Forage Res., **38** (4) : pp. 189-201 (2013) **http://forageresearch.in**

GRAIN QUALITY IMPROVEMENT IN PEARLMILLET : A REVIEW

R. K. ARYA*, SURESH KUMAR, ASHOK KUMAR YADAV[1] AND AMIT KUMAR[2]

Ram Dhan Singh Seed Farm,
CCS Haryana Agricultural University,
Hisar-125 004 (Haryana), India
*(e-mail : rajesharya@gmail.com)

(Received : 29 December 2012; Accepted : 15 September 2013)

SUMMARY

Pearlmillet is a staple food and primary source of calories for millions of people in the arid and semi-arid tropical regions. It is rich source of carbohydrates, protein, calcium, phosphorus, iron, carotene, riboflavin, niacin, tryptophan and lysine, etc. It also has good potential as a feed and forage crop. Global warming may cause serious problem in agricultural production, particularly in arid and semi-arid regions of the world. Being C4 plant, it could sustain under high temperature as compared to other cereals/millets, and have unique position in the world agriculture. The development of high grain quality cultivars and management to meet out the food/feed requirement for ever increasing human/livestock population is imperative, as the quality of the food/feed is very important. Therefore, the best option for increasing the availability of quality food/feed appears to be genetic improvement of yield and quality of grain in locally adapted as well as in new hybrid cultivars. An effort has been made to review the progress of pearlmillet quality and grain production improvement done so far towards the development and production as well as its utilization. In this review, the current status of various aspects of pearlmillet grain quality is discussed.

Key words : Grain quality, protein, starch, fat, vitamins, minerals, pearlmillet

Pearlmillet is a staple food and primary source of calories for millions of people in the arid and semi-arid tropical regions. Now-a-days, it is widely cultivated in semi-arid tropical region of world i. e. African countries, India, Pakistan, Bangladesh, Burma, Sri Lanka and American continents, Argentina and USA. In developed countries, it is mainly cultivated as a fodder crop, but, in African countries it is cultivated as food crop. In India, it is grown for dual purposes both grain and fodder purposes, and its grain is utilized as food as well as feed purposes.

Pearlmillet is highly vigorous, quick growing, drought tolerant, cereal grass with large stem, leaves and head (Arya and Yadav, 2009). In the limiting environments, pearl millet is the only successful cereal and a major source of nutrition for the poor farming community. After the release of first commercial hybrid in 1965, India witnessed a major breakthrough in the production and productivity of pearlmillet. However, little improvement has been made in the direction of grain quality. Nutritional quality of a produce (food/feed) determines its effect of continued consumption on human/animal health.

Therefore, the best option for increasing the availability of quality food/feed appears to be genetic improvement for yield and quality of grain in locally adapted as well as in new hybrid cultivars. Pearlmillet is a nutritious cereal, superior to sorghum as a basic human food, being higher in protein and energy content and without the tannins which interfere with protein utilization in some sorghum. According to Rao *et al*. (2004) maize could be replaced by pearlmillet in commercial broiler production without affecting their performance. Likewise, Mustafa (2010) concluded that pearlmillet grain could replace corn in dairy cow diets up to 30 per cent of the diet DM with no adverse effects on milk yield or milk composition. Moreover, in developing countries, where pearlmillet is an important food crop, a large population suffers from chronic malnutrition. Thus, nutritional quality improvement of pearlmillet grain along with increased grain yield may be helpful to overcome malnutrition (Arya *et al*., 2008).

[1]CSIR-IHBT, Palampur (H. P.), India.
[2]Department of Biochemistry, KUK (Haryana), India.

The grain quality of pearl millet is divided into four categories viz., marketing, nutritional, industrial and keeping qualities. In this review, the current status of various aspects of grain quality is discussed.

1. Marketing Quality

It depends on the grain colour, lusture, shape, size, texture and hardness, etc.

Grain colour, shape and size

Pearlmillet grains may be greyish white, yellow, brown, cream, ivory, light blue, purple or grey in colour (Jain and Bal, 1997) and in shapes they vary from obovate, lenceolate, elliptical, hexagonal to globular (IBPGR/ICRISAT, 1993). In pearlmillet genotypes 1000-grain weight ranges from 5 to 12 g (Chaugh and Beniwal, 2002). Muyolo *et al.* (2002) reported considerable genetic diversity among forms of the landraces/varieties, many of which bearing as many interesting traits as spike and grain shape, grain colour, and quality preference of the product. Moreover, white and yellow grain pearlmillet are kown to be rich in protein and carotene (Lakshmana and Guggari, 2001). White grain colour in pearlmillet is dominant and simply inherited. Therefore, breeding for grain colour through simple selection, mass selection, pedigree selection and back cross method will be effective (Arya *et al*., 2009).

