2. Review of Literature

Underutilized cereals is commonly applied to refer to species whose potential has not been fully realized and India is the largest producer of many kind of underutilized grains like millets which are often referred to as coarse cereals. However, their consumption is poor due to lack of ready-to-use products similar to rice and wheat, and also due to the lack of awareness, research-based studies on their nutritional quality and health benefits are little in number. They are the recognized source of dietary fiber, resistant starch, total polyphenol and antioxidant substances Eyzaguirre, (1998). Literature reviewed relevant to present study is presented in this chapter.

2.1. Underutilised cereals

2.1.1. Introduction and Origin

Eyzaguirre,(1998) reported that neglected species are those that are grown primarily in their centers of origin or centers of diversity by traditional farmers, where they are still important for the local communities. Some species may be globally distributed, but tend to occupy special niches in the local economy and in local production and consumption systems. While these crops continue to be maintained by socio-cultural preferences and local use practices, they remain inadequately characterized and neglected by research and conservation.

Underutilized species were once widely grown but are falling into disuse due to various agronomic, genetic, economic and cultural factors. Farmers may find these species less competitive than other crop species in the same agricultural environment. Consumers may be influenced by changing food culture, ease of processing and availability. The eco-geographic decline of these species may erode their genetic base thus restricting future development options (Eyzaguirre, 1998).

2.1.2. Origin

Rachie and Peters, (1977) investigated that among the minor millets, finger millet stands unique because of its superior nutritional qualities. It is a near spherical small seeded caryopsis that is widely used in India as a food crop. It is an annual robust grass that grows to a height of 40–100 cm.
Hilu et al., (1979) reported that finger millet (*Eleusine coracana* L. Gaertn), also known as African millet, commonly called as Ragi, is one of the ancient grains, which is believed to be originated in East Africa and subsequently introduced into India by sea traders around 3000 B.C.

Ismani, (1985) reported that millet were originated in the Ugandian region of Africa and was transported to India in the pre-Aryan period (1500 BC). In Sanskrit literature, it is referred to as *Nṛtya-Kondaka* which means ‘dancing grain’. Even today, in Uganda, numerous tribal rituals and religious ceremonies are associated with finger millet.

Ismani, (1985) studied that in the Balinese mythology of *Catur Bumi*, the God Ciwa sent down a bird that carried seeds of four different coloured rices - yellow, black, red, and white. On the way, the bird ate the yellow seed and only three were left. So, three types of rices (red, white, and black) are the main foodstuff of Balinese people.

Sharma, (1991) reported that the origin of coloured rices is as old as rice itself. According to a Japanese myth, the rice plant originally did not bear any grains. Then the Goddess Kuan Yin sprinkled her milk over the plant and white grains appeared, but excessive squeezing caused blood to come out and some grains became red.

### 2.1.3. Cultivation

Rachie and Peters, (1977) reported that finger millet is mainly grown in semi-arid tropics and sub-tropics of the world under rain fed conditions. It belongs to the genus *Eleusine* in the tribe Eragrostideae. *Eleusine coracana* species are the most cultivated species whereas *Eleusine africana* and *Eleusine indica* species have remained as wild grass.

Finger millet is commonly grown for human consumption in India and also in many arid and semi-arid areas of the world. It can be grown in varying soil and climatic conditions in all most all types of soil including alkaline soils with pH as high as 11 and from sea level to 2500 m altitude and the area of rainfall ranging from 800 to 1200 mm. The millet has outstanding properties as a subsistence food crop and is known as the poor man’s food due to its long sustenance. It can be stored safely for many years without infestation even in hot humid areas with marginal storage facilities. The millet grain will retain its
viability and quality longer than any other cereal crops. In good climatic conditions, the grain is said to be storable for several decades, thus making it a very important famine reserve food (Hilu et al., 1979).

Anonymous, (1998) reported that red rice occur as wild, weedy, or cultivated types, and the red kernels are covered with dark or light-coloured husk. Of the various species of wild rices, Oryza granulata, 10.48%, 9.41%, and 8.40% had red, brown, and purple pericarps respectively.

Dikshit et al., (2004) found that the collection of the Central Rice Research Institute (CRRI), Cuttack, Orissa had 2,960 entries, mainly from the eastern states of India, had a relatively higher number of red rices. Of 20% colored rices, 17.40%, 3.44%, and 2.50% were red, purple, and brown rices, respectively. A survey conducted by the National Bureau of Plant Genetic Resources (NBPGR) from 1991 to 1998, recorded about 35% and 21% red rice varieties in Orissa and Manipur. In India, red rice were prevalent in the South, East, and the hilly tracts of the Northeast and West.

Red rice cultivars have been reported high tolerance to such unfavourable environments as infertile soils, deep water, and mountain lands. Few red varieties were reported from the plains of Haryana, Punjab, Rajasthan, western Uttar Pradesh and Gujarat (Dikshit et al., 2004).

Taylor, (2004) reported that barnyard or japanese millet is a domesticated relative of barnyard grass and there exists several varieties. It is the fastest growing of all the millets and produces a crop in six weeks. In India, Japan and China it is often used as a substitute for rice when the paddy crop fails.

Taylor, (2004) reported that kodo millet is a minor grain crop in India but is of much greater importance in the Deccan Plateau. It is an annual grass species that grows to around 90cm high. Some varieties of Kodo millet are prone to attacks from mycotoxins. The grain varies in color from light red to dark grey and is enclosed in a tough husk that is difficult to remove.

2.1.4. Production

Mitter, (1974) reported that finger millet is produced in several parts of the country. Karnataka state tops in its production. Tamilnadu, Andra Pradesh, Maharashtra, Orissa, Uttar Pradesh and Uttarkhand also produce substantial quantity of this millet. The millet is known by different names in different regions
of India and also in other countries. It is adaptable to sea level as well as in high altitude (in the Himalayas) up to 3200 meters. The origin of finger millet in the country dates back to 1800 B.C.

Mittre, (1974) reported that with the advent of agricultural technology, high yielding finger millet varieties, including crosses between Indian and African species (designated as Indaf), which have a production potential as high as 3 tonnes per hectare have been developed. The name, "finger" millet is derived from the look of its earhead which consists of spikes, radiating mostly in a curving manner from a central point, resembling fingers of the human hand. The Indian varieties of the millet normally have long spikes whereas the African cultivars have shorter curving spies.

Rachie and Peters, (1977) reported that the most common species of the millet cultivated for food uses, is *Eleusine coracana*, whereas, the other two species, namely, *Eleusine indica* is a wild species and *Eleusine africana* is a semi-wild species.

Hadimani and Malleshi, (1993) reported that Zambia and Madagascar are the African countries where finger millet is cultivated prominently. The state of Karnataka in India produces nearly 65% of the Country's production of the millet and the rest is mainly contributed by states of Tamilnadu, Andhra Pradesh, Uttarakhand, Maharastra, Orissa and Gujarat. The nutritional composition of the millet is not only comparable to the major cereals but also it is superior to many other cereals with respect to several protective nutrients including micronutrients. Among the small millets, finger millet is an important and nutritionally significant minor cereal.

Apoorva et al., (2010) reported that finger millet is the third most important millet in India, next to sorghum and pearl millet, covering an area of 2 million hectares with annual production of 2.15 million tones. In Karnataka, it is grown in an area of 0.8 Mha with an annual production of 1.34 mt.

2.1.5. Processing Status

Mahudeshwaran et al., (1966) found that finger millet kernel has distinct morphological features. The pericarp is easily removed by rubbing or soaking in water. The good shelf-life of the millet and its products could also be attributed to its lower levels of fat content.
Mallanna and Rajasekhar, (1969) reported that a few varieties of finger millet with a white seed coat have also been released but they have not become productive and popular mostly because of their poor keeping qualities and bland taste.

Raghavendra and Juliano, (1970) reported that parboiling or hydrothermal treatment is commonly applied to rice worldwide and also to wheat unchanged but the protein bodies are ruptured and its solubility decreases.

Sondi et al., (1980) conducted study on rice and found that as the total fat content remains unchanged due to parboiling, some portion of the endosperm fat migrates towards the periphery of the grain and the oil globules in the aleurone layer get disrupted.

Bhattacharya and Ali, (1985) reported that parboiling or hydrothermal treatment to the cereals is known to harden the grains and improve their milling efficiency.

McDonough et al., (1986) stated that the millet kernels also contain a loosely attached thin pericarp (glumes), a non-edible component. The glumes can be easily removed by rubbing or soaking in water and the deglumed millet forms a fully edible component.

McDonough et al., (1986) reported that the seed coat of the millet comprises of multilayered testa with five distinct layers and beneath which the aleurone layer is located. The one cell aleurone layer surrounds the entire endosperm.

Pillaiyar, (1988) reported that there is increased interest in the millet due to its health benefits, but the unattractive dark color of its foods, limit its usage by the non-traditional millet consumers and the special skills are needed to prepare its conventional products. Therefore, it was felt to process the millet to obtain in a form that would be readily acceptable by one and all, similar to rice or wheat.

Malleshi, (1989) reported that the germ is embedded in a shallow depression of the endosperm. The endosperm of the millet is of soft and highly fragile texture to which the multi-layered seed coat is rigidly attached. Because of these unique textural features, the millet does not withstand the impact and pressure during pearling or decortications and fragments to finer particles along with the seed coat. In view of this, the millet is not at all amenable to polishing or
decortication similar to other cereals and millets, and hence decortication of millet has not been possible so far. Cooking the millet in the grain form also has not been possible, because the seed coat hinders swelling of the grain during cooking and prolonged cooking burst opens the kernel exposing the endosperm portion. This leads to highly sticky product which still contains the seed coat and hence is not at all acceptable to the consumer as a food. Thus, the millet is invariably pulverized and used to prepare flour based traditional products such as roti, mudde and ambali.

Kimura et al., (1993) reported that the parboiled grain becomes glassy and translucent and darker in color compared to its native form. It has been reported that, not only steaming but also steeping and drying steps cause considerable discoloration to the grain in case of rice. Unlike rice and other grains, the millet contains a substantial proportion of non-starch polysaccharides, polyphenols and other phytochemicals which may play a major role in determining the quality characteristics of the hydrothermally treated millet. The millet being a small sized grain with comparatively large surface area may behave differently compared to rice with respect to steeping and drying characteristics. Hence, detailed studies were undertaken for optimizing the various unit operations involved in the hydrothermal treatment and its influence on the physicochemical, textural and nutritional characteristics of the millet.

Rani and Krishnaiah, (2001) reported that in some areas of India, red rice are considered highly nutritive and medicinal. The rice is eaten as whole grain; Red gunja is preferred for making bread and chapati.

