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REVIEW

Significance of coarse cereals in health and nutrition: a review

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Abstract This review assesses the nutritional attributes of coarse cereals and also their utilization as food and as formulated foods. These cereals are laden with phytochemicals including phenolic acids, tannins, anthocyanins, phytosterols, avenenathramides and policosanols. They possess high antioxidant properties in vitro than staple cereals and fruits by different purported pathways. There are also some anti-nutritional factors that may be reduced by certain processing treatments. Several epidemiological studies show that these cereals are helpful in reducing several kinds of chronic diseases like cancers, cardiovascular diseases, type II diabetes and various gastrointestinal disorders. Being coarse in nature, they cannot replace our staple cereals, but can be used in different proportions with rice and wheat to formulate various nutritional products. They can be used to make porridges, biscuits, cakes, cookies, tortillas, bread, probiotic drinks, ladoo, ghatta, flakes and several fermented foods. The coarse cereals also have good potential in manufacturing bioethanol, paper, oil and biofilms.

Keywords Antioxidants · Phytosterols · Avenenathramides · Phenolic acids · Cardiovascular diseases · Cancer

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Introduction

Coarse grains refer to cereal grains other than wheat and rice or those used primarily for animal feed or brewing. These grains are warm-season cereals valued for their food, feed and fodder uses in various parts of the world. These are largely grown in the semi-arid tropical regions of Asia and Africa, under rain-fed farming systems with little external inputs with grain yield levels being low (often less than 1 tonne/ha) (Rai et al. 2008). Coarse cereals include maize (*Zea mays),* sorghum (Jowar; *Sorghum vulgare),* oats *(*Jai; *Avena sativa),* barley *(*Jow; *Hordeum vulgare)*, pearl millet (Bajra; *Pennisetum glaucum*) and other minor millets such as Finger millet (Ragi; *Eleusine coracana*), Kodo millet (Arikalu; *Paspalum setaceum*), Proso millet (Cheena; *Penicum miliaceum*), Foxtail millet (Kauni; *Setaria italic*), Little millet (Kutki; *Panicum sumatrense*) and Barnyard millet (Sanwa; *Echinochloa utilis*). They are rich in dietary energy, vitamins, several minerals (especially micronutrients such as iron and zinc), insouble diatary and phytochemicals with antioxidant properties (Bouis 2000). Finger millet is the richest source of calcium (300 to 350 mg/100 g grain). Small millets are a good source of phophorus and iron. In view of these nutritional properties these coarse cereals have of late been also designated as nutricereals. They are rich in compounds that help against several chronic diseases like ischemic strokes, cardiovascular diseases, cancers, obesity and type II diabetes (Jones et al. 2000; Jones 2006). Composition of some of the major cereals including coarse cereals and millets is presented in Table 1. They are nutritionally comparable or even superior to major cereals such as wheat and rice, owing to their higher levels of protein with more balanced amino acid profile (good source of methionine, cystine and lysine). The amino acid profile of major coarse cereals is given in Table 2.

Table 1 Nutrient composition of sorghum, millets and other cereals (per 100 g edible portion; 12% moisture)

Food	Protein (g)	Fat (g)	Ash (g)	Crude fibre (g)	Carbohydrate (g)	Energy (kcal)	Ca (mg)	Fe (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)
Rice (brown)	7.9	2.7	1.3	1.0	76.0	362	33	1.8	0.41	0.04	4.3
Wheat	11.6	2.0	1.6	2.0	71.0	348	30	3.5	0.41	0.10	5.1
Maize	9.2	4.6	1.2	2.8	73.0	358	26	2.7	0.38	0.20	3.6
Sorghum	10.4	3.1	1.6	2.0	70.7	329	25	5.4	0.38	0.15	4.3
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	42	11.0	0.38	0.21	2.8
Finger millet	7.7	1.5	2.6	3.6	72.6	336	350	3.9	0.42	0.19	1.1
Foxtail millet	11.2	4.0	3.3	6.7	63.2	351	31	2.8	0.59	0.11	3.2
Common millet	12.5	3.5	3.1	5.2	63.8	364	8	2.9	0.41	0.28	4.5
Little millet	9.7	5.2	5.4	7.6	60.9	329	17	9.3	0.30	0.09	3.2
Barnyard millet	11.0	3.9	4.5	13.6	55.0	300	22	18.6	0.33	0.10	4.2
Kodo millet	9.8	3.6	3.3	5.2	66.6	353	35	1.7	0.15	0.09	2.0
Oats	17.0	6.0	2.6	11.0	66.0	390	54	4.7	0.22	0.12	3.2

Hulse et al. (1980); Chavan and Kadam (1989)

The world production of coarse cereals grains in 2007–2008 was estimated at 1080.4 MT, which increased upto 1142.3 MT in 2008–2009 (FAO 2009). Sorghum is cultivated on more than 42 million ha worldwide with the largest area in Africa (24.5 million ha) and Asia (10.6 million ha). It is also an important crop in the USA (6.6 million ha) and Australia (0.7 million ha). India ranks first with the largest sorghum area (9.1 million ha) in the world. Pearl millet, cultivated on more than 29 million ha, has relatively more restricted geographical distribution, with Africa (15.0 million ha) and Asia (11.0 million ha), being the largest producers of the crop. India has the largest pearl millet area (9.8 million ha) in the world. Finger millet is grown in India in 1.64 million ha with a productivity of 11.79 quintal/ha. Barnyard millet is grown in 0.28 million ha land having a productivity level of 8.63 quintal/ha in India. Area of production of kodo millet, foxtail millet, common millet and little millet in India is approx. 0.399, 0.103, 0.47, and 0.310 million ha, respectively (International Grains Council 2011). Total barley production is foracasted to be 133.40 million tonnes in the world in 2011 (FAO 2011).