Grain hardness

The pearlmillet grain hardness is also genetically controlled. It varies from soft to hard. Phul and Athwal (1967) found that grain hardness was controlled by both additive and dominance gene effects with over dominance effect and moderate heritability (ns). However, Bhardwaj *et al*. (1987) reported that grain hardiness was determined by dominant genes. According to Abdelrahman and Hoseney (1984), the grain hardness is associated with a heat sensitive substance, t-butanol-extractable. Virk (1988) observed positive association between grain hardness and grain yield. The cultivars having large, spherical, uniform and hard seed give higher flour yield as compared to long and thin ones (Rooney and McDonough, 1987).

2. Nutritional Quality

It reflects the proportion of carbohydrates, protein, amino acids, fat/lipids, fatty acids, vitamins and mineral components along with anti-nutritional factors. Pearlmillet is rich in several nutrients as well as non-nutrient substances such as phenols. It has high energy, less starch, high fiber (1.2 g/100 g, most of which is insoluble), 8-15 times greater alpha-amylase activity as compared to wheat, low glycemic index (55) and is gluten free. The protein content ranges from 8 to 19 per cent and it is low in lysine, tryptophan, threonine and the sulfur-containing amino acids. The energy of millet is greater than sorghum and nearly equal to that of brown rice as the lipid content is generally higher (3 to 6%). Pearlmillet can be recommended in the treatment of celiac diseases, constipation and several non-communicable diseases (Nambiar *et al*., 2011).

Carbohydrates

These constitute the major part of the pearlmillet grain. Further, the carbohydrates are of many types viz., starch, amylase, soluble sugars, pentosans and heterogeneous polysaccharides, etc. According to Jambunathan and Subramanian (1988) starch content of pearlmillet ranges from 62.8 to 70.5 per cent, amylase from 21.9 to 28.8 per cent, soluble sugars from 1.4 to 2.6 per cent and reducing sugars from 0.10 to 0.26 per cent. The starch granules of pearlmillet grain are spherical in floury parts and polygonal in corneous and peripheral endosperm parts, and range in size from 4 to 12 mμ (Serna-Saldivar *et al*., 1991).

Fats and lipids

Yadav *et al*. (2010) reported the variable expression of fat content among the different genotypes. They observed maximum fat content (8.30%) in Barmer Pop and minimum 3.56 per cent in HMS 18B. Linoleic acid (44.8%), oleic acid (23.2) and palmitic acid (22.3) were the dominant fatty acid in millet oil followed by stearic acid (4) and linolenic acid (2.9) (Sawaya *et al.*, 1984).

Major components of pearlmillet lipids are triglycerides followed by sterol, esters, hydrocarbons and free fatty acids (Gupta, 1980). Phosphatidyl choline, sterol glycosides and di- and mono-galactosyl diglycerides are the major components of polar bound lipids and acylglycerols of the non-polar bound lipids (Lai and Varriano-Marston, 1980a). The fat content showed the variable expression against the rancidity

indicating thereby that it is not responsible for rancidity.

Proteins and amino acids

In general, amino acid profile in pearl millet is better than sorghum and maize and it is comparable with wheat and rice. A lot of variability in pearl millet protein content has been reported, ranging from 6.4 to 24.3 per cent (Jambunthan and Subramanian, 1988; Sharma, 2005). According to Burton *et al.* (1972) pearlmillet protein content ranged from 8.8 to 20.9 per cent in USA lines and 10.2 to 23.0 per cent in Indian lines. Besides, the total quantity of protein, their amino acid composition is important factor for better nutritional quality (Chaugh and Beniwal, 2002). The fraction and amino acid composition of pearlmillet protein have been investigated by various workers. The distribution of four protein fractions are : prolamine (21.4 to 37.9%), glutelin (23.8 to 37.7%), albumin (6.1 to 25.5%) and globulin (4.4 to 14.7%) (Sawhney and Naik, 1969; Singh *et al*., 1987). Among the non-essential amino acids viz. glutamic acid (20.7%), aspartic acid (98.9%), proline (6.4%) and alanine (8.4%) are the main components of pearlmillet grain protein (Singh *et al*., 1987; Singh and Nainawatee, 1999). Among the essential amino acids in pearlmillet grain, lucine, phenylanine, threonine and isoleucine are in adequate amount, but it is low in lysine, threonine and tryptophan (Singh and Nainawatee, 1999).

