

REVIEW

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Efficacy of germination and probiotic fermentation on underutilized cereal and millet grains

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Abstract

Cereals and millets have been known as poor man's crops for a long time, and have good potential in the mercenary system of food and in research and development but these coarse grains have been leftover and underutilised since a long time. In addition to nutritional properties, various elements of cereal grains contain phenolic compounds as well as various anti-nutritional factors. To improve the nutritional quality and availability of these grains, they are processed in several ways. This review discusses the effect of pre-processing techniques such as germination with a combination of probiotic fermentation on various components of underutilised coarse cereals and millets and advantages it brings into the final product. Germinated food mixture usually contains a significantly higher amount of thiamine, lysine and niacin contents. The combination of cereals with other methods results in better nutrient profile and an enhanced amino acid pattern. Fermentation is said to be the most crucial and popular process which considerably lowers the antinutrients present in coarse cereals such as trypsin inhibitor, phytic acid and tannins and hence, enhance the overall nutritive value of coarse cereals and other food grains. Also, germinated cereal-based food products have higher cell count and better growth of beneficial bacteria, thus, germination of cereals facilitates the probiotic fermentation of cereals.

Keywords: Cereals, Germination, Probiotics, Antinutrients, Phenolic compounds

Introduction

Coarse cereal grains refer to those grains which are primarily used for animal feed or brewing purposes (Kaur et al. 2014). These coarse cereals are utilised in several parts of the world. They are generally popular and well-known for their ability to be utilised as food, feed and fodder. These coarse cereals are usually grown in the rain-fed farming system along with slight external inputs (Kaur et al. 2014). These are generally called as summer season grains. They are generally grown in those Asian and African regions which are semi-arid. The levels of grain yield are generally low (< 1 t/ha) for these coarse cereals. Coarse cereals consist of wheat

(Gehoon; *Triticum aestivum*, oats (Jai; *Avena sativa*), maize (*Zea mays*), barley (Jow; *Hordeum vulgare*), rye (*Secale cereale*), sorghum (Jowar; *Sorghum vulgare*), triticale (*Triticosecale*) and trivial millets for instance Finger millet (Ragi; *Eleusine coracana*), Barnyard millet (Sanwa; *Echinochloa utilis*), pearl millet (Bajra; *Pennisetum glaucum*), Foxtail millet (Kauni; *Setaria*), Kodo millet (Arikalu; *Paspalum setaceum*), Proso millet (Cheena; *Panicum miliaceum*) and Little millet (Kutki; *Panicum sumatrense*). All of these coarse grains and millets are abundant in various phytochemicals and insoluble dietary fibre with antioxidant properties, a variety of minerals (mainly micronutrients such as zinc, magnesium and iron), dietary energy and several vitamins (Agil and Hosseinian 2012). One of the richest sources of calcium is Finger millet with a value of the 300-350 mg/100 g grain (Table 1). Some varieties of coarse cereals and

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Table 1 Proximate composition of coarse cereals and millets (Edible portion = per 100 g Moisture = 12%) Source: USDA (2018)

Food	Energy (kcal)	Fat (g)	Protein (g)	Carbohydrates (g)	Total Dietary fibre (g)	Iron (mg)	Riboflavin (mg)	Calcium (mg)	Thiamine (mg)	Niacin (mg)
Wheat	348	1.5	11.6	71.0	12.5	3.5	0.17	30	0.41	5.5
Oats	390	7.0	17.0	66.3	10.6	4.7	0.14	54	0.76	0.96
Barley	352	1.2	9.9	77.7	15.6	2.5	0.11	29	0.19	4.5
Sorghum	329	3.5	10.5	72.1	6.7	3.35	0.09	13	0.33	3.7
Pearl millet	361	5.0	11.8	67.5	11.3	8.0	0.25	42	0.33	2.2
Finger millet	336	1.5	7.7	72.6	11.5	3.9	0.19	350	0.42	1.1
Proso millet	341	1.1	12.5	70.3	–	0.8	0.18	14	0.2	2.3
Foxtail millet	330	4.3	12.2	60.9	2.4	2.8	0.11	31	0.59	3.2

milletts are rich in nutrients like phosphorus and iron (Kaur et al. 2014). In perspective of these nutritional properties that coarse cereals have, they are also designated as Nutri-cereals in the market. Cereal based foods are usually grown and build up in about 74% of the part of the world and contribute in the half of the global food produced (Charalampopoulos et al. 2002). Coarse cereals have been known as poor man's crops for a long time, and have good potential in the mercenary system of food and in research and development but these coarse grains have been leftover and underutilised since a long time. The nutritive and wellness facet of these coarse grains have an unsubstantiated agricultural understanding and a great scope and potential in scientific research (Sindhu and Khetarpaul 2001). Several types of food products can be prepared from these underutilised coarse cereals (Sindhu and Khetarpaul 2001). These coarse cereals have become successful in attracting a broad spectrum of consumers which includes people from both poor and rich community, and people who belong to both rural and urban setting in both developed and underdeveloped economies and resources (Das et al. 2012). The huge success of these cereal grains in the market is due to the constant degradation in the environment quality which further resulted in bad consequences on food and nutritional security and an understandable requirement for increasing the food production for continually increasing population (Das et al. 2012). The potential of these coarse grains for being utilised as formulated or functional foods has been researched. Coarse grains are not only limited to food uses, but also can be used as distilleries, bioethanol, feed, biopolymers, syrups and substrate for biofuels (Kaur et al. 2014). According to various previous studies, consumption of cereal grains and their products leads to the reduction of incidence of NCDs such as stroke, cardiovascular disease (CVDs), diabetes and various types of cancer related to oxidative stress (Kumari et al. 2019). Many pre-processing techniques are applied in cereal grains and two most important techniques are germination and probiotic fermentation. Germination is a well-known and traditional method to improve the nutrient profile of grains. In addition, germination has always been used for softening the structure of kernel and decreasing anti-nutritional factors (Gunenc et al. 2017). The main aim of germination is to induce the formation of hydrolytic enzymes that are not in active state in raw seeds. During germination, the biosynthetic capacity of cereal grains is utilized and various hydrolytic enzymes are developed. All these reactions in germinated grains result in structural modification and the formation of new compounds, which have bioactivity and can enhance the nutritional profile and the overall stability of cereal grains.

The other technique which is mostly used to improve the nutritional value of coarse grains is probiotic

fermentation (Boudjou et al. 2014). Probiotics can be referred to as 'live microbial feed supplements' which subsequently act on the host subject in a beneficial way by enhancing its microbial balance (Fuller 1992). Probiotic strains have been with the humankind from the moment people started gobbling fermented foods and beverages (Kumar et al. 2015). However, their valuable health benefits were only found out after Metchnikoff (Father of probiotics) in 1907 reported that the gut microflora had detrimental effects on health and referred it autointoxication. Most widely used probiotics are various species belonging to the genera of *Lactobacillus*, *Lactococcus*, *Streptococcus*, *Bifidobacterium* and some species of *Escherichia coli* and *Enterococcus*. *Saccharomyces boulardii* is the only yeast which is non-pathogenic and is considered to be a probiotic. Treatment with probiotics includes modulating immune system at the local as well as at the systemic levels and beneficial effects of this include either diminished time-span of infections or lesser vulnerability to microorganisms (Antoine 2010). The basic mechanism of action of probiotics involves ingestion of probiotics. Probiotics, when ingested, have to surpass the acidic conditions of the gastrointestinal tract (GIT). Those cells that survive this harsh environment of the gut transit then colonize themselves and cling to the intestinal mucosa interacting with the host system. The first mechanism of probiotic action is inhibition of pathogen activity by releasing various metabolites and competing for sites of adhesion to the host epithelium.