Coarse cereals have been dubbed as poor man's crops for long, have remained neglected with respect to their appropriate position in the commercialized food system, and investment in research and development. With the increasing concerns about adverse changes in environmental quality and its consequent negative effects on food and nutritional security and perceived need for increasing food production per unit resource investment for an ever increasing population, these coarse grains have good prospects of penetrating the food baskets of a wider range of consumers, both rural and urban, poor and rich and in developed and developing economies. There is both a large body of scientifically proven knowledge and also undocumented rural knowledge on the nutritive and health aspects of these grains and also various types of food products that can be prepared from them. Research and development on potential uses of these coarse cereal grains has brought out the potential of these grains for being used as formulated foods. In addition to their food uses, these cereals are also employed as feed, substrate for biofuels or bioethanol, biopolymers, distilleries and syrups.

Bioactive compounds in coarse cereals

Several constituents of cereals have biological activity in addition to the nutrition that they provide. Phenolic compounds include tannins, phenolic acids, coumarins, flavonoids and alkyl resorcinol. Phenols are responsible for the flavor, texture (such as mouthfeel of beer), color, taste and oxidative stability of plant foods (Naczk and Shahidi 2004). They have nutraceutical properties and are generally located

Table 2 Essential amino acids in cereals and millets (g/100 g of protein)

Amino acids	Finger millet	Kodo millet	Proso millet	Foxtail millet	Barnyard millet	Wheat	Rice
Isoleucin	4.4	3.0	8.1	7.6	8.8	3.3	3.8
Leucine	9.5	6.7	12.2	16.7	16.6	6.7	8.2
Lysine	2.9	3.0	3.0	2.2	2.9	2.8	3.8
Methionine	3.1	1.5	2.6	2.8	1.9	1.5	2.3
Cystine	2.2	2.6	1.0	1.6	2.8	2.2	1.4
Phenyl alanine	5.2	6.0	4.9	6.7	2.2	4.5	5.2
Tyrosine	3.6	3.5	4.0	2.2	2.4	3.0	3.9
Threonine	3.8	3.2	3.2	2.7	2.2	2.8	4.1
Tryptophan	1.6	0.8	0.8	1.0	1.0	1.5	1.4
Valine	6.6	3.8	6.5	6.9	6.4	4.4	5.5
Histidine	2.2	1.5	1.9	2.1	1.9	2.3	2.4

FAO (1970)

in bran. There are two classes of phenolic acids: hydroxycinnamic acid and hydroxyl benzoic acid. The hydroxybenzoic acids include *p*-hydroxy benzoic acid, vanillic, syringic and protocatechuic acid, whereas hydroxycinnamic acids include coumaric, caffiec acid, ferulic and sinapic acid. The phenolic acids present in various coarse cereals are listed in Table 3.

Flavonoids include anthocyanins, flavanols, flavones, flavanoids and flavanones. Cereal grains contain variety of flavonoids, located generally in the pericarp. The six common anthocyanidins found in cereals are cyanidin, malvinidin, pelragonidin, delphinidin, petunidin and peonidin. The anthocyanidins present in sorghum are apigenindin, apigeninidin-5-glucosides, luteolindin, luteolindin-5-glucosides, 5-methoxyapigeninidin, 7-methoxyapigeninidin, 7-methoxy-5-glucosides and 7-methoxyluteolinidine. 3-deoxyanthocyanidin, a unique member of the anthocyanidin group, is stable at high pH, which makes sorghum a good food colorant. Barley contains cyanidin, cyanidin-3-glucosides, delphinidine, pelargonidin, pelargonidin glycosides and petunidin-3-glucosides. Maize contains cyanidin-3-galactosides, cyanidin-3-glucosides, cyanidin-3-rutinosides, pelragonidin glycosides, peonidine-3-glucosides and petunidine-3- rutinosides (Awika et al. 2004; Seitz 2004; Wu and Prior 2005). Flavones reported in ragi are orientin, isoorientin, vitexin, isovitexin, saponarin, valanthin, lucinenin-1-tricin (Subbarao and Murlikrishna 2002), whereas glucosylvitexin, glycovitexin and vitexin are reported in pearl millet (Klopfenstein et al. 1991). Apigenin, glycosylvitexin, isovitexin, tricin and vitexin are present in oats (Peterson 2001). The flavonones reported in sorghum are eriodictyol, eriodictyol-5-glucosides, naringenin and kaempferol-3-rutinoside-7-glucuronide (Dykes and Rooney 2006), in maize kaempferol and quercetin (Peterson 2001) and in oats, homoeriodictyol, quercitin-3-rutinosides and quercitin kaempferol-3-rutinosides (Shahidi and Naczk 1995; Peterson 2001; Mazza and Gao 2005). Most abundant flavonoids and anthocyanidins are given in Table 4.

