014% • Acidity (LA %)—0.63% • Sensory score—7.1/10	Sudha et al. (2016)
Non-dairy gluten-free millet-based fermented beverages	*Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Streptococcus thermophilus* at 45 °C for 5 h	• pH —4.2–4.4 • Product had a thick consistency, velvety texture, light clotting density, and taste similar to cow's yogurt	Ziarno et al. (2019)
Fermented millet-based curd from foxtail millet, little millet, kodo millet, proso millet, barnyard millet	Soaking for 16 and 24 h, germination for 24 h, and milk extraction The extracted milk was fermented by using commercial curd culture NCDC 261 for 6 h at 30 °C	• Acidity %—0.74–1.2% • pH —3.5–4.5 • Sensory score—8/10	Sheela et al. (2018)
Rabadi from pearl millet	Germinated grain slurry was heated at 90 °C and cooled to 37 °C, fermented by mesophilic mixed-strain curd culture NCDC-167 for 12 h and finally cooled to 5 °C	• Fat—0.65% • Total solids—8.7% • Protein—2.2% • Ash—1.3% • Sensory score—7.4/10	Modha and Pal (2011)
Millet yogurt	*Lactobacillus bulgaricus* and *Streptococcus thermophilus* (ratio 1:1) culture 3%, sugar 8%, and fermentation at 42 °C for 6 h	• Acceptable sensory score	Miaomiao (2007)

25% of skim milk that took 12 h soaking and 48 h germination time (Sudha et al. 2016). The duration of fermentation may depend on the type of millet and its grain structure, such as the presence/absence of seed coat, size, and hardness. LAB fermentation of millets can be an appropriate technology to develop milk-like products for people with lactose intolerance.

LAB fermentation process can be improved by regulating the growth and survival rates of the microorganisms. For instance, the addition of calcium ion during LAB fermentation can enhance the heat resistance of the LAB, increase the survival rate, and shorten the regrowth lag times of the bacterial cell (Huang and Chen 2013). Furthermore, at low inoculum concentration of LAB (*Lactobacillus bulgaricus*), if the yogurt dispersion is agitated at the speed of 200 rpm for 5 min, it can increase the specific growth rate and final microbial count of LAB hence shortening the lag period (Aguirre-Ezkauriatza et al. 2008). Therefore, the technological intervention during LAB fermentation can be beneficial from economic perspective.

12.3 Yeast Fermentation of Millets

Yeast fermentation is another type of fermentation that is used for millet fermentation to produce alcoholic products such as wine, beer, and bread. The characteristic features of this fermentation is that yeast utilizes sugar and produces alcohol (ethanol) and carbon dioxide (Fig. 12.5) (Alba-Lois and Segal-Kischinevzky 2010).

Yeast fermentation produces several metabolites other than alcohol, such as esters, acids, terpenes, and lactones that impart a peculiar flavor to the final product and influence the organoleptic characteristics of the product (Geetha 2013). Similar to LAB fermentation, it can improve the nutritive value of millet products by reducing the level of ANFs such as tannin, phytic acid, and saponin (Adegbehingbe 2015; Agboola and Ojo 2018), that might improve the bio-availability of minerals (e.g., calcium, magnesium, potassium, and phosphorus) (Adegbehingbe 2015; Agboola and Ojo 2018) and vitamins (Mythrayee and Pavithra 2017; Khetarpaul and Chauhan 1989b; Rathore and Singh 2018). It may also contribute to improved starch and protein digestibility (Khetarpaul and Chauhan 1990a). Rathore and Singh (2018) pointed out that the fermentation by yeast may substantially improve key functional properties of millet flour such as water-absorption capacity, oil-absorption capacity, and least gelation concentration, which is useful from technological standpoint (Rathore and Singh 2018).

