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Pearl millet processing and its effect on antinational factors: Review paper

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Abstract
Pearl millet is underutilized food grains in many countries despite which is rich source of micronutrient like iron, calcium zinc etc. However the processing rate of pearl millet is very low as compare to other cereals. Major issue of processing of pearl millet is its antinutritional factors and coloring property. India is one of the leading producers of pearl millet followed by African countries. Most important key point of pearl millet is drought resistant which can be tolerate over scarcity of water. Hence the regions of water scarcity will produce easily huge amount of pearl millet however poor processing rate due to many more reasons.
Purpose: Pearl millet (*Pennisetum glaucum*) is a rich source of nutrients as compared to the major cultivated cereal crops. However, major factors which limit its utilization are the presence of anti-nutritional factors (phytate, tannins and polyphenols) which lower availability of minerals and poor keeping quality because of higher lipase activity. Therefore, this paper aims to focus on the impact of different processing methods on the nutrient composition antinutrtional-nutritional components of pearl millet.
Design/methodology/approach: This is a literature review study from 1983 to 2017, focusing studies related to pearl millet processing and their effectiveness in the enrichment of nutritional value through reduction of anti-nutritional compounds.
Findings: From the literature reviewed, pearl millet processing through various methods including milling, malting, fermentation, blanching and acid as well as heat treatments were found to be effective in achieving the higher mineral digestibility, retardation of off flavor, bitterness as well as rancidity problems found during storage of flour.
Originality/value: Through this review paper, possible processing methods and their impact on the nutrient and antinutrient profile of pearl millet are discussed after detailed studied of literature from journal articles and thesis.

Keywords: Fermentation, Processing, Pearl millet, Dehulling, Anti-nutritional factors

Introduction

Pearl millet (*Pennisetum glaucum*) is a versatile cereal cultivated for food, feed and forages (Arora *et al*., 2003) [6] particularly in African and Asian countries (Nambiar *et al*., 2011) [38]. It has the capability to survive under drought and high temperature conditions which further increases its potential to be grown in those regions where wheat, maize and other cereal crops fail to persist. Among all the millet varieties, greater than 29 million hectare area is occupied by pearl millet; however, its distribution is restricted geographically mainly in Africa (15 million) and Asia (11 million), as being the largest producer (Rathore *et al*., 2016) [19]. More than 95 per cent pearl millet production comes from developing countries, and India as the largest producer (Basavaraj *et al*., 2010) [13] covers an area of 9.8million hectares out of total world production (Rathore *et al*., 2016) [49]. Pearl millet had higher protein (14.0 per cent), fat (5.7 per cent), fiber (2.0 per cent) and ash (2.1 per cent) content (Sade, 2009) [51] when compared to the major cultivated cereal crops such as wheat (Kavitha and Parimalavalli, (2014) [30], rice (Ahmed *et al*., 2014) [4], sorghum (Awadelkareem *et al*., 2015) [9]. Superior protein quality in term of its tryptophan and threonine content (Elyas *et al*., 2002) [22] along with higher content of calcium, iron as well as zinc (Yadav *et al*., 2014; Sade, 2009; Lestienneetal., 2007) [64, 51] makes this crop very useful for human. Energy content of pearl millet is greater than sorghum and equivalent to brown rice due to its rich unsaturated fatty acids (75 per cent) and linoleic acid (46.3 per cent) contents (Jaybhayeetal. 2014) [28].

Despite its nutritional qualities, certain anti-nutritional factors (phytate, tannins and polyphenols) are also present in pearl millet (Ranasalvaand Visvanathan, 2014) [47]. Presence of these factors leads to chelation of dietary minerals in the gastrointestinal tract, thereby reducing their bio accessibility and bioavailability (Nour *et al*., 2014) [40]. Moreover, existence of polyphenolic pigments in pericarp, alurone and endosperm areas may cause the development of unpleasant gray color and taste to the finished product (Rathi *et al*., 2004) [48]. Development of off odors and taste in the flour and its products was mainly attributed with the occurrence of lipase activity in pericarp, aleurone layer and germ of grains (Galliard, 1999; Yadavetal., 2012) [24, 62]. To improve the shelf life of pearl millet flour as well as processed products reduction of anti-nutritional factors is necessary which could be achieved by using numerous processing techniques for instance dehulling, milling, malting, blanching, parboiling, acid and heat treatments (Singh and Saini, 2012; Legesse, 2013) [56, 34]. Therefore, main focus of this review is on the impact of processing techniques on the quality parameters of peal millet.