Coarse cereals also contain condensed tannins, whose primary function is to protect grains from molds and protect them from deterioration (Waniska 2000), though they are also responsible for the astringency of the grain. Besides barley and sorghum, ragi is the only millet which contains tannins (Siwela et al. 2007). Tannins decrease digestibility of proteins,

Table 3 Presence of different kinds of phenolic acids in coarse cereal grains

Coarse cereals	Phenolic acids	Amount (μg/g)
Bajra	Protocatechuic, Genistic, *p*-hydroxybenzoic acid, Vanillic, Syringic, Ferulic, Caffeic, *p*-coumaric, Cinnamic	1478
Barley	Protocatechuic, *p*-hydroxybenzoic acid, Salicylic, Vanillic, Syringic.Ferulic, Caffeic, *p*-coumaric, *o*-coumaric, *m*-coumaric, Sinapic	450–1346
Maize	Protocatechuic, *p*-hydroxybenzoic acid, Vanillic, Syringic, Ferulic, Caffeic, *p*-coumaric	601
Oats	Protocatechuic, *p*-hydroxybenzoic acid, Vanillic, Syringic, Ferulic, Caffeic, *p* -coumaric, Sinapic	472
Ragi	Protocatechuic, Genistic, *p*-hydroxybenzoic acid, Vanillic, Syringic, Ferulic,Caffeic, *p*-coumaric, Cinnamic	612
Sorghum	Gallic, Protocatechuic, *p*-hydroxybenzoic acid, Gentisic, Salicycilc, Syringic. Ferulic,Caffeic, *p*-coumaric, Cinnamic, Sinapic	385–746

Andreason et al. (2000), Subbarao and Murlikrishna 2002; Zhou et al. (2004), Matilla et al. (2005), Tian et al. (2005), Dykes and Rooney 2006; Kim et al. (2006)

Table 4 Most abundant anthocyanidins and their roles

Cereal grain	Most abundant flavonoids	Significance of abundant flavonoid	Most abundant anthocyanidin	Total anthocyanidin content (μg/g)
Barley	Catechin	antioxidation capacity	Cyanidin	4
Maize	cyaniding-3-glucoside	–	cyanidin-3-glucoside	93–96.5
Sorghum	leucoapigeninidins and leutolinidins	High resistance to molds	apigeninidins and leutolinidins	94.4

Dicko et al. (2005), Mazza and Gao (2005), El-Sayed et al. (2006)

carbohydrates and minerals and also possess anticarcinogenic, gastro-protective, anti-ulcerogenic and cholesterol lowering properties (Prior and Gu 2005; Dykes and Rooney 2006). Avenanthramides are amides of cinnamoyl-anthranilic acids and are found exclusively in oats. They have anti-inflammatory, anti-atherogenic and antioxidant properties (Emmons et al. 1999; Chen et al. 2004). Alkyl resorcinol produced by various plants, bacteria and fungi are bioactive compounds possessing beneficial activities for human health such as anticancerous activity (Kozubek and Tyman 1999; Ross et al. 2004).

Lignans are the class of phytoestrogens found in barley, oats, triticale, rye and wheat. The amount of lignans present in these cereals varies from 8 to 299 μg/100 g (Buri et al. 2004). Upon ingestion, they are converted to mammalian lignans and are believed to reduce the hormone dependent cancers (Thompson 1994; Qu et al. 2005). Phytosterols are cholesterol-like compounds that are mostly found in bran. The phytosterols in cereals exist in free forms, as esters of fatty acids or hydroxycinnamic acids (usually ferulate) or conjugated with sugars (mostly glucose). Sorghum contains 46–51 mg of non-bound phytosterol per 100 g (Singh et al. 2003), whereas corn, barley and oats contain 70–88 mg/100 g, 55–76 mg/100 g, 35–46 mg/100 g respectively (Moreau et al. 1996; Ostlund 2002; Piironen et al., 2002).

The term policosanols represents a mixture of high molecular weight (20–36 carbon) aliphatic primary alcohols, which are reported to have beneficial physiological activities. In sorghum, wax comprises about 0.2% of the grain, generally higher than in other cereals. The policosanols represent 19–46% of the sorghum wax with octacosanol (C28) and triacontanol (C30) being the most abundant (Hwang et al. 2004). Dietary fibre is the edible part of plants, which resists hydrolysis by alimentary tract enzymes. Oligosaccharides such as lactulose, fructo-oligosaccharides, transgalacto-oligosaccharides are reportedly effective in stimulating the growth of bifidobacteria and lactobacilli in human large intestine. The two oligosaccharides found in cereals are galactosyl derivatives of sucrose, stachyose and raffinose, and fructosyl derivatives of sucrose, fructooligosaccharides (Charalampopoulos et al. 2002). Cereals do not contain vitamin C, vitamin B12, vitamin A and except from yellow corn, β-carotene (Cordain 1999). However, they are important sources of most B vitamins, especially thiamin, riboflavin and niacin (McKevith 2004). Cereals also contain appreciable amounts of vitamin E.