Yeast fermentation is employed to prepare several fermented products such as *Ogi*, *Kolo*, *Kenkey*, *Enjara*, *Jandh*, *Fura*, *Kodokojaanr*, and *Oti-oka* (Karovicova and Kohajdova 2007; Tamang 2012; Amadou 2019). These products can be prepared either by spontaneous yeast fermentation or by directly inoculating yeast under controlled conditions. Different strains of yeasts such as *S. cerevisiae*, and *S. diastaticus* can be used for the fermented millets (Mugula et al. 2003; Amadou et al. 2011; Geetha 2013; Adegbehingbe 2015; Rathore and Singh 2018). Among them, *S. cerevisiae* species is the most well-known and commercially significant (Zarnkow et al. 2010). In this context, several studies exhibited the effectiveness and positive impacts of *S. cerevisiae* in the fermentation of various types of millet-based products such as *Ogwo* (Adegbehingbe 2015), *Kunu* (Agboola and Ojo 2018), *Kisra* (Ali and Mustafa 2008), and broomcorn millet porridge (Wang et al. 2019).

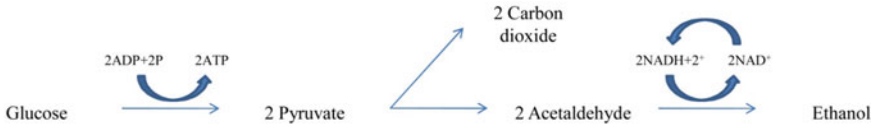

Fig. 12.5 Breakdown of sugar during yeast fermentation (Alba-Lois and Segal-Kischinevzky 2010)

Yeasts can either be used in a single form or combination with LAB for fermentation of the millet (Mugula et al. 2003; Taylor and Duodu 2015). A combination of yeasts with LAB might offer additional advantages in the quality of final products. For instance, Agboola and Ojo (2018) reported that the combination of *S. cerevisiae* and *Lactobacillus* species resulted in a higher content of calcium, magnesium, and potassium than single inoculation of each strain in fermented *Kunu*. They also observed that this combination is more effective in reducing tannin and oxalate contents than individual strain. Similarly, a recent report by Wang et al. (2019) also indicated the mixed-strains (*S. cerevisiae*, *Lactobacillus brevis*, and *Acetobacter aceti*) as the best combination starter for the fermentation of broomcorn millet sour porridge. Therefore, it can be interpreted that the use of yeast and LAB strains as mixed-strain cultures might be an effective technique to improve the final quality of fermented millet products. Table 12.1 indicates some of the studies related to the use of yeast (either single or in combination with LAB) in different fermented millet products.

Yeast fermentation technology is also known for its efficiency in the alcohol brewing industry. For this purpose, *S. cerevisiae*, cultured yeast, is commonly used in brewery industries as it provides control over the fermentation process, unlike other wild yeasts (Soden 1998). The utilization of yeast fermentation for the development of alcoholic drinks goes back to the time of Antoine Lavoiser when he used yeast paste or "ferment" to determine the chemical reaction of yeast fermentation (Alba-Lois and Segal-Kischinevzky 2010).

Some Asian countries like China, Korea, and Taiwan are known for their rice wines that are now shifting towards the millet wine development because of their better nutritional profile, unique medicinal values, and typical healthcare functions. A recent study indicated that millet yellow wine contains biologically active peptides, oligosaccharides, phenolic compounds, gamma aminobutyric acid, and other functional compounds of high nutritional values (Shang et al. 2011).

Among millets, foxtail millet (Kim and Koh 2004; Yang et al. 2006) and proso millet (Liu et al. 2018) have been explored for the production of millet wine. However, the millet wine's colloidal stability is very poor, which is associated with the prolamin of 14 and 18 kDa molecular weight (Yang et al. 2006). Moreover, a strong correlation between chill haze and prolamin proteins in millet wine was found (Passaghe 2014). Therefore, the presence of the prolamin protein can be considered as a critical indicator to determine the colloidal instability of millet wine. However, further researches are needed to minimize certain processing drawbacks in millet wine.

12.4 Technological Advancements in the Millet Fermentation Technology

The action of microorganisms in fermentation gives desirable biochemical changes and significant modification of food quality. It enriches the diet through the development of a diverse flavor, aroma, and texture in food substrate. The fermentation of the food material often prolongs its shelf-life due to the production of the metabolites such as acids and alcohols. It also enriches the food biologically with protein, essential amino acids, and vitamins (Haard et al. 1999). Although fermentation is an essential traditional technology for food processing, it has some limitations and drawbacks. The major concern with fermentation is the risk of foreign microflora. The contamination of the fermented products with toxic microorganisms can cause food-borne infection and intoxication due to microbial metabolites such as mycotoxins, ethyl carbamate, and biogenic amines (Nout 1994). Major risk factors include the use of contaminated raw materials, poorly controlled fermentation conditions, etc. These limitations of fermentation process can be eliminated by reducing the processing time either by exercitation of microorganisms or by altering the conditions during fermentation. Therefore, in order to make fermentation a safe and better technology, the intervention of advanced technologies might be useful.