The aim of this review is to discuss the functional and productive outcomes when coarse cereals are subjected to germination and fermentation, and to study the effect of germination and probiotic fermentation on various components of nutrient-rich coarse cereals and millets. Additionally, some of the cereal based fermented and germinated food and their advantages are also discussed.

Bioactive compounds

Bioactive compounds present in cereals and millets

Various elements of cereal grains and millets have biological activity. These bioactive compounds are also known as phytochemicals. Phenolic compounds are one of the highest varied group of phytochemicals. These phenolic compounds are found in all organs of plants and hence considered important in human diet. A distinctive range of free phenolic compounds as well as their glycosides and esters along with their insoluble-bound corresponding parts that are linked with polysaccharides exist in cell walls, are present in cereal and millet grains (Shahidi and Chandrasekara 2013). Those phenolics which are extracted into mixtures which are aqueous or aqueous-organic based are known as soluble phenolics (Shahidi and Chandrasekara 2013). Soluble phenolics consists of those phenolic compounds which

exists in free, non-coupled form along with those phenolic compounds joined to soluble carbohydrates through ester and ether bonds (Shahidi and Chandrasekara 2013). Phenolic compounds which are mostly form ester bonds with polysaccharides providing cross-linkage between cell polymers are known as insoluble-bound phenolic compounds. The total phenolic content (TPC) of insoluble-bound, esterified, free and etherified sections of millet grains were ranged as 3.2–81.6, 0.25–2.02, 0.55–16.2 and 0.32–3.94 μmol ferulic acid equivalents (FAE)/g fat free meal respectively (Shahidi and Chandrasekara 2013).

Phenolic compounds or polyphenols present in cereals include flavonoids, phenolic acids, alkyl resorcinol and coumarins. In plant foods, phenols provide colour, oxidative stability, flavour, taste and texture (Naczka and Shahidi 2004). These compounds are principally located in bran and have nutraceutical properties. The two categories of phenolic acids are: hydroxycinnamic acid and hydroxybenzoic acid (Fig. 1). Hydroxycinnamic acid includes ferulic acid, caffeic acid, sinapic acid and *p*-coumaric acid whereas, on the other side, hydroxyl benzoic acids involve vanillic acid, protocatechuic acid, *p*-hydroxybenzoic acid and syringic acid. In millet grains, hydroxycinnamic acids and their derivatives (HCAS) are mostly located in the insoluble-bound phenolic fraction (Shahidi and Chandrasekara 2013). Dimers and trimers of ferulates which have relatively higher antioxidant

potential have been accounted for in millet grains in addition to various monomeric compounds. In finger millet, it has been reported that the phenolic compounds are mostly in the free form (71%). Major free phenolic acid among vanillic, ferulic, gallic and caffeic acid is protocatechuic acid (45 mg/100 g) (Subba Rao and Muralikrishna 2002; Shahidi and Chandrasekara 2013). Flavonoids include flavones, flavanones, anthocyanins, flavonoids and flavanols. Coarse grains contain various flavonoids which are typically found in the pericarp. Peonidin, malvidin, delphinidin, petunidin, cyanidin and pelargonidin are the six most common anthocyanidins located in cereals. Maize consists of petunidin-3-rutinosides, cyanidin-3-galactosides, pelargonidin glycosides, cyanidin-3-glucosides, peonidin-3-glucosides and cyanidin-3-rutinosides (McDonough et al. 2004; Prior et al. 2005). Sorghum contains a variety of anthocyanidins which includes 7-methoxyluteolinidine, apigenin-5 glucosides, 7-methoxy-5-glucosides, luteolin-5-glucosides, apigenin din and 5-methoxyapigeninidin. Sorghum consists of an inimitable member of the anthocyanidin group called 3-deoxyanthocyanidin which is very stable at high pH and makes sorghum a great food colourant. Barley contains petunidin-3-glucosides, cyanidin, pelargonidin glycosides, delphinidin, cyanidin-3-glucosides. Vitexin, isovitexin, apigenin, tricrin and glycosylvitexin are few of the flavones reported in oats. Flavones present in pearl millet are glucosyl vitexin, vitexin and glycovitexin, whereas finger millet contains several flavones such as lucigenin-1tricrin,

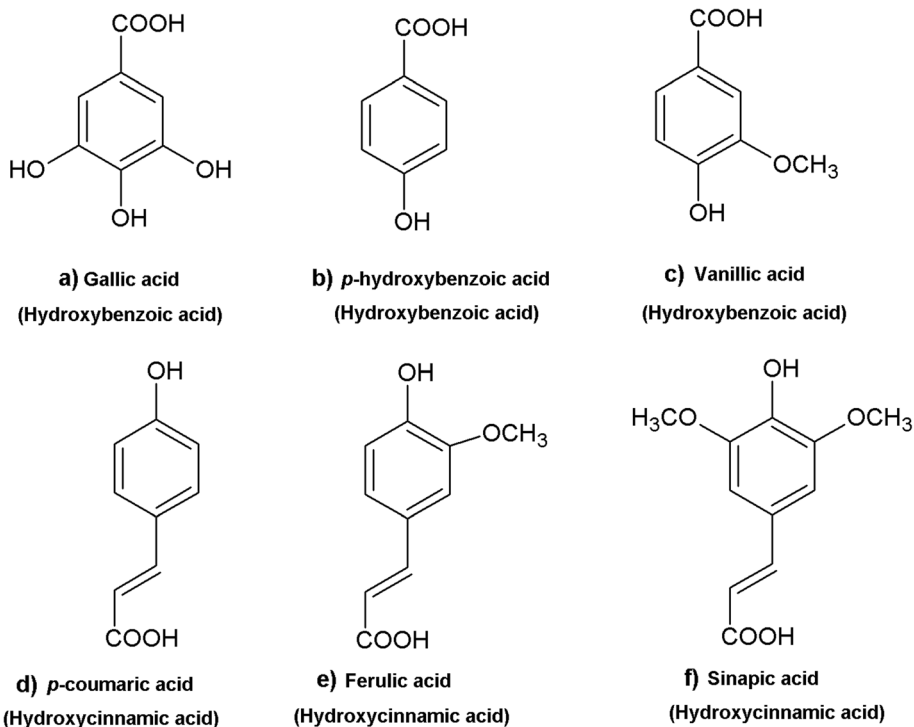


Fig. 1 Chemical structures of phenolic compounds present in cereal and millet grains

orientin, isovitexin, valanthin, isoorientin, vitexin and saponin (Subba Rao and Muralikrishna 2002).

Sorghum contains flavones namely kaempferol-3-rutinoside-7-glucuronide, eriodictiol, naringenin and eriodictyol-5glucosides (Dykes and Rooney 2006). Coarse cereals also hold condensed tannins. The main function of these tannins is to protect grains from biodegradation (Waniska 2000), however, they are also accountable for the astringency of the grain. Tannins possess gastro-protective, cholesterol-lowering, anticarcinogenic and anti-ulcerogenic properties (Dykes and Rooney 2006). Apart from sorghum and barley, the only millet which contains tannins is finger millet (Siwela et al. 2007). But these tannins sometimes have anti-nutritional properties which makes them undesirable. Oats carry amides of cinnamoyl anthranilic acids. These are known as avenanthramides and have great activity against oxidation and inflammation. Anti-atherogenic properties of oats are well-known because of the presence of these avenanthramides. Oats also contain a class of phytoestrogens which are called lignans. Other than oats, these lignans are also present in wheat and a member of a wheat tribe called rye. Oats contain approximately 8–299 $\mu\text{g}/100$ of lignan (Buri et al. 2004). When ingested, these are transformed into mammalian lignans and decrease the hormone-dependent cancers (Buri et al. 2004). Bran contains phytosterols which are cholesterol-like compounds. These phytosterols are present in cereals and exist in free forms, function as esters of fatty acids or fused with sugars (mainly glucose) or hydroxycinnamic acids (mostly ferulate). Corn, sorghum and oats contain 70–88 mg/100 g, 46–51 mg/100 g and 35–46 mg/100 g of non-bound phytosterol while barley contains 55–76 mg/100 g respectively (Ostlund Jr. 2002; Piironen et al. 2002).