Antinutrients in coarse cereals and remedial actions

Millets are considered superior to cereals with respect to some of nutrients especially protein, mineral and fat. However, the presence of various antinutrients, poor digestibility of the protein and carbohydrates and low palatability greatly affects its utilization as a food. Coarse cereals contain several antinutrient factors that limit their nutritive value. Principal among these are phytic acid and polyphenols amounting to 825.7 mg/100 g and 347.26–552.98 mg/100 g respectively (Kumar and Chauhan 1993; Abdelrahaman et al., 2007). Several processing treatments have been evaluated to reduce these antinutrient contents. There are reports that the phytic acid content decreased significantly by phytase activity during germination. The reduction was greatest in the first 2 days, after which it decreased at a lower rate from day 4 to day 6 of germination (Abdelrahaman et al. 2007). Phytase activity was observed during germination of wheat, barley, rye and oats, which hydrolyze phytate to phosphate and myoinositol phosphates (Larsson and Sandberg 1992). Similarly a decreasing trend in the polyphenol content had been observed during the germination of grains up to 6 days (Abdelrahaman et al. 2007). Hassen et al. (2006) observed that germination of the grains increased the protein content for pearl millet cultivars. The enhancement in protein content of the germinated grains may be due to quantitative reduction in anti-nutritional factors (tannin, polyphenols and phytic acid) as well as other macromolecules of the grains particularly carbohydrates.

Sprouting of pearl millet at 30 °C for 48 h reduced phytic acid, in addition to improving in vitro protein digestibility (IVPD) and HCl-extractability of P, Ca, Fe, and Zn (Kumar and Chauhan 1993). According to Sehgal and Archana (1998), blanching resulted in significant reduction in polyphenol (28%) and phytic acids (38%). Destruction of polyphenols (38–48%) and phytic acid (46–50%) was significantly higher in grains subjected to malting than blanching. The overall results suggested that malting with 72 h of germination was most effective in reducing the anti-nutrient levels of pearl millet grains. Malting of finger millet decreased its starch content owing to increased amylase activity (Nirmala and Muralikrishna 2002).

Fermentation of pearl millet with lactobacilli or yeasts with natural microflora singly or in combination after various processing pre-treatments such as grinding, soaking, debranning, dry heat treatment, autoclaving and germination indicated a significant decrease in phytic acid, amylase inhibitors (AI) and polyphenols (Sharma and Kapoor 1996). Phytic acid and amylase inhibitors were completely eliminated in samples that were soaked, debranned and germinated prior to fermentation. Fermentation of processed pearl millet grains leads to significant reduction in antinutritional factors of the grains accompanied by significant improvement in the protein digestibility. It may be inferred that among various processing treatments germination followed by natural fermentation proved to be more effective in increasing the protein digestibility of the pearl millet grains (Hassen et al. 2006). Fermentation of germinated pearl millet (at 30 °C for 24 h) sprouts with mixed pure cultures of *Saccharomyces diasticus*, *S. cerevisiae*, *Lactobacillus brevis* and *L. fermentum* at 30 °C for 72 h recorded 88.3% reduction in phytate content (Khetrapal and Chauhan 1990). Haq et al. (2002) reported that fermentation increased IVPD with a concomitant reduction in total polyphenols and phytic acid content. Lactic fermentation of different cereals such as maize, sorghum and finger millet effectively reduced the amount of anti-nutrients such as phytic acid, tannins and thus improve protein and minerals availability (Lorri and Svanberg 1993).

Health benefits

The potential beneficial effects of coarse cereals on health are discussed below:

Cancer prevention

Cancer is a leading cause of death throughout the world. According to World Health Organisation (WHO) estimates as many as 84 million people are likely to die between 2005 and 2015, if left without remedial interventions (Strong et al. 2005). Several in vitro and in vivo studies reveal that coarse cereals contain various components such as β-glucans, lignans, antioxidants and phytosterols which play important roles in prevention of breast, prostate, colo-rectal and other cancers. A study suggested that dietary sitosterol (SIT) may offer protection from chemically induced colon cancer (Awad et al. 1996). They reported 39% reduction in the numbers of rats that developed tumour and 60% reduction in the number of tumours per rat fed with 0.2% SIT in the diet for 28 weeks. Lignins selectively increase growth of bifidobacteria, which have anticancer potential or enhance formation of short chain fatty acids (SCFA) such as acetate, butyrate and propionate. Butyrate reduces survival by inducing apoptosis and inhibiting proliferation in tumour cells (Mclntyre et al. 1993). Thus butyrate acts on secondary chemoprevention by reducing the number of cells in cancerous lesions and thereby slowing or inhibiting formation of malignant tumours. The possible mechanisms of action of lignan as an anti-carcinogen may be due to direct binding to the carcinogen resulting in excretion through faeces, lowering the pH of the tract or specific action of butyrate when fermented by colonic bacteria (Philip and Lynnette 1993). Oat fibers also act as prebiotic in colon and hence are effective in colorectal cancer. It was reported that sorghum consumption consistently correlated with low incidences of esophageal cancer in various parts of the world including several parts of Africa, Russia, India, China, Iran, etc. (Chen et al. 1993). The phenol content of sorghum was correlated with its antioxidant activity (Dicko et al. 2005).