Processing methods

Processing is commonly done to enhance the quality of the grains by converting them into edible form. Utilization of millets could be enhanced by processed them into various forms like rice, flour, roasted, popped, sprouting, salted ready-to-eat grains, porridges and fermented products

(Jaybhaye *et al*., 2014) [28]. Dehulling is the process accompanied by removal of the outer layer of the grains, hull as wellaspericarp (Taylorand Duodu, 2014) [60]. In pearl millet and other smallmillets, fraction of husk varied from 1.5 to 29.3 per cent (Jaybhaye *et al*., 2014) [28]. Previously for household level, millets were decorticated by hand pounding. Nowadays, rice milling machines (Singh and Raghuvanshi, 2012) [57] and rice huller with polisher (Agu *et al*., 2007) are commonly used for this purpose. Abrasive mill (Ayo and olawale, 2003) [10] or disks with mechanical dehullers are still used for decortication purposes. About 12 to 30 per cent of outer grain surface is removed by decortication; decortication beyond this limit causes substantial losso fash, fat, micronutrients, fiber, proteins and amino acids such as lysine, histidine and arginine (Rai *et al*., 2008) [48].

Devisettietal. (2014) reported that unit operation liked husk engine centrifugal sheller, followed by removal of bran resulted in the production of pearl and little millets grains with satisfactory quality. Central Institute of Agricultural Engineering (CIAE, ICAR), Bhopal, created a machine for pearl millet processing which has agrindingability of 100kg/ h, at 10-12 per cent moisture content. This machine works at one horse power single phase electric motor having capacity of processing even 1 kg of grains. Moreover, husk is separated simultaneously with a suction arrangement and cyclone separator attached to the machine (Balasubramanian, 2015) [12]. Rural Industries Innovation Center (RIIC), Kane, Botswana, also manufactured a dehuller having ability of 400 to 600 kg/h which can be applied for sorghum as well as pearl millet decortication. This dehuller also has the capacity to be combined with hammer mill and thereby increase smilling efficiency significantly (Rai *et al*., 2008) [48]. Effect of dehulling on nutrient composition of pearl millet was studied by several researchers, and comparison was also carried out by different decortications methods. It was reported by Serna-Saldivar *et al*. (1994) 53] that decortication done up to 17.5 per cent level showed considerable improvement in protein and dry matter digestibility. However, after decortication, higher reduction in protein, fat, insoluble dietary fiber, ash, lysine, tryptophan and other amino acids was also observed which may be due to the removal of pericarp and

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Germ during the process of decortication. El Hag *et al*. (2002) [21] studied the influence of dehulling on two (Standardand Ugandi) cultivars of pearl millet. Their results showed that protein, polyphenols as well as phytic acid contents of both varieties reduced considerably after dehulling which was due to removal of outer layers. Moreover, in vitro protein digestibility of standard and Ugandi increased up to 79.1 and 78.6 per cent, respectively. Increased in vitro protein digestibility after dehulling which was due to removal of antinutrients such as polyphenols which precipitate proteins, reduce their digestibility and also resulted in production of off-colored products. Lestien neetal. (2007) studied the influence of abrasive decortication on the nutrient and antinutrient profile of pearl millet cultivars (Gampela and IKMP-5) which were grown mainly in Burkina Faso. Results of their study showed that abrasive decortication of pearl millet significantly decreased some antinutritional compounds (fiber and iron binding phenolic compounds) which were located in the bran of grains. However, higher phytate content after decortications might be associated with their occurrence mainly in germ and endosperm region. Hama *et al*. (2011) [25] studied the impact of manual and mechanical decortications on the nutrient composition of pearl millet (Gampela) grains and further compared it with systematized abrasive decortications method. In this study, no significant difference was noticed between these conventional means of decortication. Minerals (iron, zinc), fiber and phytate content were reduced considerably after the traditional decortication. However, abrasive decortication carried out with tangential abrasive dehulling device resulted in higher zinc and lipid losses possibly resulted from the removal of germ during processing. Decorticated millet can be cooked within 6 min into soft, edible grains having low hardness values. This reduction in cooking time might be associated with various factors such as smaller size, removal of seed coat, larger surface are and presence of pre-gelatinized starch in decorticated millet (Dharmaraj *et al*., 2014) [20]. From the above studies, it could be in ferred that acceptability of pearl millet flour and its product can be en hanced significantly by using the proper decortications methods.