Furthermore, it has also been reported that phenolic content, form of phenolic compounds along with their proportion and phenolic content coupled by esterification and etherification differs according to the variety of cereal and millet grains. It has been shown that brown varieties of finger millet contain higher phenolic content proportion (1.3–2.3 g%) as compared to the white varieties of finger millet (0.3–0.5 g%) (Shahidi and Chandrasekara 2013).

Bioactivities of phenolics in cereals and millets

The presence of phenolic compounds in food is directly linked with antioxidant potential (Gliwa et al. 2011). Due to the safety issues, natural antioxidants present in foods have gained wide attention in comparison with the artificial or synthetic counterparts. Antioxidant activity of cereal grains are presented via their reducing power, inhibition of reactive oxygen species, free radical scavenging and ferrous chelating properties (Shahidi and

Chandrasekara 2013; Kumari et al. 2019). These antioxidants have shown various important mechanisms which leads to number of advantages and beneficial health outcomes.

Anti-cancerous activity

Even today, when multiple strategies and technologies have been developed, cancer is a ruling cause of death worldwide. The most affected bunch of people are those belonging to the lower-income group because of unawareness and illiteracy. Many organisations surveyed in different parts of the world and as stated by the World Health Organisation (WHO), approximately 84 million people are likely to die between 2015 and 2025, if left without remedial interventions. Several studies reported that coarse cereals have abundantly present components which have very good potential in mitigating the risk factors linked with various types of cancers such as breast, colon, prostate and other. The anti-carcinogenic potential is a primitive disease-preventative effect of phenolic compounds. This involves inhibiting the commencement and progression of cancer cells by restricting the transformation of normal human cells, the growing lump angiogenesis, and metastasis. Furthermore, phenolic compounds restore the mechanism of tumor-controlling proteins like p21, p27, phosphatase, p53 and tensin homolog (PTEN) (Anantharaju et al. 2016). Gallic acid has been reported as an anticancer agent in many studies as it significantly reduces the proliferation of different carcinoma cells such as human prostate cancer cells and human leukaemia (HL)-60 (Shahidi and Yeo 2018). Methyl gallate has been known to suppress the growth of human epidermal cancer (A431) skin carcinogenic cells (Kamatham et al. 2015). The anti-cancerous capacity of phenolic acids including *p*-coumaric, vanillic, ferulic and feruloyl-L-arabinose has also been studied in various cell cultures. Ferulic acid has been reported to show the anticarcinogenic activity by regulating the cell-division cycle, disruption, apoptosis of human pancreatic cells (MIA PaCa-2) (Shahidi and Yeo 2018). Eitsuka et al. (2014) reported the symbiotic anticarcinogenic capacity of phenolic acids namely ferulic acid and δ -tocotrienol against the growth and proliferation of different carcinogenic cells. It has been investigated that the collaboration of ferulic acid and δ -tocotrienol presents an effective inhibitory effect on the growth and multiplication of pancreatic cancer (PANC-1), prostate cancer (DU-145), breast cancer in comparison with their separate use. Phenolic extracts present in millet showed anticancer activity against the HT-29 human colon adenocarcinoma cells (Shahidi and Chandrasekara 2013). Janicke et al. (2011) observed a significant protective effect of *p*-coumaric acid against the proliferation of colon cancer cells by hindering the cell cycle process of Caco-

2 colon cancer cells. Moreover, some flavonoids such as apigenin, troxerutin and myricetin have demonstrated strong anticancer potential. Apigenin presented a radiosensitive effect in human cancer cells in which the tumor cells which are preserved with apigenin displayed a higher rate of radiosensitivity and apoptosis behaviour in comparison with cells which were not treated with apigenin (Watanabe et al. 2007). Additionally, myricetin displayed an excellent anticancer potential in rats with colorectal cancer induced from 1,2-dimethylhydrazine (Nirmala and Ramanathan 2011). According to Kaur et al. (2014), consistent consumption of sorghum is correlated with reducing incidences of oesophageal cancer in several parts of the world. Phenolic content of sorghum is directly correlated with its antioxidant property (Dicko et al. 2005).

Anti-inflammatory activity

Inflammation is a crucial biotic response to any tissue injury. The response of immune system to any stimuli such as irritation, damage, or infection is the release of pro-inflammatory cytokines (Shahidi and Yeo 2018). Serious adult disorders such as CVDs, joint related disorders, cancer and allergies may result from overproduction of pro-inflammatory cytokines such as interferon tumor necrosis factor alpha (TNF- α) and interleukin (IL)-1b. Hence, suppressing of overproduction of these pro-inflammatory cytokines is essential to control and prevent these ailments. Phenolic compounds have been widely used to treat inflammation and associated disorders since prehistoric era. Pragasam et al. (2013) studied the anti-inflammatory potential of *p*-coumaric acid by observing the TNF- α expression in synovial tissue of arthritic rats. Strong anti-inflammatory activity was displayed by *p*-coumaric acid as it reduced the inflammatory mediator TNF- α expression. Anti-inflammatory potential of ellagic and caffeic acid was also reported by Chao et al. (2010). Both caffeic acids and ellagic acids were fed to mice by mixing it into their regular diet in the ratio of 2.5 and 5.0%. Inculcating these phenolic acids resulted in the reduction of expression of inflammatory mediators. Hämäläinen et al. (2007) studied the anti-inflammatory activities of flavonoids including kaempferol, quercetin, pelargonidin, isorhamnetin as well as genistein. All of these flavonoids listed blocked iNOS protein by inhibiting main transcription factor of iNOS which is κ B (NF- κ B).

Antidiabetic activity

Willett et al. (2002) reported that risk factors related to diabetes tend to get lower in individuals consuming coarse cereals in their diets. These coarse cereals have a great role in weight management as these foods generally contain a very low glycaemic index and thus gives the person consuming

them a feeling of fullness and ensures satiety. Various studies suggested that energy-restricted diets based on foods that are low in glycaemic index result in greater weight loss than high-GI food-based diets (Foster-Powell et al. 2002). Individuals with Non-Insulin Dependent Diabetes Mellitus (NIDDM) have shown a considerable decrease in plasma glucose levels on consumption of finger millets-based diets (Shahidi and Chandrasekara 2013). According to Kaur et al. (2014), individuals with NIDDM showed an average increase in insulin and glucose levels. These results were taken when NIDDM suffered subjects were fed with breakfast cereal enriched with β -glucan. A combination of finger millet and kodo millet displayed a protective effect in Wistar rats against alloxan-induced oxidative stress and hyperglycaemia (Hegde et al. 2005). Chao et al. (2010) examined the effectiveness of caffeic acid and ellagic acid in controlling the diabetic kidney disease in the rat. Continuous feed of phenolic acids for 12 weeks suppressed the sorbitol dehydrogenase activity as well as the levels of sorbitol, fructose and urinary glycosylated albumin. Anti-diabetic potential by lowering the intestinal movement of glucose via S-Glut-1 has also been discovered by various polyphenols such as epicatechin, isoflavones, catechin and chlorogenic acid (Shahidi and Yeo 2018). One main therapeutic technique for treating diabetes mellitus is reduction of postprandial hyperglycaemia by inhibiting the enzyme action required for hydrolysis of complex sugars. Hence, amylase and glucosidase inhibitors may be helpful in reducing the postprandial hyperglycaemia which is the initial metabolic irregularity in type 2 diabetes (Shahidi and Yeo 2018).