Cardiovascular diseases (CVD)

According to World Health Organization (WHO) estimates in 2005, 17.5 million people died of CVD, which accounts for 30% of all deaths globally (AHA 2007). Coarse cereals have antioxidant and cholesterol lowering properties, and hence, lower the risk of Coronary Heart Diseases (CHD). Fibers, phytosterols, β-glucans and policosanols have anticholesterolemic properties whereas flavonoids and anthocyanins have antioxidant properties. Policosanols are reported to reduce plasma LDL-cholesterol levels by suppressing 3-hydroxy 3-methylglutaryl- CoA (HMG CoA) reductase activity and increasing LDL receptor uptake by cells (Menendez et al. 1999). Oat bran reduced total serum cholesterol in hypercholesterolemic subjects by as much as 23% with no change in high density lipoprotein (HDL) cholesterol (Anderson et al. 1991). There is an average reduction of 11% in the plasma total on consumption of 140 g of rolled oats (Poinerou et al. 2001). The FDA claim for oat determined that an effective daily intake of β-glucan for controlling serum cholesterol level is 3 g. This can differ among different individuals and depends upon initial cholesterol content of the subject (Davidson et al. 1991). Awika and Rooney (2004) reported that guinea pig fed with 58% low tannin sorghum was more beneficial in lowering cholesterol than rolled oats, wheat or pearl millet. Consumption of 3 or 6 g β-glucan in barley diet resulted in significant reduction in total cholesterol content among mildly hypercholesterolemic individuals as compared to control groups. However, there was no significant effect on HDL cholesterol and triacyglycerol concentration (Behall et al. 2004).

Diabetes

A high intake of cereal fibre has consistently been associated with a lower risk of diabetes (Willett et al. 2002). Foods low in glycemic index (GI) help in weight management, as they promote satiety. Although one study observed that a similar amount of weight loss occurred with a high-GI diet as with a low-GI diet (Wolever et al. 1992), several intervention studies have found that energy-restricted diets based on low-GI foods produce greater weight loss than those based on high-GI foods (Brand-Miller et al. 2002). A decrease in peak and average increase in glucose and insulin was observed in non-Insulin dependent diabetes mellitus (NIDDM) subjects when they were fed with extruded breakfast cereal enriched with β-glucan (~15% dwb) (Tappy et al. 1996). It has been showed that the viscosity of β-glucan could account for 79–96% of the changes in plasma glucose and insulin response to 50 g glucose in a drink model (Wood et al. 1994).

Weight management

Numerous studies have linked higher intake of dietary fibre to improved management of body weight. It was demonstrated in a study that lean men and women had significantly higher fibre intake versus obese males and females (Miller et al. 1994). A study with a group of over 5,000 subjects (Appleby et al. 1998) showed that higher fibre intake is associated with lower body mass index (BMI) in both men and women. Oats, barley and other coarse cereals being rich source of fibers provide high satiety value, decreases the appetite and hence help in weight management. Numerous reports on reduced weight gain of animals (rats, pigs, rabbits, poultry) fed on high tannin sorghum are available (Lizardo et al. 1995; Muriu et al. 2002). The mechanisms by which tannin reduces nutritive value include binding of food proteins and carbohydrates or binding of digestive enzymes including sucrase, amylases, trypsin, chymotrypsin and lipases (Lizardo et al. 1995; Carmona et al. 1996; Nguz et al. 1998), thus inhibiting their activity. Inhibition of intestinal brush-border bound amino acid transporters by sorghum tannins was also reported (King et al. 2000).

Uses of coarse cereals for human consumption

Barley

Coarse cereals are used in several forms as food for human consumption, all over the world. For food uses, barley grains are abraded to produce pearled barley, which may be further processed to grits, flakes and flour. Barley is a wonderfully versatile cereal grain with a rich nutlike flavour and an appealing chewy, pasta-like consistency. Its appearance resembles wheat berries, although it is slightly lighter in colour. Sprouted barley is naturally high in maltose, a sugar that serves as the basis for malt syrup sweeteners. When fermented, barley is used as an ingredient in beer and other alcoholic beverages. In Western countries, pearled barley, whole, flaked, or ground is used in breakfast cereals, stews, soups, porridge, bakery flour blends and baby foods (Bhatty 1993). Barley flour can easily be incorporated into wheat-based products, including bread, cakes, cookies, noodles and extruded snack foods (Newman and Newman 1991). Wheat bread with barley flour added at 15–20% was acceptable, but an increased proportion of barley flour caused a decrease in loaf volume, dull brown colour and hard crumb texture (Dhingra and Jood 2004). A 4% addition of barley flour provides superior water holding capacity to ultra low fat pork bolognas (Shand 2000). Wheat flour substituted with 12–25% barley flour provides acceptable noodle making characteristics (Izydorczyk and MacGregor 2005). Barley tea is used in Asia including India prepared from roasted barley kernel and consumed as drink like water with or without meal (Newman and Newman 2006). The second most common use of barley is in the form of malt, which is used to produce beer, distilled alcohol, malt syrup, malted milk, flavorings and breakfast foods.