Milling

Milling is done mainly for separating endosperm, bran and germ to the maximum extent and for reduction of particles size of endosperm to facilitate the production of fine flour. Milling of pearl millet is difficult because of its small kernel with a firmly embedded germ along with hard endosperm (Abdelrahman *et al*., 1983) [1]. Pearl millet can be milled through hammer and roller mill. Hammer mills produce a flour with larger particle size which limits its utilization for preparation of thin and stiff porridge of rough texture and also in making baked and steamed food products of smooth texture. However, these food products can be developed easily from the fine flour obtained through roller mills (Rai *et al*., 2008) [48]. Millet grains can be cooked rapidly to obtain soft texture which may be associated with higher hydration rates of milled grains. Grinding action of roller mills is also responsible for physical damage of starch granules, thereby increasing enzymatic susceptibility of starch granules (Singh and Raghuvanshi, 2012) [57]. In rural areas, domestic purpose flour is obtained by milling of grains by non-motorized grain mill that is mostly hand operated (Saleh *et al*., 2013) [52]. Recently, Central Food Technology Research Institute (CFTRI) has industrialized a new technique for enhancing the keeping quality of pearl millet flour which comprises moist heat treatment of grains followed by drying to10-12percent moisture and the dehulling up to the preferred degree of pulverization is carried out. After treatment, various pearl millet varieties showed significant improvement in their milling characteristics due to high proportion of floury endosperm. Flour thus produced can be stored up to three to four months along with the advantages of maintaining free fatty acid below 10 per cent during the storage period (Rai *et al*., 2008). Abdelrahman *et al*. (1983) [48, 1] examined thatrollermills can be used for the production flow fat grits from pearl millet. This process was accompanied by decorticating, tempering and milling of the grains through finely corrugated rolls which resulted in an average yield of 61 percentge rits (from whole grains) with 1.2 percent fat content. Chowdhury and Punia (1997) [17] investigated the effect of milling on nutrient and antinutrient profile so pearl millet. Results of their study revealed that milling and heat treatment when making chapati (unleavened flatbread) reduced polyphenols and phytic acid levels along with significant enhancement in protein and starch digestibility. According to a study conducted by Pushparaj and Urooj (2011) [45], two cultivars of pearl millet (Kalukombu and Maharashtra Rabi Bajra) when subjected to milling (whole flour, bran rich fraction and semi-refined flour) showed higher percentage of in vitro protein digestibility mainly in bran rich fraction. These finding showed that tannin might not be responsible for lower protein digestibility and various factors such as interaction of proteins within on-protein components and proteins themselves can also affect protein digestibility. Above studies showed that milling has a positive influence on quality of the product prepared from pearl millet. Therefore, it is the need of time to promote the utilization of appropriate and motorized milling technology on the commercial scale which not only enhances the milling characteristics but also promotes the utilization of under used pearl millet crops.

Malting

Malting is the process accompanied by restricted sprouting of cereals in humid atmosphere along with controlled set of conditions. Although protein content of the grains reduced significantly after malting, yet features such as improved protein quality and higher protein efficiency ratio make this one very popular method of processing (Singh and Saini, 2012) [56]. Higher energy density, vitamin content and improved digestibility of nutrients are some common features which can be achieved through malting (Preetika, *et al*., 2004) [44]. During germination process, starch is broken down into low molecular weight carbohydrates (oligo and disaccharide) by the activity of amylase enzymes. Resulted germinated flour had reduced water holding capacity and high energy density which enhance its potential in the production of infant foods, weaning foods and enteral foods. Malted millet flour can also be used in the production of various other items such as milk-based beverages, confectionary and cakes (Shobana *et al*., 2013) [54]. Germination process was found to be responsible for activation of enzymatic activity of sprouted seeds, thereby causing the disintegration of carbohydrates, proteins and lipids into simpler forms. Bioavailability of nutrients also improved significantly as a result of degradation of proteins by protease enzymes (Singh *et al*., 2015) [57]. Effect of germination on nutrient and anti-nutritional components was studied by various researchers as shown in it. Khetarpaul and Chauhan (1990) [32] reported that total soluble sugars (6.13 g/100 g), reducing (3.43 g/100 g) and non-reducing sugar (2.70 g/100 g) contents of germinated pearl millet were higher than the control sample values (1.76, 0.36, 1.40 g/100 g). Germinated slurry when processed by homogenization and autoclaving showed further enhancement of these components along with decreased starch content which might be due to starch hydrolysis accompanied by emission of greater soluble sugars content. According to a study conducted by Archana and Kawatra (1998) [5], pearl millet grains when subjected to 48hr malting showed significant reduction of polyphenols and phytic acid.