Anticholesterolemic potential and inhibitory activity against CVDs

As stated by the WHO in 2010, 18.5 million people died of cardiovascular-related disorders, which accounts for 32% of deaths worldwide. Coarse grains have cholesterol-lowering properties and acts as an antioxidant and therefore, reduce the risk factors and incidence of Coronary Heart Diseases (CHD). Synergistic potential of phenolics in foxtail and proso millet was displayed in decreasing the level of triacylglycerol and foxtail millet was shown to lower the C-reactive proteins which is an inflammation related disorder in rats suffering from hyperlipidaemia (Shahidi and Chandrasekara 2013). This suggests potential applications of phenolic compounds in finger millet and proso millet in reducing the risk factors associated with CVD. Ferulic acid has been known to lower the prevalence of CVDs and other neurodegenerative diseases (Shahidi and Yeo 2018). Another factor which may help in lowering the incidence of CVDs are dietary antioxidants such as millet phenolics which prevents LDL oxidation (Shahidi and Chandrasekara 2013). It has been reported that millet phenolics displayed a strong inhibitory activity against copper catalysed low-

density lipoprotein cholesterol oxidation in vitro (Shahidi and Chandrasekara 2013). Flavonoids and anthocyanins present in coarse grains have antioxidant properties whereas phytosterols, policosanols, fibres and β -glucans have anticholesterolemic properties.

Anti-obesity activity

Various studies suggested that better body weight management is directly linked with high fibre diets. It was reported that anthocyanidins, which are also stated as an effective metabolic modulator of adipose tissue, displayed an excellent capacity in attenuating obesity, suppressing dysfunction of fat cells, and reducing accumulation of fat in adipose cells (Shahidi and Yeo 2018). Coarse cereals such as oats, barley are rich sources of fibres and hence, provide good satiety value, which further reduce the appetite and therefore, help in better weight management (Kaur et al. 2014).

Antibacterial activity

Antibacterial or antimicrobial agents kill or inhibit the action of bacteria without damaging adjacent cells and tissues. These polyphenols also have antimicrobial activity (Călinoiu and Vodnar 2018). Phenolic compounds present in the outermost layer of plant organs function as an inhibitory factor for the physical invasion by microbes. It has been reported that phenolic acids including ferulic acid, caffeic acid and *p*-coumaric acid showed antifungal effects (Shahidi and Chandrasekara 2013). Phenolics present in cereal grains inhibits the growth and multiplication of blood-borne hepatitis C virus (HCV) which further leads to liver cirrhosis and hepatocellular carcinoma (HCC) (Shahidi and Yeo 2018). It was also reported that growth of cariogenic and periodontopathic bacteria can be suppressed by gallic acid and various derivatives. Gallic acid and methyl gallate have also shown strong antibacterial activity against *Salmonella* (Choi et al. 2008). An inhibitory activity of a combination of gallic acid and methyl gallate was stated against herpes viruses (Shahidi and Yeo 2018). Furthermore, phenolic compounds such as tannins, isoflavones and stilbenes showed antibacterial activity against *E. coli*, *Salmonella*, *Bacillus* and *Clostridium* and showed inhibitory activity against the growth of yeasts and viruses (Alvesalo et al. 2006). Moreover, according to reports by Taguri et al. (2006), approximately 22 polyphenols showed antimicrobial activity against 26 microbial strains.

Beneficial effects of phenolics in cereals and millets on health

Besides their crucial role in plants, phenolic compounds or polyphenols in our diet provide various beneficial effects on our health (Table 2). However, health benefits of these

phenolics present in foods depends on the rate of absorption and bioavailability. It is evolving that phenolic compounds may have much more vital effect *in vivo* like improving endothelial function, anti-inflammatory properties and cellular signalling (Brglez Mojzer et al. 2016). Polyphenols also contain flavonoids which provide anti-inflammatory, gastro-protective, antioxidative, anti-allergic and anticarcinogenic properties (Duodu and Awika 2019). Some studies have also reported that flavones present in pearl millet are goitrogenic (Shahidi and Chandrasekara 2013). Barnyard millet grains contain flavones such as luteolin and tricetin. Luteolin and its glycosides showed beneficial activity such as anti-inflammatory, antioxidant and anticancer (Han et al. 2007). Tricetin on the other hand is known for its anti-tumor property as well as its antileukemic activity (Shahidi and Chandrasekara 2013). Lignans also come under the category of polyphenolic compounds. Mammalian lignans are unique and beneficial in promoting health and fighting against various chronic degenerative diseases because of strong antioxidant activity (Gani et al. 2012). Phytic acid is also considered to be a very strong antioxidant *in vitro*. Because of the ability of phytic acid to chelate free Fe, it terminates the Fe catalysed oxidative reactions (Gani et al. 2012). Phytic acid also has the ability to overpower lipid peroxidation. It also prevents renal stone development in the body by inhibiting the formation of crystals of calcium oxalate salts in the urine (Gani et al. 2012; Liu 2013). Various phenolic acids such as vanillic, ferulic, quercetin, gallic and *p*-coumaric acids have been reported to be responsible for suppressing cataract of the eye lens (Shahidi and Chandrasekara 2013).

Bioavailability of bioactive active compounds in cereals and millets

Prospective absorption of an element can be determined by measuring the amount of that element when it passes via cell membranes in the intestinal area and is present for activity inside the cells (Kumari et al. 2019). Bioavailability is defined as the quantity of compound which is released from a solid food mixture into the gut (Shahidi and Peng 2018). Phenolic compounds present in foods undergo various levels due to digestion in the gastric and intestinal phases (Kumari et al. 2019). The remains after the intestinal digestion enter colon and go through fermentation process with the help of bacterial enzymes that are responsible for the release of bound phenolics. In the large intestine, phenolic acids that exist in free form may apply their bioactivity on-site or by bioconverting into colonic metabolites on the epithelium-site (Kumari et al. 2019). Stomach, colon and intestinal lumen have the ability to recollect significant quantities of unabsorbed phenolics from food which may play a vital role in protecting gastrointestinal tract (GIT) from oxidative stress (Jenner et al. 2005). Unabsorbed

Table 2 Bioactivities of phenolic acids and flavonoids in different cereal and millet grains

Grains	Phenolic compound	Bioactivities	References
Phenolic acids			
Cereals Barley, sorghum, wheat, rice, oats, maize,	Ferulic acid	Anti-carcinogenic Prevents and controls type 2 diabetes Suppressing hypertension	Fahrioğlu et al. (2016) Narasimhan et al. (2015) Hou et al. (2004) Kaur et al. (2014)
Millet Finger, pearl and foxtail millet			
Cereals Sorghum, rice	Gallic acid	Anti-cancer Antimicrobial	Yeh et al. (2011) Kang et al. (2008) Kaur et al. (2014)
Millet Finger millet			
Cereals Barley, maize, oats, rice, sorghum	<i>p</i> -coumaric acid	Anti-cancer	Janicke et al. (2011) Kaur et al. (2014) Dykes and Rooney (2007)
Millet Finger, pearl and foxtail millet			
Cereals Maize, oats, rice, sorghum, wheat	Chlorogenic and caffeic acids	Anti-carcinogenic and anti-mutagenic	Mennen et al. (2005) Kaur et al. (2014) Dykes and Rooney (2007)
Millet Finger, pearl and foxtail millet			
Cereals Maize, oats, rice, sorghum, wheat, barley	Vanillic acid	Anti-inflammatory Antioxidant	Calixto-Campos et al. (2015) Dykes and Rooney (2007)
Millet Finger and pearl millet			
Flavonoids			
Cereals Oats, sorghum	Apigenin	Anti-inflammatory Anti-cancer	Ju et al. (2015) Watanabe et al. (2007) Dykes and Rooney (2007)
Millet Finger millet			
Cereals Maize, oats	Kaempferol	Anti-inflammatory Anti-cancer	Calderon-Montano et al. (2011) Devi et al. (2015) Kaur et al. (2014)
Cereals Barley and sorghum			
Cereals Barley and sorghum	Catechin	Preventing Parkinson's and Alzheimer's diseases	Dai et al. (2006) Kaur et al. (2014) Shahidi and Yeo (2018)
Cereals Oats, wheat			
Millet Barnyard millet	Tricin	Anti-obesity Anti-inflammatory	Lee and Imm (2017, 2018) Dykes and Rooney (2007)
Cereals Oats, sorghum			
Millet Foxtail and Barnyard millet	Luteolin	Antioxidant Anti-inflammatory	Pradeep and Sreerama (2018) Dykes and Rooney (2007)
Cereals Oats, sorghum			