Arumugasamy et al., (2001) reported that glutinous rice is used in making puttu in South India. In Himachal Pradesh, Jatu red rice is prized for its aroma and taste. Matali and Lal dhan of Himachal Pradesh are used for curing blood pressure and fever. Kafalya, from the hills of Himachal Pradesh and Uttar Pradesh, is used for treating leucorrhea and abortion complications. Kari kagga and Atikaya of Karnataka are used for coolness and as tonic, while Neelam samba is used for lactating mothers in Tamil Nadu.

Chaudhary and Tran, (2001) reported that the chinese use red rice for preparing vinegar, tart, cosmetics, red kojic, and red rice yeast, which is used for medicinal purposes. Red rice yeast is prepared by fermenting yeast Monascus
purpurea over red rice. It is said to promote blood circulation, and is used in treating upset stomach, indigestion, bruised muscles, and hangovers; and it is a cholesterol-lowering product that is commercially marketed the world over. Red rice in Japan is used for preparation of red sake, coloured noodles, and cakes for ceremonial occasions. In Sri Lanka, red rice is a favourite as food and some are used as medicines.

Usha et al., (2011) reported that the millet kernels contain soft and fragile endosperm covered by rigidly attached seed coat and get pulverized along with the seed coat whenever efforts were made for its decortication similar to other cereals and millets. In view of this, the millet has never been decorticated and it is invariably pulverized along with the seed coat and the whole meal is used for food preparation. Among the several methods of cereal processing, hydrothermal treatment or parboiling enhances the grain hardness and improves the milling characteristics. This is true with finger millet also. Hydrothermal treatment or parboiling of cereals basically involves steeping to hydrate the grains near to their equilibrium moisture content, steaming to gelatinize the starch and dehydrating the same to safe storage moisture level. During parboiling, the grains undergo physicochemical changes leading to improvement in its processing (specifically milling) and nutritional qualities.

2.2. Nutritional value of underutilized cereals

Hulse et al., (1980) reported that finger millet is exceptionally rich in calcium (300 ï¼ 400 mg %) besides, it is also a good source of many other micronutrients such as iron, magnesium, zinc, chromium, iodine and thiamine. The millet is also a very good source of phytochemicals such as dietary fibre, polyphenols, pigments and phytate.

Hulse et al., (1980) reported that the sulfur-based amino acids (0.35 mg/g protein) content of the millet protein is much higher, compared to other cereal proteins and happens to be a good source of tryptophan also. Prolamins are the major fractions of the millet protein. Similar to other cereal proteins lysine, one of the essential amino acids, forms the limiting amino acid of its protein. The leucine/isoleucine quotient of the millet proteins being about 2 is almost equivalent to rice and wheat. Albumins and globulins constitute 8 ï¼ 15 % whereas prolamins and glutelin like proteins form 12 ï¼ 28 % of the proteins in the millet.
Malleshi et al., (1986) reported that the millet is known for its richness in many of the edible phytochemicals, such as dietary fibre, polyphenols, pigments and phytate. The contents of these in the millet is about 15, 2 and 1 % of the seed matter, respectively. The dietary fibre (DF) of the millet comprises of both soluble and insoluble fibre. Cellulose forms the major portion of insoluble dietary fibre whereas hemicelluloses, pectin etc are important soluble fibre.

Malleshi et al., (1986) reported that the nonstarch polysaccharides (NSP) of the millet largely consist of cellulose, hemicelluloses and pectinaceous matter. The non-starch polysaccharide content of the millet ranges from 15 to 20% and it forms the major component of the dietary fiber. The cellulose and the hemicelluloses form the major part of insoluble and soluble dietary fiber of the millet respectively.

Malleshi, (1989) reported that the seed coat is mostly cellulosic and contains considerable proportion of phytochemicals and polyphenols which impart color to the seed coat.

Ravindran, (1991) reported that the millet seed coat being colored, contains considerable levels of anthocyanins and such other pigments. The phytate content in the millet varies from 0.5  2.0 %, but most of it is concentrated in the seed coat matter.

Parameswaran and Sadasivam, (1994) reported that in addition to their cultivating advantages, millets were found to have high nutritive value and comparable to that of major cereals such as wheat and rice.

FAO, (1995) reported that nutritionally, millets are equivalent to other cereal grains. The major nutrients contained are 60\%–70\% carbohydrates, 7\%–11\% proteins, 1.5\%–5\% fat, 2\%–7\% crude ÿbre, minerals and vitamins. Millets are a rich source of energy and are comparable with other cereal grains. Except ýnger millet, other millet types have higher fat content ranging from 3.5\% to 5.2\% compared to other cereals. Millets are rich in iron and phosphorus. In addition, ýnger millet has a high calcium content of 350 mg/100 g.

Sripriya et al., (1997) reported that finger millet has a carbohydrate content of 81.5\%, protein 9.8\%, crude fiber 4.3\%, and mineral 2.7\% that is comparable to other cereals and millets. Its crude fiber and mineral contents are markedly higher than those of wheat (1.2\% fiber, 1.5\% minerals) and rice (0.2\%
fiber, 0.6% minerals); its protein is relatively better balanced; it contains more lysine, threonine, and valine than other millets.

**Rood, (2000)** reported that the inner portion of red and white rices is alike and white. The zinc and iron content of red rices is 2-3 times higher than that of white rices. American scientists have reported a similar high iron content in the Chinese red varieties, Bloody Sticky and Dragon Eyeball.

**Qureshi et al., (2000)** reported that millets are good sources of phytochemicals such as phenolic acids, lignans and phytoestrogens. Phenolic acids like p-coumaric acid and vanillic acids are present in the bran layer of the grains and are mainly present as gently bound form with insoluble polymers. Generally grains contain low to moderate levels of tocopherol, but due to the large amount consumed in Korean diet, they provide a significant and consistent source of tocopherols.

**Lakshmi and Sumathi, (2002)** reported that the slow digesting nature of the millet diet is also attributed to the complex nature of its starch molecules. Many of the starch granules of the millet are compound in nature and are rigid. Probably, because of this, the fragmentation of the granular structure during processing and also digestion by the carbohydrases is of lower order. The nutritional qualities of the millet are strengthened by the presence of vitamins. The millet contains 42 μg/100g of carotene, 0.42 mg/100g of thiamine, 0.19 mg% of riboflavin, 1.1 mg% of niacin and 18.3 μg% of folic acid.

**Malik et al., (2002)** reported that millets are nutritionally comparable and even superior to major cereals in terms of energy value, proteins, fat and minerals.

**Arora et al., (2003)** reported that due to the presence of antinutrients like phytate, polyphenols, oxalates and tannins, mineral bioavailability is affected. These antinutrients form complexes with dietary minerals, such as calcium, zinc and iron leading to a marked reduction in its bioavailability and make them biologically unavailable to human organism.

**Ali et al., (2003)** reported that millets contains about 92.5% dry matter, 2.1% ash, 2.8% crude fiber, 7.8% crude fat, 13.6% crude protein, and 63.2% starch.

**Mohan et al., (2005)** reported that free sugars, starch and the non-starchy polysaccharides are the constituents of the millet carbohydrates. Glucose, fructose,
Maltose and sucrose form the main components of free sugars and they account for 2% of the millet carbohydrates and they are generally present in the bran tissue. They contribute towards the development of aroma during processing, especially during popping and baking. Starch content in the millet ranges from 75 to 80%, and it consists of amylose and amylopectin fractions, normally present in the ratio of 25:75. Unlike rice, there are no reports of very low or very high amylose millet varieties. The millet starch is known to be of slightly higher degree of crystallinity compared to rice starch.

Thomas et al., (2005) reported that in human and animal nutrition, oxalic acid, denoted as Oxalate is considered as an undesired compound. Oxalate is removed by excretion through the urinary system where it can precipitate calcium and form renal stones. As oxalate is an undesirable compound, the level of oxalate can be reduced by blanching where water soluble oxalates can be leached out. In the human diet, the bulk of oxalic acid intake comes from vegetables. Oxalate content should be low in foods, especially in infant formulas or in dietary foods for consumers metabolically prone to oxalate renal stone formation, the development of low ï oxalate products is considered to be reasonable.

Malleshi, (2005) reported that finger millet is a good source of dietary carbohydrates. Free sugars (1 ï 2 %), starch (75 ï 80 %) and non-starch polysaccharides (NSP; 15 ï 20 %) form the main constituents of finger millet carbohydrates.

Hegde and Chandra, (2005) reported that kodo millet and little millet were also reported to have 37% to 38% of dietary fiber, which is the highest among the cereals; and the fat has higher polyunsaturated fatty acids.

Kalinova and Moudry, (2006) investigated that the protein content of proso millet (11.6% of dry matter) was found to be comparable with that of wheat and the grain of proso millet was significantly richer in essential amino acids (leucine, isoleucine, and methionine) than wheat protein.

Ragae et al., (2006) reported that millets are also rich sources of phytochemicals and micronutrients, for example, pearl millet was found significantly rich in resistant starch, soluble and insoluble dietary fibers, minerals, and antioxidants.
Chethan and Malleshi, (2007a) reported that finger millet also is known to have several potential health benefits and some of the health benefits are attributed to its polyphenol contents.

Youngmin et al., (2007) stated that the methanolic extracts of highly pigmented red sorghum and black rice have showed significantly higher antioxidant activities and contained higher polyphenolic contents. Polyphenolic compounds are the major naturally occurring antioxidants in millets. Although carotenoids and vitamin E contents are relatively low than polyphenolics, grains may contribute to a significant supply of antioxidant to prevent oxidative stress due to the fact that grains are used as a staple food and consumed large amounts in our diets.

Glew, (2008) reported that black finger millet contains 8.71 mg/g dry weight fatty acid and 8.47 g/g dry weight protein.

Mohamed, (2009) conducted study on foxtail millet protein characterization and found that its protein concentrate is a potential functional food ingredient and the essential amino acid pattern suggests possible use as a supplementary protein source to most cereals because it is rich in lysine.

Apoorva et al., (2010), reported that finger millet grown on marginal land provides a valuable resource in times of famine. Its grain tastes good and is nutritionally rich (compared to cassava, plantain, polished rice and maize meal) as it contains high levels of calcium, iron and manganese. It has a carbohydrate content of 81.5%, protein 7.3%, crude fiber 4.3% and mineral 2.7% that is comparable to other cereals and millets. Its crude fiber and mineral content is markedly higher than wheat (1.2% fiber, 1.5% minerals) and rice (0.2% fiber, 0.6% minerals); its protein is relatively better balanced; it contains more lysine, threonine and valine than other millets.

Usha, (2011) investigated that finger millet (Eleusine coracana) or ragi is one of the important minor cereals in Indian subcontinent and also in several of the African countries. The millet contains 6 - 8% protein, 1 - 1.7% fat, 65 - 75% starch, 18 - 20% dietary fiber and 2 - 2.5% minerals.