Table 1: Effect of germination on the nutrient and anti-nutrient profile of pearl millet

Cultivar	Treatment (°C/h)	Results	References
Pearl millet grains	25-30/48-72	Maximum retardation of Polyphenols (from	Archana and
		764.45 to 451.92 mg/100 g) and phytic acid	Kawatra (1998) [5]
		(from 833.42 to 393.08 mg/100 g) was	
		obtained at 72 h	
Pearl millet (SOSAT C-88)	32/0-96	Maximum retardation of phytic acid	Badau *et al*. (2005) [11]
		(0.263%) was achieved after 96 h as	
		Compared to control sample (2.91%)	
Traditional Pearl millet	25/48	Reduction in total phenols (from 3.00 to 0.68	Nithya *et al*. (2007) [39]
variety (CO7)		g/100 g), tannins (from 1.52 to 1.00 g/100 g),	
		enhancement of reducing sugar (from 1.85	
		to 4.30 g/100 g), crude fiber percentage	
		(From 1.30 to 1.55%)	
Pearl millet seed	30-32/48	Germinated flour showed higher protein,	Sade (2009) [51]
		WAC, OAC and LGC along with significant	
		reduction in tannin and total phenols	
		content	
Kalukombu (K) and	30-32/72	Processing significantly improved in vitro	Pushparaj and
Maharashtra Rabi Bajra		protein digestibility of Kalukombu (45.5 to	Urooj (2011) [45]
(MRB)		88.2%) and Maharashtra Rabi Bajra (49.3 to	
		78.9%) varieties	
Local Udaipur variety	25-30/25	Enhancement of in vitro iron availability	Bhati *et al*. (2016) [14]
		(from 2.19 to 2.61 mg/100 g), reduction of	
		polyphenol (from 675.33 to 303.21mg/100 g)	
		and free fatty acid content (from 44.56 to 15.09 mg/100 g	

Notes: WAC-Water absorption capacity; OAC-Oil absorption capacity; LGC-Least gelation concentration

From 764.45 to 468.27 mg/100 g and from 833.42 to 449.32 mg/100 g, respectively. However, destruction was further enhanced with 72 h malting of grains which were found to have a polyphenol and phytic acid content of 451.92 and 393.08 mg/100 g, respectively. This reduction of polyphenol after malting may be associated with the presence of polyphenol.
oxidaseormayariseduetothehydrolysisoftanninproteinandtan ninenzymescomplexes which promotes the elimination of tannin or polyphenols. Furthermore, decrease in phytic level after soaking and germination may result from their leaching in soaking water under concentration gradient. Pelembe *et al*. (2004) [43] investigated the impact of germination moisture and time on pearl millet malt quality. Two pearl millet cultivars (SDMV 89004 and 91018) were used and germinated at 25°C under three different watering regimes for a period of five days. Results indicated that pearl millet malt was superior in comparison to sorghum as of its greater b –amylase activity as well as free a –a minonitrogen profile which further enhances its potential for beer brewing. Badau *et al*. (2005) [11] studied the impact of germination period and varieties on phytic acid profile and HCl extractability of minerals. Results showed that phytic acid content decreased and HCl extractability of minerals (Ca, Fe, Zn, P, I, Cu and Mn) enhanced considerably with the germination time. This might be due to the production of phytase during the process of germination which resulted in breakdown of phytic acid substance that binds minerals making them available for the body system. In another study conducted by Nithya *et al*. (2007) [39], pearl millet varieties (CO7 and COHCU-8) when subjected to 48 h sprouting revealed significant reduction in total phenols and tannins content which might be attributed with higher enzymatic hydrolysis. Higher level of crude fiber resulted from production of more cell wall material, accompanied by more shoot sand rootlets formation, thereby increasing fiber content. Nigerian cereal food commonly known as Fura prepared by germination of pearl millet grains showed higher nutrient and energy profile. Furthermore, after germination, phytic acid levels were reported to be reduced up to 230 mg/100 g than the control sample having phytic acid content of 416 mg/100g. This reduction in phytic acid profile may be associated with increased activity of phytase enzyme which hydrolyses the bond between protein, enzyme and minerals so as to release morepho sphorus, and reducing the level of phytic acid during germination process (Inyang and Zakari, 2008) [27]. Proximate composition, functional properties and anti-nutritional profile of germinated pearl millet were analyzed by Sade (2009) [51]. Results showed that crude protein content enhanced significantly along with considerable improvement in water absorption capacity, oil absorption capacity and least gelation concentration. Higher water absorption capacity after germination may be due to the alteration in quality and quantity of protein happened during the process of germination. Anti-nutritional factors (tannin, total phenol) were also reported to be reduced significantly after the treatment which may be due to the discharge of polyphenols in soaking water and improved enzymatic treatment during germination. Arora *et al*. (2011) [8] reported higher cell viability (8.64 cfu/g) in pearl millet-based, germinated food blend as compared to non-germinated sample (7.30 log cfu/g) probably resulted from the hydrolysis of germinated flours, which facilitates better media for growth. Significant improvement in vitamins (thiamine, niacin), lysine, protein fractions, sugars, soluble dietary fiber and in vitro availability of minerals were also reported as a result of germination. Similarly, Singh *et al*. (2006) [57] reported significant improvement of in vitro protein (78.55 per cent) and starch digestibility (41.13percent) in the biscuits prepared from malted pearl millet flour (25-30°C/ 6 h). This increased in vitro protein digestibility could have been due to the destruction of heat liable protease inhibitors during drying of malted grain and denaturing of globulin proteins (Chitra *et al*., 1996) [16], whereas high starch digestibility might be attributed to various factors such as starch granules rupturing by heat (Rekha, 1997) [50], activation of amylolytic enzymes and deduction of anti-nutrients. In another study conducted by Adebiyi *et al*. (2017) [2], fiber, protein and energy values of the flour and biscuits improved significantly after malting as compared to their control samples. The higher crude protein values of samples were due to accumulation of proteins and production of some additional amino acids in the sample sasa result of malting. Kindiki *et al*. (2015) [33] reported that germination (for five days) followed by fermentation (24 h) and roasting improved the nutritional composition of pearl millet which can be used for the production of superior sensory qualities porridges. Bhati *et al*. (2016) [14] concluded that malting before milling noticeably improved color, in vitroir on availability as long with along with reduction of polyphenols and free fatty acid content of the pearl millet grains. Above studies inferred that reduction of anti-nutritional factors, improved extractability of minerals and higher in vitro protein digestibility are the features which can be achieved easily after the process of germination.