phenolic compounds also play a crucial role in reducing the risk factors associated with gastric, rectal and colon cancers (Jenner et al. 2005).

Antinutritional factors

Coarse grains contain various antinutrient factors that restrict their nutritive value. Phytic acid, tannins and enzyme inhibitors are the main antinutrients present in coarse cereals.

Phytates

Phytates, also referred to as phytic acids, are generally present in the plant organs naturally. The amount of

phytic acid in these cereals are about 825.7 mg/100 g (ElMaki et al. 2007). According to various reports, phytates are known to hinder the enzyme activity which is essential for degradation of protein in the stomach and small intestine (Kies et al. 2006). It was also reported that phytates generally affect the bioavailability of various minerals. Phytic acid have been reported to have a strong effect on new-borns, pregnant and lactating women when large portions of cereal-based foods are consumed (Al Hasan et al. 2016). Due to negatively-charged structure, phytic acid generally attracts and binds to the positively-charged ions such as calcium, zinc, iron and magnesium to form complexes and lowers

the bioavailability of these metal ions. Primarily because of this chelating property of phytates, they are viewed as the most effectual anti-nutrient and a reason for minerals related deficiencies in both human and animal diets (Grases et al. 2017).

Tannins

Tannins comes under the category of phenolic compounds. The major property of tannins is that they can precipitate proteins. Tannins are considered to be secondary compounds and are generally formed in fruits, bark and leaves of the plant (Timotheo and Lauer 2018). Tannins usually form reversible and permanent tannin-protein complexes between the hydroxyl group of tannins and carbonyl group of proteins which further affects digestibility of proteins and leads to depletion of essential amino acids (Raes et al. 2014). There are two types of tannin groups in nature: hydrolysable and condensed. Peanuts and millets hold condensed tannins in plenty amounts (Chandrasekara and Shahidi 2011). Hydrolysable type of tannins is promptly broken down in ruminants during the digestion process. It was also reported that these breakdown products may contain a lot of compounds which can be toxic in nature. On ingestion, tannins make complexes with protein which can further cause inhibition in the activity of many digestive enzymes (Joye 2019).

Enzyme inhibitors

Proteinases are those enzymes which play a vital role in enhancing overall nutritional and functional properties of different protein molecules (Salas et al. 2018). Number of proteolytic activities are completed by proteases inhibitors (PIs). Cereal grains mostly comprised of plant serpins which is one of the biggest PIs family. These serpins are also knowns suicide inhibitors and are also found in various other species in plant kingdom. Serpins are known to have effective inhibition activity. It generally inhibits activities of trypsin and chymotrypsin by attacking the most reactive sites of enzymes. PIs are considered as natural inhibitors and over the years have become a significant research topic because of their active way of inhibiting enzymatic activity with the help of forming protein-protein based complexes. These PIs limit the enzymatic activity by blocking the most active site of enzyme via catalytic mode. The two main types of PIs are Bowman-Birk inhibitor and Kunitz trypsin inhibitor. There are many enzyme inhibitors in plant-based foods but those inhibitors that affect both trypsin and α -amylase activities are present in almost all cereal grains and cereal-based foods. α -amylase chiefly controls the breakdown of complex carbohydrates into simpler ones. Hence, those enzyme inhibitors

that particularly inhibit the activity of α -amylase will lead to delay in carbohydrate digestion and absorption. Rise in carbohydrate digestion time further results in reduction in the rate of glucose absorption which directly affects the normal postprandial blood glucose level. Trypsin inhibitors when occurs in human diets results in reduced growth rate due to decreased digestion of proteins and amino acids accessibility also leading to pancreatic problems (Adeyemo and Onilude 2013).

Effect of germination on antinutrients in coarse cereals and millets

Nutrient availability of coarse cereals can be improved by a simple traditional food processing operation called as malting/germination (Subba Rao and Muralikrishna 2002; Hejazi et al. 2016). With the help of this *in vivo* biotransformation process, hydrolytic enzymes improve drastically, which further enhances the bioavailability of vitamins, carbohydrates, minerals and proteins (Hejazi et al. 2016). In the presence of boiled water or milk, the amylases present in the malted flour hydrolyse starch into sugars which further leads to good taste, nutrient-dense and low bulk slurry that can be utilised as weaning food (Hejazi et al. 2016). The two main factors to observe throughout the germination process is germination duration and temperature. These two factors greatly influence the nutritional improvement of cereal grains (Narukawa et al. 2012; Sawant et al. 2012). In addition to all the benefits listed above, germination is also known as one of the most effective method for lowering the anti-nutrients of cereals grains (Nkhata et al. 2018). When seeds undergo germination, it leads to the activation of enzyme phytase which further reduces phytate and leads to reduced phytic acid levels. Germination generally affects the physical structure, nutritional composition and biochemical activity of foods. Germination results is lowering the concentration of various strong anti-nutrients like tannin and phytic acid which directly increases the bioavailability of various minerals in the body and hence results in improved nutritional value of food product (Oghbaei and Prakash 2016). It was also reported that maximum decrease in antinutrient content was noted when millets undergone germination as compared to other methods such as soaking, fermentation and milling (Singh et al. 2017). According to a study by Abioye et al. (2018) phytate level in finger millet keeps decreasing when germination duration increases. A reduction in tannin content in sorghum is also reported, which is ascribed to leaking in the malting medium (Singh et al. 2015). An increase of polyphenol oxidase activity and various other catabolic enzymes were noticed on germination (Singh et al. 2015).