Singh and Raghuvanshi, (2012) reported that nutritional quality of food is a key element in maintaining human overall physical well-being because nutritional well-being is a sustainable force for health and development and
maximization of human genetic potential. Therefore, for solving the problem of deep-rooted food insecurity and malnutrition, dietary quality should be taken into consideration.

Singh, (2012) reported that millet proteins are good sources of essential amino acids except lysine and threonine but are relatively high in methionine.

Liu, (2012) stated that the presence of all the required nutrients in millets makes them suitable for large-scale utilization in the manufacture of food products such as baby foods, snack foods, and dietary food and, increasingly, more millet products have entered into the daily lives of people, including millet porridge, millet wine, and millet nutrition powder from both grain and flour form.

2.3. Functional Components

Liu, (2007) reported that the increased consumption of whole grains and whole grain products has been associated with reduced risk of developing chronic diseases such as cardiovascular disease, type 2 diabetes, some cancers, and all-cause mortality. In addition, whole grains contain unique phytochemicals that complement those in fruits and vegetables when consumed together.

Devi, (2011) stated that the growing public awareness of nutrition and health care research substantiates the potential of phytochemicals such as polyphenols and dietary fiber on their health beneficial properties.

2.3.1. Polyphenol

Rao and Prabhavati, (1982) reported that in an unspecified variety of finger millet reported 0.36% tannin (catechin equivalents) whereas McDonough et al.,(1986) reported 0.55 - 0.59 % total polyphenols and 0.17 - 0.32 % tannins (catechin equivalent) in a small number of the millet varieties (n = 3).

McDonough et al., (1986) also substantiated the observation of Fulcher (1982) with the aid of fluorescence microscopy by observing intense fluorescence in the testa and mild fluorescence in the cell walls of the endosperm.

Rao and Deosthale, (1988) found tannin (catechin equivalents) contents in brown colored millet varieties (n = 12) but they did not detect tannins in white (n = 3) varieties.

Shankara, (1991) analyzed a large number of finger millet varieties (n = 85) from the Indian state of Karnataka and reported a wide variability in the total
polyphenols content assayed as chlorogenic acid (0.06 – 0.67 %), tannic acid (0.03 – 0.57 %) and catechin (0.03 – 2.37 %) equivalents.

**Scalbert, (1991)** reported that polyphenols are well documented to have microbicide activities against a large number of pathogenic bacteria.

**Ravindran, (1991)** reported that the millet is known for its therapeutic value because of the presence of several phytochemicals with nutraceutical values. The phytochemicals of the millet include phenolic compounds, phytic acid and flavonoids such as flavones, isoflavones, etc. It contains 0.5 - 2 g% polyphenols and 0.5 - 1.0 g% phytic acid.

**Rybka et al., (1993)** reported that in cereals, the polyphenols are generally present in cell walls and are linked to hemicelluloses in different forms such as 2-O-(5'-O-(E)-feruoyl-D-xylpyranosyl) (1-4) D-xylpyranose.

**Hatfield et al., (1993)** reported that cross-linking of arabinoxylans with phenolic acids lower the arabinoxylan solubility and swelling in water as well as reduces their microbial degradation in the human colon and also exerts antioxidant as well as membrane modulating effects.

**Sripriya et al., (1996)** investigated that the total polyphenol contents of a brown variety of the millet (0.1 %) was higher than the white variety (0.003 %). This information on the polyphenol content of the millet gives an indication that, considerable variations exists among different genotypes of the millet.

**Hatcher and Kruger, (1997)** reported that cereal grains with elevated levels of phenolic acid in caryopsis exhibit greater resistance to disease and insect but exhibit reduced extractability of endosperm.

**Shirley, (1998)** reported that the highest concentration of phenolic acids and flavonoids is normally present in the aluerone layer besides, in embryo and testa of the grains.

**Damintoti Karou et al., (2005)** reported that the mechanism of polyphenols toxicity against bacterial growth may be related to inhibition of hydrolytic enzymes (proteases and carbohydrolases) or interactions to inactivate microbial adhesions, cell envelope transport proteins, non-specific interactions with carbohydrates, etc.
Malleshi, (2005) reported that the preliminary investigations on the millet polyphenols towards inhibiting the growth of *Helicobacter pylori* has been highly promising.

Mattila *et al.*, (2005) reported that significant amounts of alk(en)ylresorcinols containing non-isoprenoid side chain (15-25 carbons in length) attached to the hydroxybenzene ring have also been detected in barley, rye and wheat.

Adom *et al.*, (2005) reported that phenolic acids and flavonoids are present in cereals in the free and conjugated forms. Phenolic acids are known to contribute to the antioxidative potential of cereal grains and may also be used for the production of the end-use of cereal products.

Shobana *et al.*, (2006) have noticed by staining the phenolics with FeCl₃ identified the phenolics in the endosperm cell walls of the millet and also by chemical estimation of polyphenols in the milling fractions, namely the seed coat rich and endosperm rich fractions.

Chethan and Malleshi, (2007a) reported that for finger millet, the high-performance liquid chromatography (HPLC) analysis of polyphenols indicated nearly 30 prominent constituent phenolics, but only about 30% of them could be identified.

Chethan and Malleshi, (2007b) reported that red and brown millet varieties contain high amounts of condensed tannins and polyphenols, which are important phytochemicals with nutraceutical properties. The millet polyphenols are highly complex in nature unlike other polyphenols of plant source. They are sparingly soluble in water, but can be extracted effectively in acidic methanol solvent system. Out of the large number of phenolics present in the millet, gallic acid forms the major constituent of the seed phenolics whereas, the ferulic acid forms the major phenolic of the endosperm cell walls. Nearly 70% of the millet polyphenols are concentrated in its seed coat tissue.

Varsha *et al.*, (2008) reported that phenolic acids from finger millet milling fractions showed antimicrobial activity against *B. cereus*.

Shobana *et al.*, (2009) reported that the millet polyphenols are known to contribute towards amelioration of the diabetes related complications.
Viswanath et al., (2009) reported that phenolic acids from the milling fractions of finger millet (whole flour, seed coat, 3%, 5%, and 7%) were isolated. Acidic methanol extracts from seed coat to whole flour were rich in polyphenol content and were found to be stable up to 48 h at pH 4, 7, and 9.

Tsao, (2010) reported that polyphenols are the biggest group of phytochemicals that have been found in plant-based foods and have been linked to several health benefits. Therefore, dietary polyphenols have received tremendous attention among nutritionists, food scientists, and consumers due to their roles in human health.

Chandrasekara and Shahidi, (2011a) reported that currently, over 50 phenolic compounds belonging to several classes, namely, phenolic acids and their derivatives, dehydrodiferulates and dehydrotriferulates, flavan-3-ol monomers and dimers, flavonols, flavones, and flavanonols in 4 phenolics fractions of several whole millet grains (kodo, finger, foxtail, proso, little, and pearl millets) were positively or tentatively identified using HPLC and HPLC-tandem mass spectrometry (MS). However, insoluble bound fraction of kodo millet showed the highest phenolic content as well as antioxidant activity in the in vitro test systems employed. Nature of phenolics present in different cereals is given in table 2.1.
Table 2.1: Nature of phenolics present in different cereals

<table>
<thead>
<tr>
<th>Cereals</th>
<th>Phenolics reported</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Wheat</td>
<td>Ferulic, vanillic, gentisic, caffeic, salicylic, syringic, <em>p</em>-coumaric acid &amp; sinapic acid as well as vanillin and syringaldehyde, Campestaryl, sitosteryl ferulates, Ferulic acid dehydrodimers (DiFA), <em>n</em>-alkylphenols coupled to a resorcinol ring at the 5 position, tricin, 6-C-pentosyl-8-C-hexosylapigenin &amp; 6-C-hexosyl-8-C-pentosylapigenin</td>
<td>Anderson and Perkin (1931); Sosulski et al. (1982); Feng et al. (1988); Herrmann (1989); Seitz (1989); Rybka et al. (1993); Faurot et al. (1995); Gracia- Conesa et al. (1997); McKheen et al. (1999); Hakala et al. (2002); Adom et al. (2005); Pathiran et al. (2005; 2006)</td>
</tr>
<tr>
<td>Corn</td>
<td>Feruloylpseudocine, <em>p</em>-coumarylpseudocine, di-<em>p</em>-coumarylpseudocine, diferuloylpseudocine, <em>p</em>-coumarylsperdidine, diferuloylspermidine differuloylspermine, and steryl cinnamic acid derivatives</td>
<td>Sosulski et al. (1982); Sen et al. (1994); Norton (1995); Seitz (1999); Grabber et al. (2000)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Hydroxybenzoic acids, hydroxycinnamic acids, flavonoids (flavanols, flavones, flavanones, isoflavones and anthocyanins), chalcones, aurones (hispidol), hydroxycoumarins, lignans, hydroxystilbenes and polyflavans (proanthocyanidins and prodeoxyanthocyanidins).</td>
<td>Chung et al. (1998); Waniska et al. (2000); Kruuger et al. (2003); Awika et al. (2004); Dykes and Rooney (2006)</td>
</tr>
<tr>
<td>Barley</td>
<td>Ferulic acid, <em>p</em>- hydroxy benzoic acid tyrosine, tyramine and its derivatives, anthocyanins, proanthocyanidins, lignans and substances related to lignin.</td>
<td>Briggs (1978); Nordkvist et al. (1984); Hernanz et al. (2001); Yu et al. (2001)</td>
</tr>
<tr>
<td>Oats</td>
<td>Quinones, flavones, flavonoids, chalcones, flavanones, anthocyanins &amp; amino phenolics. phenolics acids linked to sugars, polysaccharides, lignins, amines, long chain alcohols, glycerols, as well as long chain α-hydroxy fatty acids. Avenanthramides (conjugates of cinnamic acid with anthranilic acids) and N-acetylanthranilate alkaloids.</td>
<td>Durkee et al. (1977); Collins and Mullins (1988); Collins (1989); Emmons et al. (1999); Peterson (2001); Mattila et al. (2005)</td>
</tr>
</tbody>
</table>
2.3.2. Antioxidants

Ravindran, (1991) reported that the total dietary fiber content of the millet ranges from 17 - 20% and the insoluble dietary fiber forms a major component (15 - 17%), and soluble fiber forms minor component (1 - 2%) of the dietary fiber. Since, the millet food generally binds with the minerals, reduces their bioavailability and forms oxalate which very often leads to kidney stone.