One of the advancements in millet fermentation technology is mixed-culture fermentation. The use of a single strain of microorganism has been a norm for the production of fermented products. However, the utilization of the mixed culture of the microorganisms for the fermentation process seems to be an advantageous and better alternative as it can increase the final output yield with better organoleptic properties. Additionally, it is a new method to produce different metabolites such as enzymes and antimicrobial compounds in one process. All this is possible through the use of the synergistic utilization of different metabolic pathways. However, the growth of one microbe can enhance or hamper another microorganism's growth hence increasing or decreasing the final production rate. Nonetheless, the mixed-culture technology still has potential to increase the acidification, fermentation rate, and improvement of the functionality of the final fermented product (Adebo et al. 2018). For instance, the traditional preparation of *Ting*, a traditional fermented sorghum product of Botswana, requires 2–3 days to attain a pH below 4 to initiate the fermentation process. However, the use of mixed culture for the *Ting's* preparation reduced the fermentation time to 8 h (Sekwati-Monang and Ganzle 2011).

Another advanced fermentation technique is "Very High Gravity" (VHG) technology. This technology is defined as "the use of mash containing more than 27 g or more solids dissolved in 100 g of mash" (Puligundla et al. 2011). In case of the finger millet fermentation, the VHG fermentation technology using *S. bayanus* with additional nutritional supplements increased final ethanol production by 15% that can be of great economic advantage at the industrial scale (Puligundla et al. 2010).

Other technologies such as extrusion have also been used in combination with millet fermentation technology. These technologies have the potential to develop a novel product as well as may simplify the cumbersome process of millet fermentation. Sangeetha and Devi (2012) explored the dehydrated finger millet milk powder for the development of the pasta using the extrusion technique. The extrusion technology has also been explored for the development of ready-to-eat *Uji*, a fermented East African food prepared from maize, millet, sorghum, or cassava. Onyango et al. (2004) showed that the application of extrusion technology in the development of *Uji* from maize and finger millet (1:1) composite flour could produce self-preserving low moisture *Uji* that readily reconstitutes in warm water.

Although, there are different advanced technologies that have emerged in the fermentation technology field, the application of which has not been extended to millet fermentation. These novel technologies include non-thermal processes such as high-pressure processing, ultrasound, gamma irradiation, microwave irradiation, and pulsed electric field; and thermal processes such as Ohmic heating, radiofrequency, and microwave heating. The non-thermal methods are usually aimed at acceleration of the rate of chemical reactions and also used for monitoring of fermentation process. In contrast, thermal methods are usually employed to inactivate pathogens, improve metabolic activities, and shorten the fermentation process (Adebo et al. 2018). The use of these modern techniques combined with the existing millet fermentation technologies seems promising to make fermentation much safer and efficient. These technological advancements can aid in expanding the spectra of fermented millet products in the market.

12.5 Conclusion

Millets are small-seeded, drought-tolerant crops with several health-promoting nutrients including protein, essential fatty acids, dietary fiber, B-vitamins, and minerals. In spite of that, its utilization is limited to the local consumers due to the lack of suitable processing technology. In Asian and African countries, millets are fermented to prepare traditional dishes, such as *Kisra*, *Ogwa*, *Kunu*, *Ogi*, *Idli*, *Dosa*, and *Rabadi*. Although fermentation is an old millet processing technology, it demands technological advancements to develop convenience food products.

Several attempts are being made to improve the efficiency of millet fermentation technology and a number of novel fermented millet products, such as milk, milk powder, yogurt, and curd, are being explored. Technologies such as mixed-culture fermentation, very high gravity fermentation, as well as the combination of extrusion technology with fermentation have been shown to improve the product yield and quality. However, various novel thermal and non-thermal technologies have emerged in the field of fermentation technology, the application of which is still unexplored in millet fermentation. The intervention of these advanced technologies in millet fermentation can promote and expand the spectra of fermented millet products in the market.

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