Effect of probiotic fermentation on antinutrients in coarse cereals & millets

Coarse cereals and millets play a very crucial role in human diets. The combination of cereals with other methods result in better nutrient profile and an enhanced amino acid pattern. However, the chief hindering factor in the bioavailability of coarse cereals are the high amount of antinutrients and inhibitors. Likewise, tannins and phytic acid are also known to hamper the activity of amylolysis and proteolysis (Peyer et al. 2016). Several methods and combination of methods is known to decrease the antinutrient content. Fermentation is said to be the most crucial and popular process which considerably lowers the antinutrients content and hence, enhance the overall nutritive value of coarse cereals and other food grains. Fermentation of cereals is a primaevial and economical food preservation method. In most of the developing countries, within the aboriginal communities, fermenting cereals is a traditional and regular practice (Blandino et al. 2003). Fermentation aids in the multiplication of selected microorganisms and their metabolic-related activities in food. Fermentation not only enhances the nutritional value but also improves the digestibility of raw products. It improves the sensory characteristics and also enhances the functional qualities of foods and beverages (Blandino et al. 2003). Such type of food or food product would be beneficial for all the age groups including children, adults and senior citizens. This type of food mixture can be consumed by a large group of the vegetarian population of the developing countries. Due to many issues like lactose intolerance, vegetarianism among the population and costly dairy products, the concept of combination of probiotic and coarse cereals was developed (Coda et al. 2010). Cereal grains have the capability to provide probiotic, prebiotic

as well as general whole cereal benefits (Lamsal and Fau-bion 2009). Many researchers suggested that probiotic yeasts have the perfect characteristics to be developed as probiotic and cereal-based functional product. Yeasts have the capability to maintain its viability and stability when food processing conditions changes (Peyer et al. 2016). Yeasts can tolerate a wide variety of salt concentration, pH and oxygen activity (Arroyo-López et al. 2008; Bonatsou et al. 2015). Many researchers concluded that fermentation of coarse cereals and millets with probiotics significantly impact the antinutrients content (Table 3). Sindhu and Khetarpaul (2001) reported that fermentation with different probiotics resulted in further reduction in the antinutrient contents. It was reported that when millet was subjected to fermentation for 12 and 24 h, various anti-nutrients such as PIs, phytic acid and tannins were reduced (Coulibaly et al. 2011). In a recent study, to examine the effect of fermentation on anti-nutritional activity, maize flour was undergone fermentation with a consortium of Lactic Acid Bacteria (LAB) with 12 h intervals in between. The results displayed that with increase in fermentation time, considerable deduction in antinutrients were noticed in fermented maize flour (Chibuikie Ogodo et al. 2014). Fermentation performed with single cultures of *L. casei* and *L. plantarum* showed a decreasing trend in phytic acid by about 66 and 64% respectively. However, when a combination of these cultures was used for fermenting the food mixture, a complete elimination of phytic acid was observed (Sindhu and Khetarpaul 2001). Polyphenol content decreased by 31% after combination culture fermentation with *S. boulardii* and *L. plantarum* (Sindhu and Khetarpaul 2001). No trypsin inhibitor activity was found neither in single nor in sequential fermentation (Sindhu and Khetarpaul 2001).

Table 3 Nutritional and functional effects of different probiotic strains on cereals and millets (Verni et al. 2019)

Probiotic strain	Effect
<i>Lactobacillus plantarum</i> LB1	Increase antioxidant activity Increase phenolic content Decrease anti-nutritional factors
<i>Lactobacillus brevis</i>	High fibre solubility Increase peptide and free amino acid content
<i>Lactobacillus bulgaricus</i>	High fibre solubility Increase peptide and free amino acid content
<i>Lactobacillus rhamnosus</i> GR1	Increase folic acid High fibre solubility
<i>Saccharomyces cerevisiae</i>	Anti-stress Anti-fatigue Anticancer
<i>Bacillus subtilis</i>	Antioxidant
<i>Debaryomyces hansenii</i>	Production of phenolics and xylitol
<i>Lactobacillus reuteri</i>	Increase of gamma-linolenic acid and β -carotene

Effect of germinating and non-germinating seeds on pH, acidity, cell count and proximate composition in cereal foods

According to Kaur et al. (2014), due to germination, the titratable acidity of coarse cereals tends to increase and thus there is a considerable reduction in pH of these germinated samples. While, on the other side, the samples which doesn't undergo germination has lesser titratable acidity and hence higher pH. The decrease in pH during germination maybe because of hydrolysis of starch into sugars, which is promptly used by the organisms and converted into lactic acid. Germinated cereal based food products have higher cell count and better growth of bacteria as compared with the non-germinating cereal-based food product (Arora et al. 2010). The reason for higher cell count may be resulted from hydrolysis of flours that undergone germination as this further provides media with a better environment for the optimum growth of these organisms. The moisture, ash and fat content of germinated and non-germinated food mixtures did not differ considerably (Arora et al. 2009). The protein and fibre values of food mixture containing germinated cereal flour are notably lower in comparison with the food product developed from non-germinated cereal flour. Similarly, according to the results, Hejazi et al. (2016) also reported an enhancement in protein extractability and reduction in the amount of total protein in germinated finger millet. Elkhalfa and Bernhardt (2010) noted a considerable increase in the nitrogen solubility index of sorghum which might be because of the steady breakdown of stored protein into amino acids and short length peptides caused by rising the concentration of protease enzymes. This further results in increase in the overall nutritive value of germinated sorghum grains by gradually increasing its protein digestibility and hence, partially hydrolysed reserve proteins may be more easily accessible for pepsin attack. This result implies that flour made from the germinated sorghum would be excellent firming agent and would be beneficial in food products such as pie and dishes which involve thickening or gelling properties as germination leads to denaturation of proteins which further results in more aggregation. Food mixture which was subjected to germination has better thiamine and niacin content as compared to the food mixture which was not germinated (Hejazi et al. 2016). It was also reported that germination was found to be effective in increasing the HCl extractability of various minerals including calcium and iron. Extractability of iron and calcium increased from 18.1 and 76.9% in raw finger millet to 37.3 and 90.2%, respectively whereas extractability of a trace element like zinc when germinated increased from 65.3 to 85.8% which was due to reduction in phytic acid content from 0.36 to 0.02 g/100 g dry

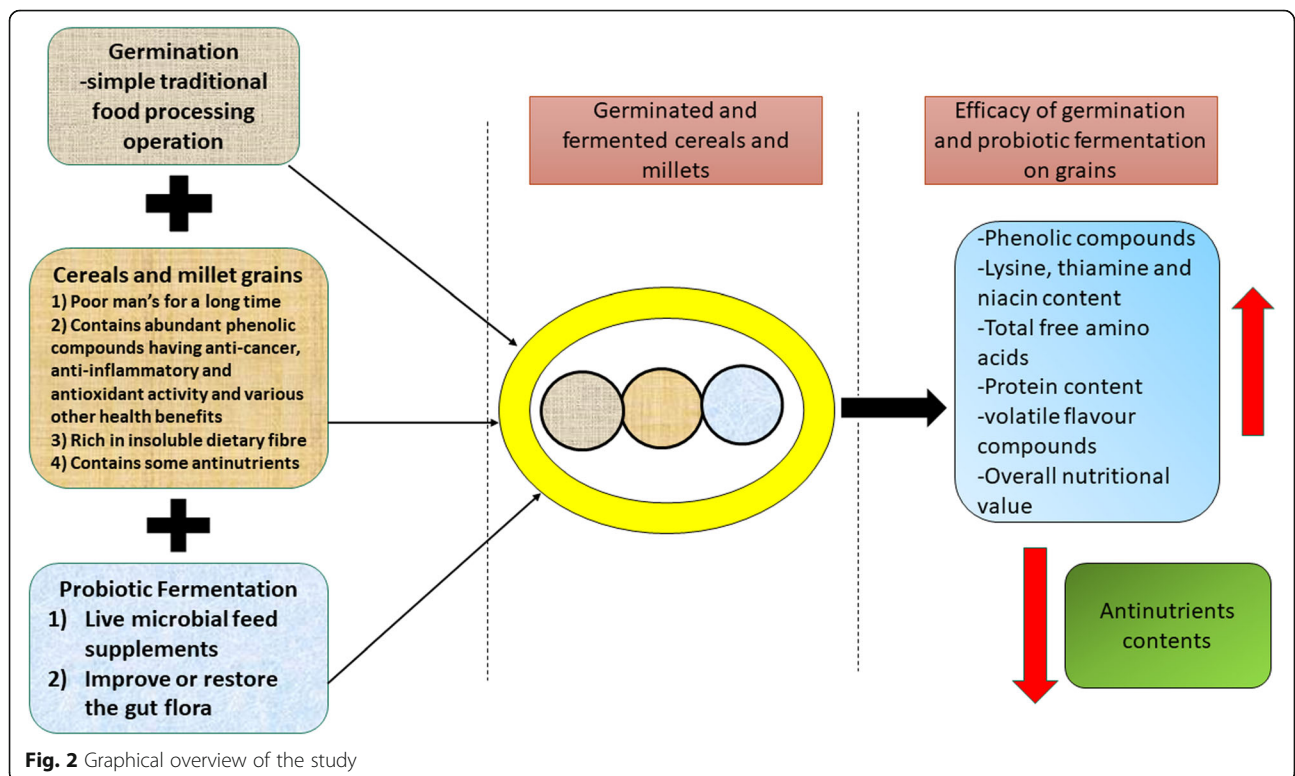
matter (Mbithi-Mwikya et al. 2000). According to Arora et al. (2009), the concentration of thiamine and niacin content after germination was almost doubled. Germinated food mixture contained notably higher lysine content in comparison with food mixture which was not germinated (Arora et al. 2009). According to Hejazi et al. (2016), during germination, there was a prompt rise in total free amino acids by about 4–6 folds. The starch content decreased significantly in germinated food mixture in comparison with the food mixture which is not germinated. This may be because germination leads to the enzymatic hydrolysis which results in the conversion of starch into simpler sugars. The concentration of both types of sugar: reducing and non-reducing indicated a rising trend in germinated based food in comparison with non-germinating food. On the other side, food mixture developed from germinated flour has significantly lower total, soluble and insoluble dietary fibre contents in comparison with the food mixture formulated flour which was not germinated (Arora et al. 2009). It might be because of the fact that germination caused a considerable decrease in all the dietary fibre components. Germinated cereals contain an enzyme called β -galactosidase which partly attacks galactomannan to form galactose. Thus, the reduction in the polysaccharide and mucilage concentration might be ascribed to their disintegration and utilisation by the growing sprouts (Hooda and Jood 2003). Due to the breakdown of high molecular weight polymers in the process of germination, the cereal grains often lead to grouping of bio-functional substances and the enhancement of the organoleptic properties because of the softening of texture and improvement of flavour in barley, finger millet and oats (Subba Rao and Muralikrishna 2002).