Watanabe, (1999) reported that based on literature data, millet grains can be used as functional food ingredients and as sources of natural antioxidants. It was reported that 3 antioxidative phenolic compounds, 1 serotonin derivative, and 2 flavonoids were isolated from an ethanol extract of Japanese barnyard millet grains. Although the antioxidant activity of luteolin was lower than that of N-(p-coumaroyl) serotonin, it was nearly equal to that of quercetin, whereas the activity of tricin was lower than that of luteolin.

Bindu and Malleshi, (2003) reported that the antioxidant activity of the millet polyphenols was slightly lower than the synthetic antioxidant compounds. Finger millet polyphenols exhibited the antioxidative properties effectively on super oxide, hydroxyl and nitric oxide radicals also.

Hegde and Chandra, (2005) reported that kodo millet, finger millet, little millet, foxtail millet, barnyard millet, and sorghum bicolor grown in India and their white varieties were screened for free radical quenching of 1,1, diphenyl-2-picrylhydrazyl (DPPH) by electron spin resonance. Methanol extracts of the kodo millet flour showed 70% DPPH quenching in comparison to other millet extracts that showed 15% to 53%. Further, the white varieties of sorghum, finger millet, and foxtail millet showed lower quenching than their colored counterparts, indicating that phenolics in the seed coat could be responsible for the antioxidant activities.

Asharani et al., (2005) have shown that the millet contains 199 + 77 µg/100g, 4 + 1 mg % and 15.3 + 3.5 TE/g for carotenoids, Vitamin E and the total antioxidant activity respectively. They have identified the isomers of these and reported that the antioxidant activity of whole meal of finger millet is considerably higher than other millets.
Dykes and Rooney, (2006) reported that finger millet extracts were found to have a potent radical-scavenging activity that is higher than those of wheat, rice, and other species of millet.

Choi, (2007) stated that much attention has been devoted to investigations of the nutraceutical and antioxidant properties of some major millet varieties, including finger millet, pearl millet, and foxtail millet. It has been reported that foxtail millet contains 47mg polyphenolics/100 g and 3.34 mg tocopherol/100 g (wet basis); however, proso millet contains 29 mg polyphenolics/100 g and 2.22 mg tocopherol/100 g (wet basis). In addition, a positive and significant correlation ($R^2 =0.9973$, $P<0.01$) between polyphenolic content and radical cation scavenging activity was observed.

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Varsha et al., (2008) determined the antioxidant activity of the polyphenol extracts from finger millet seed coat and the whole meal, and reported that the seed coat extract exhibits about 5 times higher activity compared to whole meal assayed in terms of reducing power assay and the beta-carotene bleaching method.

Viswanath, (2009) reported that the reducing power of finger millet seed coat extract was significantly ($P < 0.05$) higher than that of whole flour extract.

Chandrasekara and Shahidi, (2010) reported that soluble- and insoluble-bound phenolic extracts of several varieties of millet (kodo, finger, foxtail, proso, pearl, and little millets) and whole grains are rich sources of phenolic compounds and show antioxidant, metal chelating, and reducing powers. However, the potential of whole millets as natural sources of antioxidants depends on the variety used.

Veenashri and Muralikrishna, (2011) reported that xylo-oligosaccharides (XOs) mixture of finger millet exhibited relatively higher antioxidant activity than the XOs of rice, wheat, and maize by DPPH and ferric reducing antioxidant power assays.

Suma and Urooj, (2011c) reported that for foxtail millet, methanolic extracts of whole flour and bran-rich fraction exhibited a significantly higher ($P <$
0.05) radical-scavenging activity (44.62% and 51.80%, respectively) using a DPPH model system, and reducing power (0.381 and 0.455, respectively) at 2 mg, than the ethanol and water used for extraction.

Amadou, (2011) found that 50% ethanol extract from defatted foxtail millet bran was found to be the best-promoting phenolic compound with substantial antioxidant activity.

Mohamed, (2012) reported that defatted foxtail millet protein hydrolysates also exhibited antioxidant potency. Thus, millet may serve as a natural source of antioxidants in food applications and as a nutraceutical and functional food ingredient in health promotion and disease risk reduction. However, more studies in animal models and with human subjects should be performed to verify their activity and health benefits.

2.3.3 Phytic acid

Zhou and Erdman, (1995) reported that phytic acid has a strong ability to chelate multivalent metal ions, specially zinc, calcium, iron and as with protein residue. The binding cand result in very insoluble salts with poor bioavailability of minerals.

Rosa et al., (1999) stated that cereal phytic acid values ranged between 3±4 mg/g for soft wheats, 9 mg/g for hard wheat and 22 mg/g for whole wheat. Corn, millet and sorghum reported a mean of 10 mg/g and oat, rice, rye and barley between 4 and 7 mg/g. Wheat brans had wide ranges (25±58 mg/g). The phytic acid for oat brans was half that of wheat bran (20 mg/g) and higher value (58 mg/g) than that for rice bran. The milling products (semolinas) from hard wheat exhibited 10 mg/g and soft wheat showed a mean of 23 mg/g of phytic acid.

Okazaki and Katayama, (2005) stated that phytic acid content of cereals varies from 0.5 to 2.0%. Phytate is known as a substance to decrease mineral absorption however, it has also been looked at as a possible beneficial vitamin-like substance.

Shanmuganathan et al., (2006) reported that presence of a high content of phytic acid, makes pearl millet grain barely digestable.

Pelig-Ba, (2009) stated that Phytic acid is widely distributed in nature because it is a major storage of phosphorous (P) in cereals, legumes and oil seeds
and is typically found in outer aleouron layer of cereal grains in the endosperm of legumes and oil seeds.

### 2.3.4. Dietary fibre

Pushparaj et al., (2011) investigated that total dietary fiber content of the whole flour of pulses was higher in K variety (13.3%) than MRB variety seeds (11.91%). The partial removal of bran by sieving to obtain semi refined flour retained significant amount of dietary fiber (10.6%-MRB & 9.2%-K). Dehusking has been reported to decrease dietary fiber content in pulses.

Robin et al., (2012) reported that refined cereal flours contain a low amount of fiber (between 2 and 5%). Whole grain flours contain a higher amount of fiber (between 10 and 15%). The highest quantity of fiber is found in the bran part of cereals (20-90%). In cereals, dietary fiber is mostly insoluble except for oat in which about 50% of the fiber is soluble. Hydrocolloids such as inulin, fructooligosaccharide (FOS), pectin or gums are fully soluble.

Bisoi et al., (2012) investigated that total dietary fiber content of debranned millets is ranging from 9.0 to 16.0%. Therefore, after removal of husk and major portion of bran, millets contained appreciable amounts of dietary fiber. The millet bran, besides containing considerably higher proportion of oil, appears to be a good source of dietary fiber, out of which 10-15% was soluble fraction.

Amadou et al., (2013) reported that the phytic acid content of the unmalted pearl millet grain ranged from 2.91% to 3.30%. The total dietary fibre (22.0%) of finger millet grain was reported relatively higher than that of many other cereal grains (e.g. 12.6%, 4.6% and 12.8% respectively for wheat, rice, maize and sorghum. However, the dietary fibre content in pearl millet ranges between 8 to 9%.

Ahmed et al., (2013) stated that pearl millet was found significantly rich in resistant starch, soluble and insoluble dietary fibers, minerals, and antioxidants.

### 2.3.5. Health benefits

Van Rensburg, (1981) reported that it has been reported that populations consuming sorghum and millet have lower incidences of esophageal cancer than those consuming wheat or maize.
Thompson, (1993) reported that millet grains based on literature values are known to be rich in phenolic acids, tannins, and phytate that act as antinutrients. However, it has been established that these antinutrients reduce the risk for colon and breast cancer in animals.

Kumari and Thayumanavan, (1997) reported that rats fed with a diet of native and treated starch from barnyard millet had the lowest blood glucose, serum cholesterol, and triglycerides compared with rice and other minor millets. Also, the feeding of proso millet protein improved plasma levels of adiponectin, high-density lipoprotein (HDL) cholesterol in genetically obese type-2 diabetic mice under high-fat feeding conditions.

Bravo, (1998) reported that millet grains are rich in antioxidants and phenolics; however, he stated it has been established that phytates, phenols, and tannins can contribute to antioxidant activity important in health, aging, and metabolic syndrome.

Saito et al., (1998) stated that some of the phenolic compound as well as flavonoids are utilized as antibiotics, antidiarrheal, anti-ulcer and anti-inflammatory agents, and also in the treatment of hypertension, vascular fragility, allergies, hypercholesterolemia and similar disorders.

Lakshmi and Sumathi, (2002) reported that the lower glycemic response of whole finger-millet-based diets may also have been due to the presence of antinutritional factors in whole FMF, which are known to reduce starch digestibility and absorption.

It has been found that methanolic extracts from finger millet and kodo millet inhibited glycation and cross-linking of collagen, the chemical reaction between the aldehyde group of reducing sugars and the amino group of proteins, termed as nonenzymatic glycosylation, is a major factor responsible for the complications of diabetes and aging. Therefore, there is potential usefulness of millets in the protection against aging (Hegde, 2002 Monnier, 1990).

USDA, (2005) reported that the U.S. Dept. of Agriculture’s nutritional guidelines put grains and grain products at the base of the food guide pyramid to emphasize grains or grain product consumption as part of a normal diet for optimal health.
Edge, (2005) reported that the vitamins, minerals, essential fatty acids, and fiber in whole grains were believed to be responsible for their health benefits, but recent research suggests that the combination of other bioactive substances also works to exert positive effects. They include resistant starch; oligosaccharides; lipids; antioxidants such as phenolic acids, avenanthramides, and flavonoids; hormonally active compounds including lignans and phytosterols; and antinutrients such as phytic acid and tannins.

Fardet, (2008) reported that there is strong epidemiological evidence that whole-grain cereals protect the body against age-related diseases such as diabetes, cardiovascular diseases, and some cancers.

Chethan et al., (2008) reported that phenolic compounds from millet grains also showed potential antidiabetic effects. Finger millet polyphenols (FMPs) were reported as major antidiabetic and antioxidant components, when evaluated for aldose reductase (AR)-inhibiting activity.

Thompson, (2009) reported that persons adhering to a gluten-free diet must consume foods made from gluten-free grains in place of wheat, barley, and rye-based foods, including rice, corn, sorghum, millet, amaranth, buckwheat, quinoa, wild rice, and oats.

Pradhan et al., (2010) reported that studies were conducted on human diabetics (male and female) living in different rural and urban locations in India, and 13 diabetics were selected and asked to replace their regular wheat chapati with multigrain chapati (millet and wheat in a 30 : 70 ratio). The sugar level in high-glucose persons was lowered by continuous consumption of multigrain flour. All persons who consumed the multigrain chapati were found to have considerably decreased blood glucose levels. Therefore, millet grains have the potentials to be useful in prevention and treatment of diabetics.