Oats

Oats are available in variety of forms that can be used in formulation of different cereal based consumer products. Oats have numerous uses in food: most commonly, they are rolled or crushed into oatmeal, or ground into fine oat flour. It is chiefly eaten as porridge, but may also be used in a variety of baked foods, such as oatcakes, oatmeal cookies and oat bread. Oats is also used as an ingredient in many cold cereals, in particular muesli and granola. Oats are also consumed many a times as raw food. It is considered to be the richest source of dietary fibre, both soluble and insoluble (approx. 5 g/100 g serving). It is also rich in essential fatty acids like linoleic and oleic acids, which contributes to the lowering of LDL cholesterol and HDL cholesterol, besides it is also rich in several minerals such as Mg, K and Ca. It is a good source of folic acid which promotes heart health. Avenanthramides, is an antioxidant unique to oats which has been reported to inhibit formation of oxygen free radicals. Due to the high lipid content, oat flour is highly adhesive and difficult to handle. Instead, most common whole grain oat product is oat flakes, which are often used as a raw material in baking. Polar lipid fraction of oat oil has a large potential to be used as an emulsifying agent (Peterson 2002). There has been increased demand for oat protein concentrates with tailored technological properties (Guan et al. 2006). Oat products are used as ingredients in a wide variety of bread and baked products as they provide unique flavour and moisture retention characteristics besides enhancing the nutritional benefits of these products. In conventional wheat bread processing, up to 10–20% of wheat flour can be easily replaced with oat flakes. Even higher amounts of oats can be used by adopting optimized baking technologies (Flander et al. 2007). A probiotic drink using lactic acid bacteria was prepared using oat as a substrate. The levels of starter culture, oat flour and sucrose content affected the fermentation process. β-glucan content in the drink (0.31–0.36%) remained unchanged both during fermentation and storage of the drink. The drink could be stored for 21 days under refrigerated conditions (Gotcheva et al. 2006). A new low fat mayonnaise is prepared using oat dextrin having Dextrose Equivalency of 8.1, viscosity 1,620 MPa-s and a lower caloric value 597.7 kcal/100 g compared to full-fat mayonnaise. Pound cake with some additive mixtures (10 g dextrins, 25 g chemically modified starches and 25 g oats fiber per 100 g) presented better textural characteristics than conventional one (Sanchez-Pardo et al. 2010).

Sorghum and millets

Processed sorgum and pearl millet grains and meals from them are used to prepare various types of traditional and non-traditional food products. Murty and Kumar (1995) summarized and classified them into 9 major food categories (thick porridge, thin porridge, steam-cooked products, fermented breads, unfermented breads, boild rice-liked products, alcoholic beverages, non-alcoholic beverages and snacks). Traditional flatbreads can be made from sorghum and millets. It might be regarded as leavened if they are fermented like *injera* (Ethiopia) or puffed like *chapati*/*roti* (India) (Murty and Kumar 1995). Unlike composite breads, wheat-free sorghum breads are suitable for celiac intolerant persons (Schober et al. 2005). Pure sorghum breads were reported to be quite unattractive, but the corresponding buns were more acceptable (Olatunji et al. 1992). It was reported that in contrast to bread, cake and cookies could be successfully made from sorghum flour (Anglani 1998). Cookies made from 100% pearl millet or sorghum could be produced, but are very tough, hard, gritty, and mealy in texture and taste. They also lacked spread and top surface cracks, both desirable traits. They identified lipid composition as partly responsible for this inferior quality (Taylor and Duodo 2009). In contrast to above study, it was found that sugar cookies from 100% sorghum generally had the highest spread factor (width to thickness) relative to cookies from a commercial wheat cookie flour and cookie flour-sorghum mixtures (Lorenz and Coutler 1991). A traditional use for sorghum is in tortillas. Noodles have also been successfully prepared from decorticated sorghum (Suhendro et al. 2000).

Sorghum contains a higher proportion of insoluble dietary fibres. This causes slow release of sugars, thus making the food products based on them especially suitable for those suffering from or prone to diabetes. For instance, whole grain sorghum based products (*chapati, upama and dhokla*) have been found to lead to lower glucose levels, lesser percent peak rises and lesser area under the curve in diabeteic subjects compared to those prepared from dehulled sorghum and wheat (Lukshmi and Vimla 1996). Various types of cookies and biscuits were prepared for diabetics using malted and unmalted sorghum flour. Cookies prepared from 40% wheat flour blended with 60% malted sorghum flour led to an increase in fibre content. Wet heat treatment of sorghum is known to lower its digestibility. This characterstic feature could perhaps be made use of to market sorghum flakes as diabetic flakes. During the flaking process, the starch undergoes retrogradation leading to formation of resistant starch or enhancing the dietary fibre contents (Mangala et al. 1999). This added advantage in sorghum flakes could be of potential benefits in the dietary management for diabetes. Tannin sorghums are slow in digestion. Some cultures in Africa prefer tannin sorghums since it contributes to a longer period of satiety or fullness as compared to other cereals. Thus, tannin sorghums have potential applications in foods for diabetics (Awika and Rooney 2004). Sorghum is also gluten free and hence, has a good chance of being commercialized for the food based management of this problem. Sorghum, especially, is a potential source of nutraceuticals such as antioxidant phenolics and cholesterol-reducing waxes. Sorghum contains unique anthocyanins (3-deoxyanthocyanins), which are more stable at high pH, thus increasing their values as good natural food colorants (Taylor 2006).

Pearl millet is an important minor cereal crop cultivated mainly in Indian subcontinent and Africa. Though, it is utilized only by a segment of population, in recent years, it has gained importance due to its nutritional importance. Besides being a staple food, pearl millet is used for the preparation of snack foods such as noodles, *pappads*, vermicelli, *ladoo* etc. *Chapati* prepared from pearl millet flour produced after the grains had been bleached or acid-treated for heat-treated has been reported to have enhanced overall acceptability as compared to the *chapati* prepared from the raw untreated grains. Singh and Sehgal (2008) developed a *ladoo* using popped pearl millet, dehulled chickpea and groundnut. The product had a higher mineral content, but the antinutrients like phytate and polyphenol affected the in vitro digestibility of protein and starch. Singh et al. (2006) developed a biscuit from blanched and malted pearl millet flour in combination with soybean flour in equal proportions, milk powder, fat, sugar and other minor additives. The product had higher mineral (calcium, iron, manganese and phosphorus) contents and improved in vitro digestibility. Various types of biscuits developed by incorporating different levels of blanched as well as malted pearl millet flour have been found to be acceptable and to store well upto 3 months (Singh et al. 2003). Pearl millet grits and flour can be used to prepare RTE products. Such products have crunchy texture and can be coated with traditional ingredients to prepare sweer or savoury snacks.