A number of essential and non-essential amino acids are found in pearlmillet grain. Among the essential amino acids, leucine, phenylanine and valine are present in large quantities; threonine and isoleucine are present in adequate quantities; and lysine, methionine and tryptophan in low quantities (Singh *et al*., 1987). Moreover, genetic diversity in protein concentration and relative lysine concentration of Indian pearlmillet lines has been reported by Kumar *et al*. (1983) and it was found independent of grain yield (Buerket *et al*., 2001).

Based on amino acid scores, the first and second most limiting amino acids in both sorghum and millet grains are lysine and methionine, respectively, followed by arginine in sorghum and threonine in millet. Considering all the amino acids essential to poultry, millet protein was superior to egg protein in leucine, isoleucine and valine, whereas sorghum grain was deficient in all except leucine and glycine. Apart from glycine and leucine, the amino acid score for each of the other amino acids is higher for millet than for sorghum, indicating that millet may be better than sorghum in overall protein quality (Odiba and Sanford,1999).

Improvement in protein quality through conventional breeding could not get much success. The increase in protein content showed increase in prolamine content, which resulted in lower proportion of glutelin, albumin and globulin fractions (Jambunathan and Subramanian, 1988).

Vitamins

The pearlmillet grain is rich in some water soluble vitamins viz., riboflavin, niacin, thimine and tryptophan. Likewise, it is also good source of fat soluble vitamins, though not much information is available on vitamin E, D and K. Vitamin A content was reported to 220 I.U./100 g. The carotene content 85-445 µg/100 g in total carotenoids and 14-63 µg/100 g in beta-carotene (Khangura *et al*., 1980). The discovery of high beta-carotene accession from Burkina Faso has been reported (ICRISAT, 1997), which may be utilized to increase the beta-carotene content of pearlmillet grain in new varieties/ hybrids (Buerkert *et al*., 2001).

Minerals

In pearlmillet grain minerals, namely, potassium and phosphorus are higher as compared to other cereals. However, sodium, magnesium and copper are at par with the wheat. The mineral content in pearlmileet is not influenced by increased level of nitrogen fertilizer, but some increase in the level of magnesium at higher nitrogen levels has been reported (Bailey *et al*., 1980). Considerable variability for calcium, phosphorus and total mineral contents their positive correlations indicate the possibility to improve these traits simultaneously (Dhillon and Gupta, 1975). However, negative association between total mineral content with grain yield may affect progress (Sukhchain and Phul, 1990). The hybrids and varieties differed significantly in their calcium and iron contents (Malik *et al*., 2002).

Anti-nutritional factors in pearlmillet

Pearlmillet has high nutrient contents but nutrient bioavailability is low, inherent to the presence of certain antinutritional factors. One of the anti-nutrients of pearl-millet grain is phytate. Phytate content of pearlmillet is

in the approximate range of 172 and 327 mg per 100 g (Taylor, 2004). Phytate binds multivalent metal ions such as calcium and iron thereby interfering with their absorption in the gut. In contrast, the fact that phytate binds pro-oxidant cations such as iron and copper ions may be desirable for the stability of pearlmillet flour triglycerides. But some fermentation and processing are known to reduce these anti-nutrients and librating the nutrients locked into plant structure and cell by indigestible materials. Unique to pearl millet, is the presence of the phenolic compounds, C-glycosyl flavones (Akingbala, 1991). These are concentrated in the outer layers of the grains and contribute to the grey colour of the gain (Taylor, 2004). In areas of Sudan, where pearlmillet is also a staple food, these compounds have been implicated in goitre. Furthermore, C-glycosyl flavones are believed to be the cause of the previously mentioned disagreeable mousy odour of damp pearlmillet grain flour. Bangar *et al*. (1999) attributed this to peroxidase action on the C-glycosyl flavones. Unlike sorghum, tannins are apparently absent in pearlmillet grain (Taylor, 2004).

Polyphenols limit protein and starch utilization either by binding with proteins or by inhibiting the digestive enzymes especially trypsine and amylase. In pearlmillet, the concentration of polyphenols has been reported ranging from 608 to 788 mg/100 g (Sharma, 1994). On the contrary, lower concentration (about 50.87 mg/100 g) of polyphenol in the pearlmillet (HTP 94/54) has also been reported by Yadav *et al*. (2010). Banger *et al.* (1999) studied comparative distribution of phenolics in pearlmillet grain fractions and reported that concentration of water soluble phenolics in the defatted pearlmillet meal was lower (136 mg/100 g) than in the germ (1216 mg/100 g). In whole grains it was 80 mg/ 100 g.