Lee, (2010) stated that concentrations of serum triglycerides were significantly lower in the fingermillet and prosomillet groups of hyperlipidemic rats than those of the white rice and sorghum groups. In addition, concentrations of serum total, HDL, and lowdensity lipoprotein (LDL) cholesterols were significantly higher in the sorghum group than in the white rice, finger millet, and proso millet groups. Therefore, finger millet and proso millet may prevent cardiovascular disease by reducing plasma triglycerides in hyperlipidemic rats.
Ugare et al., (2011) reported that dehulled and heat-treated barnyard millet has been reported beneficial for type 2 diabetics in which low glycemic index (GI) for dehulled millet was 50 and heat-treated recorded GI of 47.

Shukla and Srivastava, (2011) reported that finger millet flour incorporated noodles were found nutritious and showed a hypoglycemic effect.

Chandrasekara and Shahidi, (2011b) reported that phenolic extracts from kodo, finger, proso, foxtail, little, and pearl millets were evaluated for their inhibitory effects on lipid peroxidation in in vitro copper-mediated human LDL cholesterol oxidation and several food model systems, namely, cooked comminuted pork, stripped corn oil, and a linoleic acid emulsion. At a final concentration of 0.05 mg/mL, millet extracts inhibited LDL cholesterol oxidation by 1% to 41%.

Chandrasekara and Shahidi, (2011c) reported that a recent study has demonstrated that millet phenolics may be effective in the prevention of cancer initiation and progression in vitro.

Kim, (2011) reported that the intake of whole grain foods is suggested to be beneficial for the prevention and management of diabetes mellitus, and epidemiologically lower incidence of diabetes has been reported in millet-consuming populations. For example, consumption of finger-millet-based diets resulted in significantly lower plasma glucose levels, mean peak rise, and area under curve that might have been due to the higher fiber content of finger millet than rice and wheat.

Chandrasekara and Shahidi, (2011b, 2011c) reported that millets are gluten-free, they have considerable potential in foods and beverages that can be suitable for individuals suffering from celiac disease. Therefore, millet grains and their fractions have the potential to be useful in cancer prevention and for producing food products for celiac people.

Chandrasekara and Shahidi, (2012) reported that epidemiological evidence from research studies has shown that diets rich in plant foods are protective against several degenerative diseases such as cancer, cardiovascular ailments, diabetes, metabolic syndrome, and Parkinson’s disease.

Gupta et al., (2012) reported that millets must also be accepted as functional food and nutraceuticals because they provide dietary fibers, proteins,
energy, minerals, vitamins, and antioxidants required for human health. Several potential health benefits such as preventing cancer and cardiovascular diseases, reducing tumor incidence, lowering blood pressure, risk of heart disease, cholesterol, and rate of fat absorption, delaying gastric emptying, and supplying gastrointestinal bulk were reported for millets.

**Brennan et al., (2012)** observed that all the extruded products made with the inclusion of pseudocereals (amaranth, buckwheat, and millet) showed a significant reduction in readily digestible carbohydrates and slowly digestible carbohydrates compared to the control product during predictive *in vitro* glycemc profiling.

### 2.4. Effect of processing technology on physicochemical, nutritional and functional components of underutilized cereals

**Hazel et al., (1989)** found that refining of the whole maize by fine milling and complete removal of husk and germ led to a slight increase of diffusible iron. However the iron content was reduced by the milling process. The diffusibility increased by the partial loss of phytic acid and fibers. Maize corn flour displayed even higher iron diffusibility because it contains virtually no phytic acid or fibers.

**Monnier, (1990)** reported that IR heating involves exposure of the soaked grains to electromagnetic radiation in the wavelength range of 0.8 to 1000 μm. Similarly, microwave heating is also explored wherein, the soaked grains are cooked using a microwave. However, the quality of the parboiled grains varies depending upon the method of the parboiling and severity of the processing conditions.

**Kadlag et al., 1995**, reported that hotwater blanching at 98 °C for 10 min or dry-heating of grains at 100 °C for 120 min is very effective in minimizing the undesirable changes in lipids of pearl millet meal during storage.

**Malleshi et al., (1996)** reported that a variety of ready-to-eat traditional snacks, breakfast cereals, supplementary foods and also pet foods were prepared by extrusion cooking technology.

**Sripriya et al., (1996)** investigated the antioxidant properties of polyphenols extracted with methanol was able to quench about 77 % of hydroxyl radicals. According to them the DPPH radical quenching ability of finger millet
was 94 %, whereas its germinated and fermented counterparts showed only 22 and 25 %, on the other hand germination followed by fermentation showed only 10 % quenching. This showed that these kinds of processing of the millet reduce its free radical quenching capacity. The major antioxidant principles identified by them was catechin.

**Chowdhury and Punia, (1997)** studied the effects of milling on nutritional contents of millet grains and their milling fractions, where milling of pearl millet grains was found to reflect a change in gross chemical composition. Milling and heat treatment during *chapatti* (an unleavened bread) making lowered polyphenols and phytic acid and improved the protein digestibility and starch digestibility.

**Rao and Muralikrishna, (2002)** reported that, the antioxidant activity of free phenolic acids was higher compared to that of bound phenolic acids. They reported an increase in the antioxidant activity coefficient from 770 to 1686 in the case of free phenolic acids and a decrease from 570 to 448 upon 96 h of germination in bound phenolic acids.

**San Martim et al., (2002)** reported that application of high hydrostatic pressure (HHP) in food processing has been increased within the food industry as an alternative to thermal processing to protect sensory and nutritional attributes of food products.

**Amparo et al., (2003)** investigated that cereals and millets are the primary sources of minerals in most vegetarian diets, secondary sources being legumes. Besides inherent factors such as phytate, tannin, and fiber negatively influencing the bioavailability of zinc and iron from these food grains, the same may also be influenced by processing, such as cooking, boiling, roasting or germination which these food grains undergo.

**Rathi, (2004)** studied the effect of depigmentation on sensory characteristics and nutritional parameters of pearl millet pasta. Pearl millet grains were depigmented by soaking in 0.2 N hydrochloric acid for 18 h, followed by washing, blanching (98 °C for 30 s), and sun drying. It was found that depigmentation is an effective processing technique for developing acceptable pearl millet products with better *in vitro* protein and starch digestibility.
Ushakumari, (2004) reported that popping or puffing is one of the traditional food processing methods used for the preparation of expanded cereals and grain legumes to prepare ready-to-eat products. It has been reported that the traditional (popping and flaking) as well as contemporary methods (roller-drying and extrusion-cooking) of cereal processing could be successfully applied to foxtail millet to prepare ready-to-eat products, thereby increasing its utilization as a food.

Malleshi, (2006) reported that, decorticated finger millet contained 0.067% of polyphenols as against 0.24 % in the native millet.

Pawar et al., (2006) reported that barley (Hordeum vulgare) is used for malting and brewing because of its high diastatic power. Barley grains after dehulling and malting resulted in reduction of phytate phosphorus content which significantly improved ionizable iron content.

Guha and Malleshi, (2006) reported that the millet grits equilibrated to about 18 % moisture content on extrusion cooking form well expanded ready-to-eat food products with porous and crunchy texture. Extruded products are crisp and crunchy similar to deep-fried foods, without actually deep-frying in oils or fat. Roller drying of millet finds applications as a base for soup. Extrusion cooking and roller drying of finger millet blended with other food ingredients holds promise for preparation of snacks and supplementary foods, besides feed formulations.

Sreeramaiah et al., (2007) carried out a study to evaluate the influence of heat processing (pressurecooking and microwave heating) on the bioaccessibility of zinc and iron from food grains consumed in India such as Cereals Î­ rice (Oryza sativa), finger millet (Eleusine coracana), sorghum (Sorghum vulgare), wheat (Triticum aestivum), and maize (Zea mays), and pulses Î­ chickpea (Cicer arietinum) Î­ whole and decorticated, green gram (Phaseolus aureus) Î­ whole and decorticated, decorticated black gram (Phaseolus mungo), decorticated red gram (Cajanus cajan), cowpea (Vigna catjang), and French bean (Phaseolus vulgaris) demonstrated that zinc bioaccessibility considerably reduced upon pressure-cooking, especially in pulses.

Sreeramaiah et al., (2007) reported that among cereals, pressurecooking decreased zinc bioaccessibility by 63% and 57% in finger millet and rice,
respectively. All the pressure-cooked cereals showed similar percent zinc bioaccessibility with the exception of finger millet. Bioaccessibility of zinc from pulses was generally lower as a result of pressure-cooking or microwave heating.

**Ushakumari, (2007)** reported that when decorticated finger millet was subjected to a high-temperature short-time treatment to prepare expanded millet, a ready-to-eat new-generation product, it was observed that flattening the grains to the desired shape and moisture content were critical factors for obtaining millet with maximum expansion ratio. The optimum conditions for preparing a product with the highest expansion ratio were found to be about 40% moisture content prior to flattening, with the shape factor ranging from 0.52 to 0.58 and drying time varying from 136 to 150 min.

**Sushma et al., (2008)** reported that soaking, boiling and germination resulted in a significant reduction of phytate phosphorus. The concentrations of calcium, magnesium, iron and zinc increased upon soaking and germination, while boiling decreased calcium, magnesium and iron concentration. Solubility of minerals was higher in soaking and germination than in boiling.

**Randhir et al., (2008)** reported that thermal processing has long been perceived while generally increasing the digestibility of foods, also to lead to a loss of certain heat-labile nutrients thus lowering the nutritional value.

**Nantanga et al., (2008)** reported that thermal treatments can be applied to extend whole pearl millet flour shelf-life, and the treatment such as toasting, boiling, and toasting and then boiling can be used to produce pearl millet flour that cooks more quickly.

**Mohamed et al., (2010)** studied irradiation-induced effects during storage on total protein and amino acid compositions of raw and processed flour of 2 pearl millet cultivars. Storage of the irradiated whole and dehulled flour for 60 d slightly reduced the protein content, even after cooking. The effect of irradiation in combination with the treatments applied to the grains and/or flour on amino acid was found to be varying between the cultivars. Most of the amino acids were stable against all treatments except leucine, glutamic acid, and phenylalanine.

Processing techniques traditionally used such as soaking, milling, sieving, germination, fermentation, boiling and frying to produce four maize foods commonly consumed in Africa were investigated for the nutritional composition,
with special focus on iron and zinc factors affecting their bioavailability of the products. The impact of the processes on lipid, fiber, phytate, iron and zinc contents varied with these processing methods (Valerie et al., 2011).

Dharmaraj and Malleshi, (2011) reported that decortication of hydrothermally processed finger millet caused significant changes in the nutrient contents.