Effect of probiotic fermentation on pH, nutrient composition and volatile compounds in cereal-based foods

Those samples which contain coarse cereals and millets when subjected to probiotic fermentation results in a considerable reduction in pH and rise in titratable acidity. Such type of trend was commonly reported when a variety of foods including cereal-based mixture and finger millet undergoes lactic acid fermentation (Sindhu and Khetarpaul 2001). According to Sindhu and Khetarpaul (2001), the most effective bacteria in lowering pH other than yeast is *Lactobacillus spp.* The moisture, ash and fat contents of food mixtures after fermentation with probiotics did not vary considerably (Sindhu and Khetarpaul 2001). Crude protein and crude fibre contents of food mixture decreased considerably after probiotic fermentation. It was reported that fermentation of food causes the solubilisation of fibre which indirectly

results in a reduction in crude fibre content (Arora et al. 2010). Many researchers also reported that fermenting natto and tempeh results in a notable rise in free amino acids content (Nassar et al. 2008). This can be due to the fact that throughout the fermentation process, microbes release various hydrolytic enzymes which are responsible for the conversion of complex proteins into simpler proteins (Nassar et al. 2008). Likewise, increased protein content due to fermentation has also been reported in millets (Elkhalifa et al. 2007). Additionally, Fermentation has also known to increase the nutritional composition of various cereal grains by increasing such as tryptophan, lysine and methionine (Mohapatra et al. 2019). As far as B complex vitamins are concerned, cereal-based food mixture which was fermented with probiotic strain resulted in enhancement of thiamine and niacin contents. Similarly, Arora et al. (2010) reported that when pearl millet was fermented with *L. acidophilus*, there was an insignificant rise in thiamine content but when fermentation of pearl millet was done with the help of *Saccharomyces cerevisiae* and *Saccharomyces diastaticus*, thiamine content was almost doubled up. When the cereal-based food mixture fermented with *L. acidophilus*, it caused a considerable increase in lysine content (Arora et al. 2010). Likewise, Elkhalifa et al. (2007) showed that fermentation causes a significant increase in lysine and methionine concentration. This is in agreement with the other findings which shows that

fermentation causes an increase in lysine content and overall availability. Hassan et al. (2006) reported that the content of total free amino acids showed a rapid increase of about 3–5 folds when subjected to germination and this amount doubles up when subjected to fermentation (Fig. 2). However, on fermenting with the probiotic organism, starch content was notably decreased. This caused a rise in content of reducing sugar and a corresponding decrease in total soluble and non-reducing sugar contents. Lower starch content in fermented food product may result from fermenting microbes which causes the hydrolysis of polysaccharides (Sindhu and Khetarpaul 2001). Fermented mixtures contain soluble sugars which are used by the microflora as a source of carbon and the fermented food product may eventually contain a lower amount of sugars. According to various researches, in the starting of the fermentation process, levels of sugars seems to be higher, but as the fermentation progresses, the levels of sugars show a downward trend. This is because of the prolonged period of fermentation which leads to utilization of sugar by the fermenting microflora. The considerable reduction was also observed in total and insoluble dietary fibre and improvement in soluble fibre of fermented cereal-based food mixture, due to increased activity of hydrolysing microbial enzymes. Cereals contain some indigestible oligosaccharides such as stachyose, verbascose, and raffinose which further results in flatulence



in stomach, diarrhoea and digestion problems. These types of sugars have some α -Dgalactosidic bonds which are somewhat heat resistant. These bonds can be devalued by some LAB including strains of *L. fermentum*, *L. plantarum*, *L. salivarius*, *L. brevis*, *L. buchneri* and *L. cellobiose* as these strains include galactosidase enzymes (Holzapfel 2002). During the process of fermentation, these microbes completely disintegrate these oligosaccharides and convert them into beneficial di- and mono-saccharides (Leroy and De Vuyst 2004). Fermentation in cereal grains also leads to release of various bioactive compounds by structural break down of cereal cell wall (Liukkonen et al. 2003). When already germinated rye was subjected to fermentation, there was a rapid increase in the levels of phenolic compounds, lignans and folates (Singh et al. 2015). The folate levels were improved up to seven-fold and that of phenolic compounds up to ten-fold after undergoing both germination and fermentation.

Ogunremi et al. (2015) reported that probiotic strain *Pichia kudriavzevii* OG32 when added in the cereal-based food mixture enhanced the formation of volatile flavour compounds in the fermented product.

Role of cereals in synbiotics

The significance in using articulations of prebiotics and probiotics appeared when it was found out that these components have the ability to enhance the intestinal homeostasis and overall health of the individual (host) (Pandey et al. 2015). The combination of synbiotics and cereals can do wonders in improving overall health and bioavailability of various vitamins and minerals in the body. Salmerón (2017) also suggested the potential application of synbiotics in modulating lipid metabolism by controlling blood lipid levels during *in vivo* tests of *Lactobacillus acidophilus* based fermented rice bran. Synbiotics alter the intestinal microbiota and enhance the microbes-based interactions with the immune system. The concept of synbiotics have the encouraging ability to be utilised in the connection between gut and brain and also have the potential in dealing and treating autism (Dar et al. 2017).