Fermentation

Fermentation is necessary mainly for food preservation, flavor development and for enhancement of nutritional quality of raw products (Saleh *et al*., 2013) [52]. Fermentation process is done by malting and souring with mixed cultures of yeast and Lactobacilli. Starch and soluble sugar present in millet get degraded by the enzymes present in grains and fermentation media (Rai *et al*., 2008) [48].

Table 2: Effect of fermentation on the chemical composition of pearl millet

Cultivars	Treatment (°C/h)	Micro-organism	Results	References
Fermented rabadi	30-50/3-9	–	Fermentation (9 h) showed	Dhankher and
prepared from whole			maximum reduction of polyphenols	Chauhan (1987) [19]
grain pearl millet			and phytic acid at all the	
Flour			temperatures	
Pearl millet	20-50/24-96	Lactic acid	Fermentation (72 h at 40 and 50°C)	Mahajan and
		bacteria	showed best results of reduced	Chauhan (1987) [19]
			Phytic acid content and increased	

			extractable phosphorus content	
Pearl millet	20-30/72	S. diastatieus, S. cerevisiae, L. brevis and L. fermentum	Natural Fermentation increased thiamine content of autoclaved pearl millet flour	Khetarpaul and Chauhan (1989) [31]
Standard and Ugandi cultivar of pearl Millet	30/14	Mixed culture of yeast and lactobacilli	In vitro protein digestibility also improved from 72.7 to 83.6% and 70.4 to 81.6% for Standard and Ugandi cultivar	El Hag *et al.* [21] (2002)
Composite population III and Baladi (breeder seed 1997)	30/0-36	Mixed culture of yeast and lactobacilli	Maximum reduction in polyphenols and higher IVPD (%) were observed after 24 h for Composite popualtion III and after 20 h for Baladi (breeder seed 1997) cultivar	Elyas *et al.* [22] (2002)
Pearl millet	/72	–	Tannin and total phenols were reduced considerably after the treatment	Sade (2009) [51]
Lohoh bread prepared from fermented pearl millet Flour	/24	–	Significant reduction in Enzymes inhibitors and phytic acid content	Osman (2011) [26]