Hama et al., (2011) reported that the influence of traditional decortication of pearl millet and white sorghum by hand-pounding or using a mechanical device were performed and compared to abrasive decortication in the laboratory using the same kernel lots. The decortication characteristics and nutritional composition (iron, zinc, phytates, lipids, fibers, and starch) of decorticated grains were measured. The results showed that decortication had numerous effects on grain composition, but no significant differences were observed between the two traditional methods of decortication.

Bagdia et al., (2011) found that decortication had no effect on the protein and fat content of millets; however, it significantly decreased the content of crude fiber, dietary fiber, minerals, total phenols content, and antioxidant capacity. Therefore, the applicability of millets as functional food was decreased.

Suma and Urooj, (2011a) conducted a study in which two pearl millet varieties were milled into whole flour, semi-refined flour, and a bran-rich fraction and were evaluated for nutrients, antinutrients, and mineral bioaccessibility. The results showed that nutrient content of semirefined flour was comparable to whole flour, except for the fat content (1.3%). Due to partial separation of the bran fraction, semirefined flour was low in antinutrients that improved its mineral bioaccessibility making it nutritionally superior. The bran-rich fraction, a by-product of flour-milling contained a significantly ($P \leq 0.05$) higher ash content.

Dharmaraj et al., (2011) reported that steaming the millet at elevated pressure and temperature increased the milling yield, and steaming beyond the threshold level showed a detrimental effect on the yield of head grains.

Dharmaraj, (2011) reported that hydrothermal treatment did not change the gross nutrients composition of finger millet, it only affected the nutrient profile.
Mohamed et al., (2011) studied the effects of refrigeration effects during storage on total protein and amino acids composition of raw and processed flour of 2 pearl millet cultivars were evaluated. The effect of refrigeration in combination with the storage period, cooking, or dehulling was found to be varying between amino acid composition and even between cultivars. Regardless of the storage period and processing method, the amino acid content remained unchanged after refrigeration for both cultivars.

Choudhury et al., (2011) reported that crude fat and crude fiber contents of popped foxtail millet were significantly lower than raw millet, while the carbohydrate and energy values were significantly higher. This is mainly because fat and fiber contents are higher in outer coat of grains, thus more affected by processing compared with nutrients located in inner layer.

ElShazali et al., (2011) reported that the irradiation process alone had no effect on tannin and phytate contents of two cultivars of pearl millet, but when followed by cooking significantly \((P \leq 0.05)\) reduced the level of antinutrients for whole and dehulled flour of both cultivars. Also, irradiation alone for the whole or dehulled seeds had no effect on the protein digestibility but slightly improved the quality attributes of both cultivars. However, irradiation followed by cooking significantly \((P \leq 0.05)\) reduced the protein digestibility but improved the quality attributes of both cultivars.

Hama et al., (2011) reported that the reduction in some nutrients (minerals, fibers, and antioxidants) and antinutrients (phytates, tannin) could be attributed to the fact that they are mainly located in the peripheral parts of the grains (pericarp and aleurone layer); therefore, removing of the pericarp during decortication leads to reduce their contents.

Krishnan et al., (2012) reported that dehulling of pearl millet grains reduced total phytic acid, polyphenols, and tannin and significantly \((P \leq 0.05)\) increased the protein digestibility but decreased the quality attributes of millet.

Oghbaei and Prakash, (2012) analyzed that finger millet whole flour (WFM), sieved flour (SFM), wafers, and vermicelli with altered matrices (added Fe or Zn or reduced fiber) for chemical composition, bioaccessible Fe, Zn, and Ca, in vitro digestible starch (IVSD), and protein (IVPD) and bioactive components (polyphenols and flavonoids). It was found that WFM and SFM
flours differed significantly in their composition. Sieving decreased the content of both

Lohani et al., (2012) reported that protein, fat, ash, and fiber contents were decreased according to the increase of moisture and milling time and 8% to 10% (db) of moisture content, and 3 min of milling time could be recommended for polishing barnyard millet in a rice polisher without much loss of nutritional values.

Yadav et al., (2012) reported that hydrothermal treatment of pearl millet grains was found an effective method to inactivate lipase and to enhance the shelf-life of the resultant flour. Hydrothermally treated grains yielded flour with acceptable physical, functional, and pasting properties and increased the storage stability significantly ($P < 0.05$) up to 50 d at ambient conditions (15 to 35°C) as compared to 10 d for the control flour.

Angioloni and Collar, (2012b) reported the impact of HHP treatment on dough viscoelastic reinforcement of highly replaced wheat cereal matrices. It was found that HHP is an efficient strategy to modify the gelatinization and gelling behavior of oat, millet, sorghum, and wheat hydrated flours.

2.5. Effects of bio-processing technology on cereals / underutilized cereals

Anthoni and Singaravadivel, (1980) reported that during soaking or steeping the grain, a number of enzymatic changes take place. It has been reported that during steeping a large part of sucrose gets converted into reducing sugars, a small portion of soluble proteins including amino acids and sugars are generally leached out.

McManus et al., (1981) reported that the precipitation of polyphenols - protein complexes is due to the formation of sufficient hydrophobic surface on the complex.

Malleshi and Amla, (1988) reported that the information on the status of polyphenols of malted millet has received the attention since, the millet is used for malting to a significant extent.

Rao and Deosthale, (1988) reported 0.91 % tannins in ungerminated grain which decreased by about 72 % on 72 h germination, whereas Sripriya et
(1996) reported decrease in the total polyphenols on germination is by 35% but increases by 34% on fermentation.

**Chavan et al., (1988)** reported that improvement in the IVPD caused by fermentation could be attributed to the partial degradation of complex storage proteins to more simple and soluble products.

**Khetarpaul and Chauhan, (1991)** reported that protein efficiency ratio, feed efficiency ratio, apparent protein digestibility, true protein digestibility, net protein utilization, net protein retention, protein retention efficiency, and utilizable protein values in the case of pure-culture-fermented pearl millet flour were higher than in the control.

**Parameswaran and Sadasivam, (1994)** reported that germination or malting of cereal grains may result in some biochemical modifications and produce malt with improved nutritional quality that can be used in various traditional recipes. It has been found that germination of proso millet grains increased the free amino acids and total sugars and decreased the dry weight and starch content. Increases in lysine, tryptophan, and nonprotein nitrogen were also noticed.

**Sharma and Kapoor, (1996)** reported that pearl millet grains were fermented with *Lactobacilli* and yeast alone, in combination and with the natural flora at 30 °C for 48 h after giving various processing treatments. It was found that combination of *Lactobacilli* and yeast was more effective in increasing the protein as well as starch digestibility as compared to pure culture fermentation. This increase in the protein digestibility could be attributed to the degradation of tannins, polyphenols, and phytic acid by microbial enzymes (Hassan and others 2006).

**Sripriya et al., (1997)** reported that major biochemical changes occurred during fermentation (48 h) of finger millet compared to its germination (24 h). The processing decreased the pH from 5.8 to 3.8 and increased the total sugars, reducing sugars and free amino acids. The phytate content decreased by 60% while the phytate Ca/Zn molar ratio decreased from 163 to 66.2, indicative of an increased Zn bioavailability. The study revealed that a combination of germination and fermentation is a potential process for decreasing the antinutrient levels and enhancing mineral availability.
Malleshi and Klopfenstein, (1998) reported that malting of finger millet is one of the traditional processes largely practiced for preparation of local beer in Africa and also at the Himalayan belt. But in India, the millet malt is mainly used to prepare specialty foods. Malting is nothing but in vivo biotransformation process, which converts the seed into a storehouse of hydrolytic enzymes. During this process, the bioavailability of proteins, carbohydrates, vitamins and minerals are enhanced and the concentrations of anti-nutritional factors are considerably reduced.

Usha and Chandra, (1998) reported that indigenous fermented foods prepared from major cereals are common in many parts of Africa and mainly used as beverages. Fermented millet is also used for preparation of breakfast cereals or snack foods and also weaning foods.

Mugocha et al., (2000) reported that commercial cultures can also be successfully used to produce a composite fermented beverage from finger millet and skim milk.

Aarchana and Kawatra, (2001) reported that germination also appreciably improved the in vitro protein (14% to 26%) and starch (86% to 112%) digestibility in pearl millet, and the improvement by germination was significantly higher than by blanching.

Rao and Muralikrishna, (2002) reported that the processing methods such as malting, decortication, soaking, and cooking were found to affect the content and activity of the antioxidants in millet grains. In one study, the antioxidant capacity of the fraction containing free phenolic acids was increased (2-fold) after 96 h of malting of finger millet, whereas the antioxidant capacity of the fraction containing bound phenolic acids was decreased.

Elyas et al., (2002) reported that natural fermentation was also found to cause a significant reduction in total polyphenols and phytic acid content of pearl millet. In addition, natural lactic acid fermentation of pearl millet slurries resulted in a decrease of phytates and α-galacto-oligosaccharides (Songr´e-Ouattara and others 2008).

ElHag, (2002) reported that the enhanced proteolytic activity during fermentation is generally associated with improved protein digestibility, which
increases amino nitrogen by partial breakdown of proteins to peptides and amino acids.

**Truswell, (2002)** reported that the chemical components, with the exception of starch, were reduced when the millet grain was fermented into *ogi*, a naturally fermented cereal product in Nigeria. However, availability of starch and protein for digestion was higher in *ogi* than in the grain. In addition, lysine, tryptophan, and vitamin B<sub>2</sub> contents were increased, while vitamin A and flavonoid contents and paste viscosity were reduced by the conversion of grain into *ogi*.

**Malleshi, (2002)** reported that the malted millet is nutritionally superior to that of native millet and is a good source of amylases. When the malt flour mixed with water or milk is heated to boiling, the amylases hydrolyze the starch to simple sugars thereby reduce its water holding capacity and as a result form low bulk and nutrient-dense foods. This natural process of enhancing the nutritional density has been used for developing various specialty and health foods such as infant food, weaning food, enteral food and milk based beverages and also in confectionary.

**Rao and Muralikrishna, (2002)** recorded a two fold decrease in all the major phenolic acids after 96 h of germination. The decrease in the bound phenolics may be due to the action of esterases developed during germination which is known to act on various phenolic acid esters linked either to arabinoxylans or other non-starch polysaccharides. A threefold decrease in protocatechuic acid content but marginal loss in caffeic acid upon 96 h of maltling was reported by these workers.

**Hooda and Jood, (2003)** reported that the changes in nutrient contents of grains after germination can be attributed to the utilization by growing sprouts.

**Pelembe, (2004)** reported that in terms of its potential for lager beer brewing, pearl millet malt was reported to have some advantages compared to sorghum as it has higher beta-amylose activity and higher free α-amino nitrogen.