The acid treated pearl millet aids products of better acceptability as compared to that from just decorticated pearl millet. Pearl millet blended with soya or protein rich ingredients such as legumes or groundnut cakes on extrusion give nutritionally balanced supplementary foods (Mallesshi et al. 1996). Sumathi et al. (2007) showed that extruded pearl millet products prepared from a blend of 30% grain legume flour or 15% defatted soyabean head, respectively, 14.7% and 16.0% protein and 2 and 2.1 protein efficiency ratio. Noodles, macaroni and pasta like extruded products could be prepared from millet flour (Desikachar 1975). Extruded snacks prepared with mixed millet flour containing rice flour or corn flour or tapiooca starch in various proportions have been shown to have acceptable appearance, colour and texture (Siwawij and Trangwacharakul 1995). Popped pearl millet is a good source of energy, fibre and carbohydrates. Varieties with hard endosperm and medium thick pericarp exhibit superior popping quality (Haldimani et al. 2001). The lipolytic enzymes are denatured during the process of popping. The nutritional advantage of the popped millet is utilized in developing formulations for supplementary foods or weaning foods for children and mothers (Bhaskaran et al. 1999). Pearl millet is rich in oil and linoleic acid, accounts for 4% of the total fatty acids in this oil, giving it a higher percentage of n-3 fatty acids as compared to maize in which linoleic acid accounts for only 0.9% of the total fatty acids, hence is highly deficient in n-3 fatty acids. The n-3 fatty acids play an important role in physiological functions, including platelet aggregation, LDL cholesterol accumulation and the immune system. Pearl millet bran contains a high proportion of soluble dietary fibre and could be tapped for hypocholesterolemic and hypoglycemic effects. In view of this, fibre regulated millet flakes could be an ideal snack for the obese and calorie conscious people (Haldimani and Malleshi 1993). Some of the traditional foods prepared from pearl millet are *ogi* (a cereal besed food from Nigeria), *fura* (a traditional product of Nigeria), *ben-saalga* (a fermented gruel from Burkina Faso) etc.

A process has been developed for the manufacture of dried complementary food by using whey-skim milk blend, pearl millet and corn flour along with certain minor ingredients by employing tray or spray drying (NAIP 2010). The moisture, fat, protein, ash and crude fiber in the product were 2.64, 1.24, 12.82, 2.02 and 0.86, respectively and the tray dried product did not vary significantly from the spray dried one. Almost 50% of wheat flour could be replaced by pearl millet flour in iron- and protein-enriched biscuits made from a mixed cereal flour and whey protein concentrate combination (NDRI News 2011). The iron-fortified variant of pearl millet biscuits contained 18.81, 12.23, 1.13, 1.42, 3.20 and 63.28% of fat, protein, ash, crude fibre, moisture and carbohydrate, respectively and 6.53 mg/100 g iron. A 30-day feeding trial established that the haemoglobin concentration increased significantly by 25% and 70% in normal and anaemic rats, respectively. The digestive utilization were also greater for the iron deficient animals, as established by greater apparent digestibility co-efficient, iron balance and iron retention. Pearl millet based *kheer* dessert has been prepared and reported to be liked by consumers (Jha et al. 2011).

Corn

Corn has its significance as a source of a large number of industrial products besides its uses as human food and animal feed. Corn fiber gum can potentially replace gum arabic for beverage flavor emulsification (Yadav et al. 2007). Food additives, including corn fiber oil, corn fiber gum, cellulosic fiber gels, xylo-oligosaccharides, ferulic acid, vanillin and xylitol are also useful by-products. Corn gum can serve as adhesive, thickener or additive in plastics, whereas corn starch may be used to produce corn syrup, anhydrous sugar, maltodextrin, dextrose, glucose and starch (Singh et al. 2000). Refined corn oil is composed of 99% triacylglycerols with 59% polyunsaturated fatty acid (PUFA), 24% monounsaturated fatty acids (MUFA) and 13% saturated fatty acid (SFA). Mendonca et al. (2000) found that incorporation of corn bran in extruted snacks at the rate of 150–320 g/kg can significantly decrease the radial expansion ratio, apparence and general acceptability of the finished product. Holguin-Acuna et al. (2008) found that corn bran at 300 and 400 g/kg gave the lowest breaking strength and that the poor performance of corn bran in baked goods could be improved by extrusion. Cellulosic fiber gel from corn bran could be promoted as fat mimetics under the name of Z-trim. Corn bran and fibers could also be used as substrates for production of xylitol—a low calorie, non-carcinogenic sweetner (Winkenlausen and Kuzmanova 1998).