Note: IVPD – *in-vitro* protein digestibility

Impact of fermentation time and temperature on nutritional and anti-nutritional composition was evaluated by several researchers, and results of their worker presented in it. Pearl millet flour when subjected to lactic acid fermentation (20, 40 and 50°C) fora period of 72 h or longer showed approximately total exclusion of phytic acid content along with the advantages of improvement of extractable phosphorus content. Higher extractability of phosphorus might be due to the hydrolysis of phytic acid by the phytase enzymes present naturally in food grains (Mahajan and Chauhan, 1987) [19]. Dhankher and Chauhan (1987) [19] investigated theef fects of fermentation Time (3,6and9h) and temperatures (35, 40, 45 and 50°C) on polyphenols and phytic acid levels of rabadi prepared from a mixture of pearl millet flour and butter milk. It was reported that for all temperature conditions, as the fermentation period increased, phytic acid and polyphenol content decreased steadily. Moreover, at all temperature combinations, a fermentation periodofnine hours was found to be sufficient for maximum reduction of phytic acid (27-30 per cent) as well as total polyphenols (10-12 per cent). This reduction of phytic acid may be due to its hydrolysis caused by pearl millet phytase and by the microform of fermenting media. Furthermore, lowering of polyphenols after fermentation may be due to the activity of polyphenol oxidase or microform of fermentation media.

Khetarpaul and Chauhan (1989) [31] described that natural fermentation of pearl millet showed significant improvement of fat as well as thiamine content without having any significant impact on its protein content. Higher fat content after fermentation may be due to the fat producing effect of yeast strains occurred during the natural fermentation of pearl millet. Khetarpaul and Chauhan (1990) [32] stated that sprouts fermented with S. diastaticus and L. brevis combination showed the highest content of total soluble (reducing and non-reducing) sugars along with lowest starch content. Lesser starch content after fermentation might be associated with amylolytic action of microorganisms in the fermenting mixture. Elyas *et al*. (2002) [22] studied anti-nutritional profile in addition to invitro protein digestibility of naturally fermented pearl millet cultivars (Composite Population III and Baladi). Their results showed that for Composite Pop. III, polyphenols levels came down to 196 from 319 mg/100 gafter 24 hand for Baladi, these levels decreased to 294mg/100 gafter 20h which might be associated with the activity of enzyme polyphenol oxidase during fermentation process. Dough fermented on room temperature for 36h revealed substantial decrease of phytic acid profile from 786 to 393 mg/100 g and from 618 to 309 mg/100 g for Composite Population III and Baladi, respectively. This reduction in phytate content might be due to the activity of endogeneous phytase during the fermentation process. Furthermore, in vitro protein digestibility was increased from 60.5 to 86.0 percent (24h) and from 61.9 to 86.2 percent (28h) for both the cultivars. According to a study conducted by El Hag *et al*. (2002) [21], Standard and Ugandi cultivars of pearl millet when subjected to fermentation (14 h at room temperature) showed substantial decrease in total polyphenols and phytic acid content. However, considerable reduction in starch content was also reported in this study which possibly resulted from yeast growth which leads to degradation of sugars into ethanol and CO2. Hassan *et al*. (2006) [9] reported that processed pearl millet when subjected to fermentation showed notable decrease in anti-nutritional factors, as well as higher in vitro protein digestibility. They concluded that it might be due to the partial disintegration of complex storage proteins to more simple and soluble products (Chavan *et al*., 1988) [15]. Osman (2011) [26] studied the influence of traditional fermentation on the proximate composition, soluble sugars, amino acids, enzymes inhibitor activities, phytic acid and tannins profile of pearl millet flour through preparation of lohoh bread. Results indicated no significant difference between protein, lipid and ash contents, except the carbohydrate profile which was reduced considerably after fermentation. Furthermore, pearl mill*et al*so showed a significant reduction in the levels of enzymes inhibitors as well as phytic acid content after the traditional fermentation. However, increased tannin profile alsore ported in this study which may adversely affect the nutritional quality of lohoh bread. Legesse (2013) [34] investigated that fermented pearl millet had higher protein (20.79 per cent) content than the control sample (11.72 percent). Fermented flours how significant reduction of tannin (0.83mg/100g)and phytate (167.14 mg/100 g) content as compared to the raw pearl millet values (3.64 and 288.69mg/100g). Ranasalva and Visvanathan (2014) [47] investigated that bread produced from the cooked fermented pearl millet flours by substitution of the refined wheat flour at 10, 15 and 20 per cent level had good textural and physical properties. Moreover, prepared bread also exhibits good compatibility against market bread in term of its quality characteristics. Cookies when prepared by replacement of refined wheat flour with 50 per cent cooked fermented pearl millet flour showed higher acceptability. Therefore, it may be concluded that destruction of anti-nutritional compounds and higher in vitro protein digestibility as well as improved vitamins levels (thiamine) are the features which can be easily after the fermentation carried out with optimized conditions. Therefore, we have to lay stress on a large-sale industrial utilization of fermentation process so that acceptability of pearl millet-based product can be enhanced.