**Rao et al., (2004)** reported that finger millet can be incorporated as a source of dietary fiber both in the native and malted forms, in the preparation of various health foods without altering the dough characteristics or the quality of the end product.
Hegde and Chandra, (2005) reported that cooking of kodo or finger millet by roasting or boiling resulted in a reduction in antioxidant activity. Fractionation of kodo millet into husk and endosperm also decreased the DPPH quenching activity and the phytochemicals appeared to act synergistically.

Hassan et al., (2006) reported that the improvement in protein digestibility after germination, soaking, debranning, and dry heating can be attributed to the reduction of antinutrients such as phytic acid, tannins, and polyphenols, which are known to interact with proteins to form complexes.

Eyzaguirre et al., (2006) reported that the relative in vitro solubility of iron was doubled by the germination of pearl millet grains.

Grewal and Jood, (2006) reported that increased mineral availability during germination may be due to increased phytase activity, which resulted in decreased content of phytate in sprouts. Antinutrients like polyphenols and saponins are also known to hinder the availability of minerals, which are catabolized during germination leading to improvement in mineral availability.

Hassan et al., (2006) reported that the chemical compositions of millet grains and their food products were found to be modified by fermentation. Therefore, millet grains are used to produce different kinds of traditional fermented foods in developing countries in Africa and Asia.

Eyzaguirre et al., (2006) reported the effects of single operations of pearl millet and of porridge preparation scenarios on levels and in vitro solubility of iron, zinc, and mineral-complexing factors (phytates). Soaking of pearl millet grains resulted in a 25% loss of iron, but also facilitates endogenous phytates degradation, particularly when combined with milling and cooking. Zinc in vitro solubility tended to increase on cooking with kanwa (alkaline rock salt), but decreased in cooked fermented flour.

Pawar and Machewad, (2006) reported that the simple processing of foxtail millet like dehulling, soaking, and cooking resulted in a significant decrease in antinutrients such as polyphenols and phytate, and improved the bioavailability of minerals such as iron and zinc and also protein digestibility in vitro. Therefore, soaking and cooking of millet grains can be used as pretreatments under optimized conditions to reduce the antinutrition contents in millet grains to enhance nutrient bioavailability and nutritional quality of millet food products.
Malleshi, (2006) reported that, hydrothermal treatment and decortication of finger millet decreases polyphenols by 74.7%. Utilization of protein in animal and human diet is adversely affected by phenolic constituents since they have the ability to bind with and precipitate proteins.

Li et al., (2007) reported that a growth-promoting medium was developed to enhance the production of a hydroxyl radical inhibitory water-soluble protein from germinated millet. The single factor test indicated that H$_2$O$_2$ plays a key role in the inhibition activity.

Lestienne et al., (2007) reported that soaking of grains is a popular food preparation technique used for reducing antinutritional compounds such as phytic acid to improve bioavailability of minerals. The degradation and leaching of phytates, phytase activity, and iron and zinc concentrations have been studied after soaking of whole seeds, dehulled seeds, and flours of millet. The results indicated that dehulling and milling before soaking facilitated the leaching of phytates and phytases in aqueous medium, and hence, phytate degradation. However,

Li et al., (2008) reported that to increase the yield of the hydroxyl radical inhibitory water soluble protein from stress-germinated millet, the effects of the sprouting conditions (temperature, time, and pH of stress medium) on the hydroxyl radical inhibition were investigated. The optimal conditions were identified as temperature 28 $^{\circ}$C, culture time 54 h, and stress medium pH 7.5. Under optimum conditions, the highest inhibition (60.38%) was achieved.

Inyang and Zakari, (2008) reported the effect of germination and fermentation of pearl millet on proximate, chemical, and sensory properties of instant fura (a Nigerian cereal food). It was found that germination appeared to be a promising food processing method for improving the nutrient and energy densities of fura and, when combined with fermentation, reduced phytic acid significantly ($P < 0.05$).

Ahmed, (2009) reported that fermentation of pearl millet caused appreciable changes in the chemical composition (moisture, ash, fiber, protein, and fat contents), but markedly reduced the mineral contents (Na, K, Mg, Cu, Fe, Mn, and Zn).
Das, (2009) reported that in the case of dry heat parboiling method, the grains are soaked to the EMC and subjected to conduction heating using hot air or sand or such other heat transfer media. Recently, newer methods of heat transfer have been explored for the preparation of parboiled grains wherein, thermic fluid and Infrared radiation (IR) are used to enable quick conduction of heat.

Platel et al., (2010) reported that malting generally improves the nutrient content and digestibility of foods and it could be an appropriate food-based strategy to derive iron and other minerals maximally from food grains.

Choudhury et al., (2011) reported that crude protein and fat contents were decreased in foxtail millet after germination. This decrease in the protein and fat contents can be attributed to loss of low molecular weight nitrogenous compounds during soaking and rinsing of the millet grains and hydrolysis of lipid and oxidation of fatty acids during germination.

Coulibaly and Chen, (2011) reported that germination of foxtail millet for 3 days allowed obtaining flour with high DPPH-scavenging activity.

Pradeep and Guha, (2011) reported the effects of germination, steaming, and roasting on the nutraceutical and antioxidant properties of little millet. The results showed that the total phenolic, flavonoid, and tannin contents of processed little millet increased by 21.2, 25.5, and 18.9 mg/100 g, respectively, compared to the native sample.

Arora et al., (2011) reported that a pearl millet-based, germinated, autoclaved, and fermented food blend maintained adequate cell viability as compared to a nongerminated food blend. Germination and probiotic fermentation caused significant improvement in the contents of thiamine, niacin, total lysine, protein fractions, sugars, soluble dietary fiber, and in vitro availability of Ca, Fe, and Zn of food blends.

Coulibaly and Chen, (2011) reported that germination of foxtail millet for 3 days resulted in flour with a high concentration of minerals.

Osman, (2011) reported that during 24 h fermentation of pearl millet, protein and lipid contents were not significantly ($P > 0.05$) changed. Carbohydrate content significantly ($P > 0.05$) decreased with a parallel increase in soluble sugars. In addition, amino acid analysis revealed that fermentation significantly ($P > 0.05$) decreased glycine, lysine, and arginine contents.
Fermentation was also found to cause significant reduction in trypsin and amylase inhibitor activities and the phytic acid content. However, tannin content showed a significant ($P < 0.05$) increase after fermentation.

Arora et al., (2011) reported that the changes in starch content and digestibility in the fermented product may be attributed to amylolytic action of microorganisms in the fermenting mixture.

Krishnan et al., (2012) reported that the in vitro extractability and bioaccessibility of minerals such as calcium, iron, and zinc were increased in finger millet and pearl millet by germination; however, the antinutritional factors such as phytic acid were decreased.

Chandrasekara et al., (2012) reported that dehulling and hydrothermal treatments were found to affect the antioxidant potential and phenolic content of pearl millet grains and the reduction in antioxidant contents and their activities can be attributed to oxidation.

Chandrasekara and Shahidi, (2012) reported that dehulled and cooked grains of 5 millet varieties (kodo, finger, proso, foxtail, and pearl) were subjected to in vitro enzymatic digestion and microbial fermentation under physiological conditions in order to determine the bioaccessibility of their phenolic compounds. It was demonstrated that phenolic compounds of processed millets were bioaccessible and colonic fermentation released the phenolics bound to the insoluble fiber in the grain.

2.6. Exploitation of underutilized cereals for processed / value added product

2.6.1 Utilisation of millets in development of value added product

Raghavendra et al., (1970) reported that the bulgur wheat is mainly used for preparation of popped bulgur, grits, in bakery products, baby food mixes, fortified breakfast cereals and also in food aid programs. Both dry and wet heat parboiling methods are followed for the preparation of bulgur.

Ananthachar et al., (1982) reported that similar to expanded cereals, flakes are prepared from the parboiled cereals using roller flaker. Flaked cereals are very popular breakfast foods and are generally produced using edge runner or multiple impact flaker from dry heat parboiled rice.
Chinnaswamy and Bhattacharya, (1984) reported that to prepare the products like expanded and flaked cereals, parboiling technique has been extensively used.

Bhattacharya and Ali, (1985) reported that parboiling of rice is practiced to a large extent and changes in rice during parboiling of rice has been extensively studied.

Malleshi and Desikachar, (1986) reported air-popping in a suitable mechanical device. However, the air popped product normally lacks the characteristic aroma compared to that prepared using sand or other heat transfer media.

Chinnaswamy and Bhattacharya, (1986a) reported that expanded rice is a very popular product in India. Usually dry heat treated paddy, after milling is used for preparation of expanded rice but pressure parboiling is recommended for better expansion of rice.

Li, (1986) reported that in the northern area of China, foxtail millet has been widely used as a nourishing gruel or soup for pregnant and nursing women, and has been applied as food therapy.

Thompson, (1993) reported that the major portion of the millet produced is generally used for preparation of traditional foods such as roti, mudde and ambli, but a considerable quantity is also processed to prepare malted and popped millet, and very little is diverted for feed and other uses such as preparation of alcoholic beverages

Kadlag et al., (1995) reported that traditional flatbreads from sorghum and millets might be regarded as leavened if they are fermented like injera (Ethiopia) or puffed like chapatti/roti (India). Another well established use of sorghum in leavened baked goods is in wheatī sorghum composite breads.

Ferriola and Stone, (1998) reported that white proso and foxtail millets have been used in the formulation of a flaked whole grain ready-to-eat breakfast cereal where the effects of dried honey or molasses as secondary sweeteners were also evaluated. The results showed that use of 100% millet in ready-to-eat breakfast cereals seems feasible.
Waniska et al., (1999) reported that malted sorghum is used to produce alcoholic beverages. The high solids beer is sour, alcoholic, pinkish and effervescent. The fermentation time is short and the beer is drunk while actively fermenting. The beers vary from sweet to very sour, alcohol and their solids content vary.

Awika et al., (1999) reported that finger millet has industrial potential in the manufacture of baby and sick person’s food formulations and breakfast cereals. Other than brewing, the malting process can be used in making cheap, digestible, liquid foods for children.

Watanabe, (1999) reported that the grains of Japanese barnyard millet are a traditional food in the cold districts of Japan, especially in the Tohoku district where it is considered an important crop because of its ability to be stored for a long time as a food, as well as a seed with extended germination ability.

Eneche, (1999) reported that biscuits were produced from millet flour and pigeon pea flour blends with blending ratios millet/pea of 100 : 0, 75 : 25, 65 : 35, and 50 : 50. It was found that all biscuits contained high proportions of protein and digestible carbohydrate. Sensory evaluation results also indicated that all the biscuits had high sensory ratings and the recipe with the 65% millet/35% pea blend resulted in the highest scores for flavor, texture, and general acceptability.