Fermented foods based on coarse cereals

There are varieties of fermented foods produced from coarse cereals either alone or by combination of two or more cereals and also ingredients from other food groups. Corn is fermented to make weaning food in West Africa known as *Ogi*. The predominant species involved is *Lactobacillus plantarum* along with other organisms such as *Corynebacterium* sp. (Caplice and Fitzgerald 1999). *Ogi* is also made from sorghum and other millets. *Kenkey* is another fermented dough made from corn in Ghana. The fermentation is dominanted by *L. fermentum and L. reuteri* (Halm et al. 1993). *Pozol* is another fermented maize dough which is wrapped in banana leaf and left overnight and consumed by natives in Southern-Mexico. *Injera* is a fermented drink made from teff, sorghum, maize, finger millet and barley. There are several other fermented products based on cereals (such as *Chicha, Mahewu, Boza, Mangisi, Mawe* etc.) prepared and consumed all over the world. Togwa is a sorghum based fermented weaning food beverage to which *Lacobacillus plantarum*, *L. brevis* and *L. fermentum* upto 10^9 cfu/g have been added and this is reported to improve intstinal mucosa barrier function in children with acute diarrhoea (Kingamkono et al. 1999; Mugula et al. 2002). A fermented oatmeal soup made by cooking with malted barley flour utilizing probiotic *Lactobacillus* strains like *L. plantarum* and *L. reuteri* has been reported to maintain intestinal function and structure after surgical operations (Marklinder and Lonner 1992; Johansson et al. 1993). Similarly, in a related development, an oat bran based fermented product, flavoured with fruit berries, containing *Lactobacillus acidophillus* LA-5, *Bifidobacterium bifidum* Bb-12 upto 5×10^7 cfu/g has been shown to have a potential synbiotic effect leading to cholesterol lowering and blood glucose attenuation (Salovaara and Kurka 1997; Salovaara 1998).

Traditional cereal-based beverage (*raabdi)* based on pearl millet and sorghum were developed by mixing germinated cereal flour with milk, heat processing and inoculating with suitable starter culture (NDRI 2009). The curd thus obtained was mixed with a stabilizer-spices-salt mix and kept well for 7 days at 7–8 °C. The shelf life could be extended to 35 days using suitable biopreservatives. Awad et al. (2010) formulated cereal-rich fermented probiotic beverages using barley flour and selected probiotic strains (*L. acidiphilus* NCDC 14*, L. casei* NCDC 297 *and L. rhamnosus* LGG). It was reported that 4–5% barley flour and *L. acidiphilus* NCDC 14 resulted in the best beverage based on sensory characteristics. Mishra et al. (2011) prepared fermented *khichri* from a skim milk-pearl millet base using a standard *dahi* culture (NCDC 167). It has been established that an inoculum of 4% *L. acidophilus* NCDC 13 in a composite substrate comprising of germinated pearl millet flour and liquid barley malt extract in a whey-skim milk medium could result in a probiotic count of 10^{12} cfu/ml and could form an excellent base for a cereal-dairy probiotic beverage (Ganguly and Sabikhi 2011).

Potiential uses of coarse cereals in other industries

Sorghum grain polymers are being investigated for their potential to make biodegradable, edible bioplastic films and coatings. Kafirin, the sorghum prolamin storage protein is a good choice for making bioplastics as it is the most hydrophobic of the prolamins (Belton et al. 2006). Mixtures of sorghum wax or carnauba wax together with medium chain length triglyceride oil were compared as edible coatings for gelatine-based candies (Weller et al. 1998). Wu et al. (2006) reported that pearl millet can be potentially used for the production of ethanol. On a starch basis, ethanol yield was similar to that of sorghum and maize with an efficiency of 94.2%. Research on the use of sweet-stemmed sorghum for the production of bioethanol has been reported elsewhere (Schaffert 1995; House et al. 2000). Coarse cereals–singly or in combination of two or more have been used to produce various kinds of beers. The African brews *ajon* made from finger millet, *omuramba* from sorghum and *kweete* from maize and millet (Mwesigye and Okurut 1995) are few examples. Sweet sorghum (*Sorghum bicolor*) is the only crop that provides grain and stem that can be used for sugar, alcohol, syrup, jaggery, fodder, fuel, bedding, roofing, fencing, paper and chewing. It has been used for nearly 150 years to produce concentrated syrup with a distinctive flavour (Schaffert 1992). Sweet sorghum can be potentially used for the production of paper.

Conclusion

One of the greatest constraints in the popularization and commercialization of coarse cereals has been its branding as poor man's food, which seems to be misplaced. These grains have traditionally been grown in difficult soil and climatic conditions. They could not make it to the food basket of urban elite whose consumption choices play a dominant role in the commercialization of any food product. Grain quality and nutritional studies now show that these grains are more appropriate choices for the nutritional security of the rural and urban poor who have limited access to other sources of dietary components. Coarse cereals have been known for their rich nutrient contents and drought resistance quality. These are comparable and at times even better than wheat and rice in to other sources of dietary components. In addition, these grains could also be more appropriate choices than the fine cereals such as wheat and rice for the elite who will benefit from their high nutraceutical properties. their calorie and other nutrient contents. Coarseness of the grains and poor shelf life of flour are some of the major constraints for the commercialization of these cereal grains. The grain utilization for manufacture of shelf stable, ready-to-serve and ready-to-reconstitute products will require new processing technologies. The emphasis, therefore, should be on exploiting the potentially useful intrinsic qualities of these grains to produce unique and alternative value-added products. Commercialization of coarse cereal grains for alternative and health food uses needs to be viewed in a broader context from production to utilization and emerging challenges and opportunities, in the backdrop of good potential for food processing industry and promising health beneficial effects.

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