Reichert (1979) identified 3-pH-sensitive pigments known as C-glycosyl flavones viz., glucosylvitexin, glucosylorientin and vitexin. The concentration of total C-glycosylflavones was 124 mg/ 100 g in whole pearlmillet grain. Yadav *et al.* (2010) revealed that the maximum C-glycosylflavone was found in case of HHB 94 (36.80 µmole/100 g flour) and the minimum was found in case of HTP 94/54 (24.50 µmole/ 100 g). Reichert *et al*. (1980) reported a steep gradient in C-glycosylflavones concentration from outer to inner portion of the seeds with much higher percentage in the outer layers.

The high moisture content of sample stored at 42ºC may accelerate development of both fat acidity and objectionable odour (Lai and Varriano-Marston, 1980a; Yadav, 2003). In a study, Yadav *et al.* (2010) reported the fat acidity ranged from 245.37 to 350.57 and it was not found linked with rancidity.

3. Industrial Quality

It reflects the use of pearlmillet grain for malt extraction, biscuit and cake making quality and many other food and feed products.

Malt and biscuit/cake making quality

Pearlmillet is a cheap source of raw starch. It is more or less similar to the starch of maize in most of physio-chemical properties. It was also observed that pearlmillet starch had higher amylase, swelling power, solubility and inherent viscosity. The cooking quality as well as palatability of the grain is determined by amylose content. The amylose contents of different pearlmillet genotypes varied from 17 to 29 per cent (Rooney and McDough, 1987). Amylose content is negatively correlated with chapatti quality characteristics of pearlmillet. Starch is negatively associated with protein and positively associated with amylase (Subramaniam *et al*., 1981).

In pearlmillet, soluble sugars content is 2.1 per cent. Further, in soluble sugars sucrose (68%), raffinose (25%), stachyose with other cereals raffinose content was found high, but maltose was found totally absent (Subramanian *et al*., 1981; Chugh and Beniwal, 2002). According to Chugh and Beniwal (2002) pentosans are heterogeneous mixture of polysaccharides and make up the backbone of dietry fibre. These polysaccharides, many of which contain protein moieties, differ in their physical and chemical properties, have been shown to markedly affect end uses (backing and cooking) of cereals. Pearlmillet pentosans contain varying amount of eight sugars in four fractions isolated under different experimental conditions : ribose, rhaninose, fucose, arabinose, xylose, mannose, galactose and glucose (Bailey *et al*., 1980).

Beverage production

Pearlmillet could be substituted successfully for sorghum to produce improved “oti-oka” like beverage that is more acceptable to the ‘Western palate’ in terms

of nutritional, anti-nutritive contents and sensory properties using combine starter culture of *S. cereviseae* and *L. fermentum* (Ogunbanwo and Ogunsanya, 2012).

Ethanol production

Wu *et al*. (2006) showed that the fermentation efficiencies of pearlmillets, on a starch basis, were comparable to those of corn and grain sorghum. Because pearlmillets have greater protein and lipid contents, distillers dried grains with solubles (DDGS) from pearl-millets also had greater protein content and energy levels than did DDGS from corn and grain sorghum. Therefore, pearlmillets could be a potential feedstock for fuel ethanol production. Poonia *et al*. (2010) studied ethanol production from pearlmillet flour by *Saccharomyces cerevisiae*. The fermentation of hydrolysate with *S. cerevisiae* HAU-1 at 30°C for 48 h resulted in production of 11.4% (v/v) ethanol. Simultaneous saccharification also accomplished during fermentation of pearlmillet flour.

4. Keeping Quality and Rancidity

Rancidity in flour

It reflects the storage ability of pearlmillet grain flour and its products. In spite of availability in abundance, low cost and comparatively good nutritional value, use of pearlmillet is very low because of rapid development of rancidity and bitterness in its flour on storage (Patel and Parameshwaram, 1992). The pearlmillet grain is small, but has a proportionally larger germ than all other cereal grains, except maize (Taylor, 2004). Hence, pearlmillet tends to contain a higher content of triglycerides. These are rich in unsaturated fatty acids (Rooney, 1978; Lai and Varriano-Marston, 1980a; Kapoor and Kapoor, 1990). When pearlmillet is reduced into flour, it is noted as having poor keeping quality especially under conditions of moderately high moisture and oxygen exposure (Abdelrahman *et al*., 1983; Chaudhary and Kapoor, 1984). This is attributed to the deterioration of its triglycerides through lipolysis and subsequent oxidation of de-esterified unsaturated fatty acids (Lai and Varriano-Marston, 1980b). These chemical changes manifest themselves as off-odours and/or off-taste of the flour or in products made from the flour, thus making it unpleasant for consumption (Nantanga, 2006).