Fasano and Catassi, (2001) reported that consumers did accept the color and appearance of a lighter-colored sorghum muffin, resembling a plain or maize muffin as well as a dark brown one, resembling a chocolate, pumpernickel or dark bran muffin.

Waniska et al., (2002) reported that millet bread remains the main challenge as they are gluten free. Limited number of studies has addressed the issue of wheat-free loaf breads from sorghum. Sorghum is useful in food products because it does not impart unusual colors or strong flavors and it could be desired over maize flour for these reasons.

Premavalli et al., (2003) reported that the popped millet is a precooked ready-to-eat product and can be used as snack after seasoning with spice and condiments. Also it can be pulverized and mixed with vegetable or animal protein sources such as popped bengal gram, milk powder and oil seeds, and sweetened by jiggery or sugar to prepare a ready-to-eat nutritious supplementary food.
Bhattacharya and Narasimha, (2005) reported that *papad* is a thin crispy Indian wafer sometimes described as a cracker or flatbread and its preparation involves cooking the fine flour in appropriate quantity of water to completely gelatinize the starch, flattening the dough using roller pins to desired circular size and drying.

Mohapatra and Srinivasa Rao, (2005) reported that wheat is another cereal which is parboiled and the parboiled wheat is known as bulgur.

Schober *et al.*, (2005) reported that cakes, cookies, pasta, a parboiled rice-like product and snack foods have been successfully produced from sorghum and millets. Unlike composite breads, wheat-free sorghum breads are suitable for coeliacs and might possibly replace wheat breads in developing countries, reducing expensive wheat imports.

Rooney *et al.*, (2005) reported that the dark colors from black or tannin-containing sorghum varieties might be advantageous in products for the health market or in countries where dark, rye-based bread is common (e.g. Germany or Eastern Europe). A sorghum line with red pericarp produced interesting, pinkish-brown bread that might be promoted as specialty bread.

Obilana, (2003) reported that processing and converting millet for use in traditional meals is common in many developing countries in Africa and Asia. In many African countries, millet is often the main component of many meals and is essentially consumed as steam-cooked products ("*couscous*"), thick porridges ("*fufu*"), and thin porridges ("*oggi*" that can be used as a complementary food for infants and young children, it is also used in brewing beer.

Guha and Malleshi, (2006) reported that even though, the millet *papads* appear dark and slightly unappealing, the expansion characteristics of the product are very good and the product on deep oil frying, form crisp product with appealing color. Recently, utilization of the millet for preparation of soup has also been explored. For the purpose, incipient germinated millet is mixed with vegetables, spice and condiments, cooked and roller dried, and subsequently blended with other adjuncts such as milk powder and maltodextrin. The refined flour from the millet could be roller-dried to prepare thin wafery ready-to-eat product, which can be used for various specialty food preparations and also as a thickening agent in soups etc.
Vijayakumar and Mohankumar, (2009) reported that the incorporation of millet flour blend was also found to improve the quality of composite flour containing kodo and barnyard millet flour, whole wheat flour and defatted soy flour in terms of increasing nutrient density, thinner gruel by lowered viscosity, and an increase in the level of syneresis that may improve the resistant starch content on storage.

Adebayo et al., (2010) reported that in Nigeria, kunu is a very nutritious beverage that can supply most of the nutrient requirements by the body. Also, from the analysis, it was seen that kunu from millet gives the highest nourishment to the body; it has more nutritive value and is a good source of energy because of the high amount of protein, normal total solids, moderate pH, and acidity. Millet does have a high amount of calcium that helps in healthy bone strength and strong teeth.

Durojaiye et al., (2010) reported that conversion of millet grains to fura, a common millet food in the West African region and one of the major sources of nutrients in the region, has been studied with respect to its nutrient and flavanol contents and its storage properties. The results showed that flavanol content of the grain decreased during conversion to fura by about 46.3%. Vitamin B2 content was also decreased during transformation of grain to meal, flour, and fura by 31.4%, 34.3%, and 45.7%, respectively.

Osman, (2011) reported that in Saudi Arabia, pearl millet is grown in the south-west region of Jazan and used by locals to prepare fermented bread known as lohoh.

Saha et al., (2011) reported that biscuits prepared from flour composites containing 60 : 40 and 70 : 30 (w/w) finger millet : wheat flour were evaluated for dough characteristics and biscuit quality. It was indicated that a composite of finger millet and wheat flour (60 : 40) was best, particularly regarding biscuit quality.

Rajiv et al., (2011) reported the effect of replacement of wheat flour with 0%, 20%, 40%, 60%, 80%, and 100% FMF, 60% FMF, emulsifiers and hydrocolloids on the batter microscopy, rheology, and quality characteristics of muffins. Use of a combination of additives in muffins with 60% FMF significantly improved the volume and quality characteristics of muffins.
Mamiro et al., (2001) reported that finger millet and kidney beans (*Phaseolus vulgaris*) were processed by soaking, germination, autoclaving, and fermentation for incorporation into a complementary food for children. The results showed that various processing methods, especially germination, increased mineral extractability. Addition of vitamin C and mango could be used to enhance mineral extractabilities, thereby helping to alleviate micronutrient deficiencies in populations subsisting on these foods.

Krishnan et al., (2011) reported that the finger millet seed coat is an edible material and contains a good proportion of dietary fiber, minerals, and phytochemicals. The seed coat matter (SCM) forms a by-product of the millet milling, malting, and decortication industries and can be utilized as a composite flour in biscuit making. The sensory evaluation of the biscuits indicated that 10% of SCM from native and hydrothermally processed millet and 20% from malted millet could be used in a composite biscuit flour.

Balasubramanian et al., (2012) reported that *upma*, a popular breakfast of southern India, traditionally made from wheat, was prepared using pearl millet semolina. The sensory quality during storage was found to be stable for 6 mo at ambient conditions (20 to 35 °C) in polyethylene pouches (75 μm). It has also suggested that being a high energy (29.5% fat) and good protein (6.7%) source, it can be used in mid-day meals and other feeding programs.

Singh et al., (2012) reported that for the preparation of breads, millet-based composite flours were optimized. Barnyard millet plus wheat composite flour was formulated and prepared by mixing 61.8 g/100 g barnyard millet, 31.4 g/100 g wheat, and 6.8 g/100 g gluten. The results of sensory analysis showed that the acceptability of bread samples prepared from composite flours was almost equal to that of the wheat bread.

Angioloni, (2012b) reported that the suitability of oat, millet, and sorghum in bread making was assessed in simple binary wheat flour matrices in which wheat flour was replaced from 0% to 60%. The results indicated that oat, millet, and sorghum represent a viable alternative to make aerated breads with mitigated technological and sensory constraints based on nonviscoelastic cereals.

Brennan et al., (2012) reported that millet was also used with amaranth and buckwheat in the manufacture of extruded breakfast cereal products as a
replacement for wheat and maize flour. The results showed that the use of these flours altered the physical and nutritional quality of extruded breakfast cereals. Further, all of the extruded products made with the inclusion of pseudocereals showed a significant reduction in readily digestible carbohydrates and slowly digestible carbohydrates compared to the control product during predictive in vitro glycemic profiling.

2.6.2 Extrusion technology in development of value added product

Almeida-Dominguez et al., (1993) reported that for improvement of the nutritive value of food and diet to avoid malnutrition and certain diseases, different approaches are needed to offer adults and children improved food with low-cost and locally available food formulations. It has been established that porridges prepared from extruded millet and press-dried cowpea had high nutritional quality with acceptable properties of weaning foods (an intermediate consistency, smooth texture, and pleasant color and flavor).

Singh et al., (2004) reported that the traditional methods like popping and flaking as well as contemporary methods like roller drying and extrusion cooking of cereal processing could be successfully applied to foxtail millet to prepare ready to eat products.

Sowbhagya and Ali, (2005) reported that noodles and papads based on the millet flour are gaining popularity. The CFTRI process for preparation of noodles involves pretreatment to the millet enabling its cold extrusion and retention of texture of the noodles without fissuring when cooked in water.

Lu, (2005) reported that lajia noodles (noodles were found remaining from late Neolithic China) were propositioned to be made of foxtail millet and proso millet flours by repeatedly stretching the dough.

Guha and Malleshi, (2006) reported that extrusion cooking characteristics of the millet are very poor. However, the meal from the millet can be blended with other cereals and can be extruded in a twin screw or single screw extruder to prepare ready-to-eat products such as snacks and supplementary foods.

Sawant et al., (2009) studied the use of Finger millet to develop Ready-To-Eat (RTE) snack food through extrusion cooking in which seven composite mixes were prepared using brown finger millet flour, maize flour, rice flour, full fat soy flour, bengal gram flour, and skimmed milk powder in varying
proportions. It is found that the composite mix comprising of brown finger millet flour, maize flour, rice flour, and full fat soy flour in the ratio of 20:50:20:10 produced the most acceptable.

Ge et al., (2011) reported that in order to test the proposition that the lajia noodles can be made from millet, noodle-manufacturing experiments using different flours and starch grains analysis were performed. The results demonstrated that it was not possible to stretch pure millet dough into noodles.

Shukla and Srivastava, (2011) reported that in order to develop finger-millet-incorporated noodles for diabetic patients, FMF was blended in various proportions (30% to 50%) into refined wheat flour and used for the preparation of noodles. Based on the basis of sensory evaluation, the 30% finger-millet incorporated noodles were selected and evaluated for glycemic response compared to a control. The results indicated that glycemic index of 30% finger-millet-incorporated noodles was significantly lower than control noodles.

Potter et al., (2012) produced extruded products of high nutritional quality with acceptable sensory qualities during extrusion and investigated the interactions between the different raw ingredients, the extrusion process and the physical properties and nutritional qualities of the resulting extruded product.

2.6.3 Linear Programming in product development

Chaiyakul et al., (2009) investigated the application of Linear programming technique to obtain low-cost formulations containing at least 20 g protein per 100 g of final food and a nutritionally adequate amount of lysine and sulphur amino acids, with glutinous rice as the major ingredient, and studied the effect of extrusion parameters on the physical and chemical qualities of extrudates.

Amegovu et al., (2009) studied nutrient composition of sorghum-peanut blend (SPB) mixed with honey and ghee, and micronutrient-fortified corn-soy blend (CSB), a traditional food supplement, prepared using linear programming.

Balasubramanian et al., (2012) reported that whole pearl millet, finger millet, and decorticated soybean-blended (millet plus soy) extrudate formulations were designed using a linear programming (LP) model to minimize the total cost of the finished product. LP-formulated composite flour was extruded through a
twin-screw food extruder at different extrusion conditions. It was found that the pearl-millet-based blend expanded snacks showed promising features for the production of low-cost extrudates.