Blanching

One of the most effective techniques for enhancing the shelf life of pearl millet flour is blanching, which slows down the enzymatic activity without having any significant effect on its nutritional composition. It is done by boiling water at 98°C, followed by immersing of the grains in the boiling water (1:5 ratio of seeds to boiling water) for 30 sand drying at 50°C for 60 min (Rai *et al*., 2008) [48]. Blanching of pearl millet grains done at 98°C for 10 to 20 s resulted in a meal having three-to four fold lower fat acidity, acid value and percentage free fatty acid (FFA) profile than untreated meal sample (Kadlag *et al*., 1995) [29]. Archana and Kawatra (1998) [5] reported that pearl millet when blanched at 98°C for 30 s showed a significant reduction in polyphenols (from 764.45 to 544.45 mg/100 g) and phytic acid content (from 833.42 to 512.10mg/100g) which might be due to the leaching of polyphenols and phytateions into the soaking medium under three effect of concentration gradient. Singh *et al*. (2006) reported higher calcium (34.13 mg/100 g), phosphorus (185.34 mg/100 g), iron (3.97mg/100g), manganese (0.52mg/100g) and poly phenol content (202.81mg/100g) in the biscuits prepared after the blanching of pearl millet grains (98°C60 min). According to Bhati *et al*. (2016) [14], bleaching of pearl millet done for 90 s resulted in advantages of higher *in-vitro* iron availability (from 2.19 to 3.29 mg/100 g), greater reduction in free fatty acid content (from 44.56 to 20.59 mg/100 g) and grains with improved color characteristics Therefore, nutritional quality and shelf life of the pearl millet flour can be elevated successfully through appropriate blanching methods.

Acid treatment

Dark gray color of pearl millet grains limits their utilization in food preparation. This problem can be overcome by treating the decorticated seed with various organic acids such as (acetic, fumaric, tartaric acid) or sometimes natural acidic material such as tamarind (Rai *et al*., 2008) [48]. Effect of acid treatment on nutrient and anti-nutritional components were studied by various researchers from a longer time. Dilute hydrochloric acid when compared with other acidic solutions such as citric acid, acetic acid was found to be more effective during the depigmentation of whole grain before milling (Naikare *et al*., 1986) [37]. Arora *et al*. (2003) [7] concluded that acid treatment carried out by soaking the grains in HCl solution (0 0.2 N) for 6, 12, 18 and 24 h, followed by washing, blanching (98°C for 30 sec) and sun drying (two days) showed signifi can't improvement in extractability of phosphorus, calcium and iron as the period of acid soaking prolonged. This improvement of HCl extractability was further accompanied by higher bioavailability of minerals. Bhati *et al*. (2016) [14] reported that pearl millet grains when subjected to acid treatment (2, 12, 18, 24 h) revealed lower polyphenols and free fatty acid profile. Moreover, 18h acid treatment was found to be most effective in maximum enhancement of in vitro iron availability as compared to raw grains (2.19 to 3.01 mg/100 g). However, lower iron content observed in this study could be associated with leaching of minerals that were present mainly in pericarp of seed. Therefore, for the production of pearl millet-based food products having the advantages of lower anti-nutritional profile, higher bioavailability of minerals and improved color characteristics, it is necessary to promote the use of acid treatment on a large scale.