Fermented foods based on coarse cereals and millets in the market

Boza

Boza is a popular fermented food product in the Balkan countries of region naming Turkey, Romania, Bulgaria and Albania (Nyanzi and Jooste 2012). It is a traditional highly viscous product and includes ingredients such as millet, wheat, rice, maize, rye and other cereals mixed with sucrose. Boza is very famous for its pleasant taste, unique flavour and overall nutritional value. Unconstrained fermentation involves LAB and yeasts (Nyanzi and Jooste 2012). There are

various LAB species isolated from Boza includes *L. mesenteroides subsp. Mesenteroides*, *L. oenus*, *L. brevis*, *L. mesenteroides subsp. Dextranicum*, *L. fermentum*, *L. raffinolactis*, *L. plantarum*, *L. coryniformis*, *L. sanfrancisco* and *L. coprophilous*.

Kvass

Kvass is a popular non-alcoholic fermented cereal-based beverage mainly consumed in Eastern Europe. This beverage is made from sucrose, rye flour, rye and barley malt and stale rye bread. It is manufactured with the help of two methods. The first method involves the hydrolysis of gelatinised starch by the utilisation of malt enzymes, while the second technique includes the utilisation of stale dough bread in which sugars are obtained for the fermentation of yeasts with the help of bread-making process (Nyanzi and Jooste 2012). Various microorganisms found in kvass are *L. casei*, *L. mesenteroides* and *S. cerevisiae*.

Koko

Koko is impulsively fermented beverage based on millets. This sort of beverage is chiefly consumed in Northern Ghana. Microbial species found in Koko during fermentation are *L. fermentum* and *Weissella confuse*. Many studies reported that strains isolated from Koko showed tolerance against 0.3 ox gall bite, great antimicrobial activity, resistance against acids at pH 2.5 (Nyanzi and Jooste 2012). These are the features of excellent and fine quality probiotic strains.

Proviva

Proviva is popular to be the first oats-based probiotic beverage. It has been very popular in Sweden since 1995. Malted barley in proviva functions as a liquefying agent. The predominant microorganism in Proviva is *L. plantarum*. A mixture of fruit juice and 4% oatmeal having a probiotic bacterial count of 5×10^{10} CFU/L (Nyanzi and Jooste 2012).

Fermented foods based on coarse cereals and millets developed

Barley, Coprecipitate, green gram and tomatoes (BCGT) food mixture (Sindhu and Khetarpaul 2001)

Aboriginally formed BCGT food product contains sprouted green gram slurry, barley-based flour, tomato pulp and milk precipitate (1:2:1:1 w/w). This type of food mixture was inoculated with 2% culture in liquid form. Two types of fermentation were done, i.e., single culture-based fermentation and sequential culture-based fermentation. Microorganisms mainly used are *S. boulardii*, *L. plantarum* and *L. casei*. Both types of fermentation techniques significantly decreased the phytic acid, trypsin inhibitor activity and tannic acid content

while correspondingly enhancing the in vitro starch and protein digestibility.

Millet based probiotic yoghurt (Di Stefano et al. 2017)

Probiotic yoghurt has been developed by using a pure culture of *Lactobacillus rhamnosus* GR-1 and *Streptococcus thermophilus* C106. This probiotic yoghurt developed contains fiti sachet. It has gained wide acceptance in the developing countries to reduce the incidence and risk factors associated with malnutrition and other nutrition-related disorders. The main aim of this study was to analyse the fermenting ability of millet on the addition of fiti sachet consortium. Fermentation of millet was proved to be advantageous as many organic acids were quantified, especially phytic acid, which was observed to be decreasing when fermentation time increases, hence, this results in the improvement in bioavailability of particular micronutrients.

Cereal mix -based probiotic functional food (Ogunremi et al. 2015)

A cereal mix containing pearl millet, white sorghum, red sorghum and wheat was undergone fermentation with probiotic strain *Pichia kudriavzevii* OG32. This probiotic strain enhanced the viscosity of cereal mixture prepared with the inoculum size of 1.84×10^5 CFU/ml and simultaneously giving the highest viscosity of 1793.6 mPa. A total of forty volatile compounds were found in cereal mix based fermented food product, while esters and acids were considered to be in the largest percentage. This product scavenged 2,2-diphenylpicrylhydrazyl (DPPH) activity from a methanolic solution by 55.71%. Probiotic yeast used here enhanced the organoleptic and functional properties of the cereal-based mixture during the fermentation process.

Pearl millet-based food blend (Arora et al. 2010)

This type of food blend was prepared by mixing germinated pearl millet flour, whey powder and tomato pulp (2:1:1 w/w). Adding whey powder and tomato pulp not only improved the nutrient content of food mixture but also provided a perfect medium for the growth of probiotic *L. acidophilus*. Probiotic fermentation in pearl millet also enhanced the bioavailability of calcium, zinc and iron. Hence, pearl millet-based food blend provides unique nutritional and therapeutic value.

Finger millet and oats based synbiotic drinks (Dar et al. 2017)

A synbiotic drink was developed using finger millet, oats and double toned milk. Malt drink with the ratio of 60:40 (finger millets: oats) with three times of water was finalised based on the sensory evaluation conducted. The ratio of 47:53 (malt drink: double toned milk) was

finalised and selected. To further improve the nutritional and functional properties, rose syrup and marigold powder was added for flavour. The prepared drink was higher in carbohydrates, energy content, total solids and minerals, while it was low in lactose, cholesterol and fat in comparison with dairy milk. The composite drink was rich in healthy components such as anthocyanins, beta-glucan and soluble dietary fibre, these components are otherwise absent in dairy milk. This drink proves to be a good prebiotic due to the presence of dietary fibre.

Conclusion

This review is about the aptness of coarse cereals and millets as viable delivery vehicle for probiotic-based fermentation to develop a functional cereal-based probiotic product (Fig. 2). The formulation of functional fermented coarse cereals-based food products in association with specific probiotic microbial strain meets the ongoing demand for healthier, nutritional, functional and diversified foods. It may be concluded that association of germination along with probiotic fermentation of an indigenously formulated cereal-based food blend is a potential application for developing products with improved and better nutritional quality. Such type of fermented food blends not only provides distinctive nutritional and therapeutic value but also are safe for human consumption. Fermentation with probiotic has an effect on sensory and functional characteristics of cereal-based slurry. It can be concluded that with the incorporation of probiotic strain in the cereal-based food product, the bioactivity of various phenolic acids increases and there are improvements in flavour, colour and overall quality of the product. Therefore, from nutritional outlook, specifically for people who consume less vegetables and fruits than the daily recommended intake. Lastly, coarse cereals-based foods and beverages can be beneficial for health and to be used like prebiotics and probiotics. Although, it is crucial to note several challenges associated with coarse cereals grains and how they may evade in enhancing probiotic cereal food product delivery to the target population.

Future aspects and recommendations

The utilisation of a huge range of cereal substrates fermented with single or sequential probiotic microbial cultures can be found out with under-utilised and unpopular coarse cereals in association with different microbial strains and under different conditions. To substantiate such therapeutic and functional claims, pre-clinical and clinical trials can be done. The utilisation of probiotic microbial cultures in association with coarse cereals and millets has to be done on a number of discussions such as pathogen inhibitory capabilities, functional and technological properties.

Abbreviations

LAB: Lactic Acid Bacteria; CVD: Cardiovascular diseases; Pls: Protease inhibitors; TNF: Tumor necrosis factor; WHO: World Health Organisation; NIDDM: Non-Insulin Dependent Diabetes Mellitus; BCGT: Barley, Coprecipitate, Green gram and Tomatoes; NCDs: non-communicable diseases

Acknowledgements

None.

Authors' contributions

Savita Budhwar: Conceptualization, Validation and Supervision. Kashika Sethi: Literature Search, Writing- Original Draft, Writing- Reviewing and Editing. Manali Chakraborty: Editing. The authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on request.

Competing interests

None.

Received: 20 March 2020 Accepted: 4 May 2020

Published online: 01 June 2020

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