Heat treatment

Pearl millet flour when stored developed the problems of bitterness and rancidity which limited its shelf life. These problems occurred due to the activity of lipase enzymes which caused the breakdown of glycerides and subsequent increase of free fatty acid profile (Arora *et al*., 2002) [6]. Therefore, its inactivation before milling is necessary for the enhancement of mealquality. This can be achieved by exposing the pearl millet grain to a dry heat treatment which significantly retard the lipase activity and minimize the lipid de composition during storage (Rai *et al*., 2008) [48]. Dry heating can be done by heating the grains in hot air oven maintained at 100 6 2°C for 60 to 120 min, followed by rapid cooling and finally milling to obtain whole meal (Kadlag *et al*., 1995) [29]. Combination of acid treatment (18 h) and dry heat (120 min) also showed significant reduction of fat acidity, free fatty acid and lipase activity of pearl millet flour throughout a storage period of 28 days. These results were further accompanied by the higher shelf life of the flour than its control sample (Rai *et al*., 2008; Singh and Saini, 2012) [56, 48]. According to Kadlag *et al*. (1995) [29], pearl millet grains when subjected to dry heating for 120 min revealed significant reduction in fat acidity, acid value, free fatty acid profile during 30 days of storage period. Dry heat treatment of pearl millet grains prior to milling resulted in flour of better keeping quality without having any negligible effect on its acceptability. Furthermore, shelf life of the products improved also improved significantly after the treatment (Arora *et al*., 2002) [6] as shown in it. Nithya *et al*. (2007) [39] reported whole pearl millet grains when subjected to dry heat treatment (110°C/1 h) showed substantial reduction in anti-nutritional compounds such as polyphenols (from 3.00 to 2.27 g/100 g) and tannin (from 1.52 to 1.30 g/100 g) which might be attributed to the loss of compounds due to high heat treatment of the grains. Reduction of free fatty acid content (from1.85to1.50g/100g) after dry heating might result from the inactivation of lipase activity at high temperature. Yadav *et al*. (2011) [63] reported significant (P # 0.05) reduction in phytic acid after soaking and steaming which have been attributed to the heat induced degradation of phytic acid. Furthermore, steaming at high pressure (1.05 kg/cm2) extended the storage through complete removal of lipase enzyme activity. Similarly, Yadav *et al*. (2012) [62] stated that microwave heating (18 per cent moisture level, 80 s) of pearl millet grains decreased lipase activity significantly ($P < 0.05$) which may be attributed to high temperature attained by the sample (107.6°C) during transformation of microwave energy into thermal energy. Moreover, microwave treated flour remained acceptable after 30 days of storage (15-35°C) than the control flour havings helflife of only10days.

Table 3: Effect of dry heat treatment of pearl millet seeds on fat acidity (mg KOH/100 g meal), and free fatty acids (%) profile of pearl millet flour during different storage periods

	Fat acidity (mg KOH/100 g meal)		Free fatty acids (%)		References
Storage days	Control	Heat treated at 100°C for 10 min	Control	Heat treated at 100°C for 10 min	
0	13.7	8.4	0.82	1.0	Kadlag *et al*. (1995) [29]
5	60.6	14.5	4.5	1.2	
10	108.0	21.5	6.5	1.6	
15	147.4	26.9	8.7	2.3	
20	201.3	32.7	11.7	3.0	
30	267.6	46.0	16.9	3.7	
0	30.3	28.0	282.0	67.0	Arora *et al*. (2002) [6]
7	42.4	30.9	427.3	70.0	
14	58.1	34.4	789.0	75.0	
21	87.3	41.2	942.0	80.0	
28	123.7	50.5	1,115.0	84.0	

According to Tiwari *et al*. (2014) [61], pearl millet flour when subjected to heat treatment carried out at 110°C for 60 s showed significant reduction in fat acidity and free fatty acids profile. Moreover, pearl millet flour which has undergone heat treatment could be stored up to a period of six days at ambient conditions. Dry heat treatment, done at130°Cfor2or4h on this flour, resulted in higher pasting viscosity (Sun *et al*., 2014). Dry heat treatment of pearl millet grains (100°C for 120 min) showed higher in vitro iron availability (2.19 to 3.58 mg/100 g) along with maximum retardation of polyphenol (675.33 to 477.93 mg/100 g) and free fatty acids content (from44.56 to16.23mg/100 g)than raw grain. However, loss of minerals (phosphorus, iron and calcium) observed during the processing may attributed to the destruction of minerals as a result of heating (Bhati *et al*., 2016) [14]. According to a study conducted by Obadina *et al*. (2016) [2], functional properties of flour (water and oil holding capacity) improved significantly after roasting which might be due to the changes in the bioavailability of nutrients such as proteins in the flour after roasting (Gabrelibanos *et al*., 2013) [23]. Greater iron content of the roasted flour was due to the migration of leached iron from the roasting pan into the samples. Therefore, it can be concluded that pearl millet-based food products having the advantages of longer shelf life with reduced anti-nutritional content will be produced commercially thought he use of heat treatments.

Conclusions

Processing methods and their impact over the nutrient and anti-nutrient profile of pearl millet were reviewed in details. It can be concluded that processing methods are necessary for improving the nutritional availability and storage stability of flour as well as the products. Therefore, for encouraging the commercial utilization of pearl millet grains in food formulations and to achieve the better food security feature, it is necessary to use appropriate processing methods.

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