Development of rancidity in pearlmillet flour during storage has been attributed to different factors viz., presence of volatile compounds (Thiam *et al*., 1976), hydrolytic cleavage of lipids (Carnovale and Quaglia, 1973), changes in composition of lipids, oxidative changes in unsaturated fatty acids (Lai and Varriano-Marston, 1980), presence of phenolics (Reddy *et al*., 1986), presence of high peroxidase activity (Banger *et al*., 1999) and enzymatic changes in C-glycosylflavones (Reddy *et al*., 1986). Kaced *et al*. (1984) observed that fat content was the major contributing factor to the rapid increase of fat acidity in ground millet. Reddy *et al*. (1986) reported that the odour generating precursor was one of the C-glycosylflavones present in pearlmillet. Water soluble phenolics and peroxidase activity concentrated mainly in the germ fraction of the grain appeared to be responsible for odour generation in stored pearlmillet meal (Banger *et al*., 1999). Chavan and Hash (1998) in their studies on pearlmillet flour identified increased activity of peroxidase as the sole cause for generating rancid odour. Based on studies on pearlmillet genotypes (grey hybrid HHB 94, CMS lines and yellow hybrid (ICMA 94222A x 78/711) differing in total phenol content, fat content and peroxidase activity, Yadav (2003) concluded that both total phenol content and peroxidase activity were responsible for increasing free fatty acids content and fat acidity in the flour stored for 13 days. Praduman (2006) reported that development of off odour might be related to peroxidase activity as well as phenolics particularly C-glycosylflavones content.

Yadav *et al*. (2010) tested for rancidity, and biochemical traits related to viz., fat content, total phenols, C-glycosylflavones, fat acidity, free fatty acid, peroxide value and peroxidase activity among various pearlmillet genotypes. They reported that the genotypes 94222A X 78/711, Barmer Pop and H77/833-2 exhibited low score for rancidity. However, the genotypes HHB 67, 97111A X HBL 11 and HHB 67 exhibited higher score for rancidity along with high total phenols, C-glycosylflavones and peroxidase activity. But, variable expression was observed for fat content, fat acidity, free fatty acid and peroxide value in relation to rancidity. Therefore, it was revealed that the total phenols, C-glycosylflavones and peroxidase activity were responsible for rancidity.

Free fatty acid

Kaced *et al*. (1984) reported that the acidity produced in ground pearlmillet during storage was the

result of free fatty acids. Aggarwal (1992) reported that free fatty acid content of pearlmillet flour increased with increase in temperature and period of storage. Patel and Parmeshwaran (1992) and Kadlag (1995) also noticed increase in free fatty acids on storage of pearlmillet flour. After storage of flour of the cultivar RHRBH 8609 for 30 days acid value increased from 3.17 to 40.43 mg KOH/g of oil (Palande *et al.*, 1996). Yadav (2003) studied the effect of storage of flour in two pearlmillet hybrids i.e. HHB 94 and ICMA 94222 x 78/711 and reported that free fatty acids in both hybrids increased with time of storage.

Peroxide value

Based on periodical differences in the peroxide values for samples stored in different containers, Kaced *et al.* (1984) concluded that most likely the procedure measured some volatiles. Reddy *et al.* (1986) also found that the characteristic mousy, acidic odour generation in ground pearlmillet during brief storage was not associated with oxidative rancidity of kernel lipids. Kapoor and Kapoor (1980) studied chemical changes in raw pearlmillet flour and flour treated with salt and antioxidant. They reported that development of peroxides in the antioxidant treated flour samples was lower as compared to salt treated samples and untreated samples.

Peroxidase activity

Yadav (2010) observed that peroxidase activity in HHB 94 and HTP 94/54 was 14.70 and 8.90, respectively. Kumar *et al.* (2002) studied peroxidase activity and isozyme analysis of pearlmillet seedlings and their implications in downy mildew disease resistance and found the cultivars, IP 18292 and IP 18294, as highly resistant, P 310-17 and MBH 110 as resistant, 5141 B and 81 B as susceptible and 23 B and HB3 as highly susceptible.

5. Breeding for Grain Quality

Genetic variability

It is a highly nutritive course grain, staple food and the primary source of calories for millions of people in the dry and hot regions of the world. It is a rich starch (56.05-73.37%), fat (1.5-9.9%), protein (6.40-24.25%), iron (4.0-58 mg/100 g), calcium (13.0-52.00 mg/100 g), magnesium (46-128 mg/100 g), phosphorus (9185.0-363.0 mg/100 g) and total carotenoids (85-445 mg/100 g) than some of the other important cereals (Singh and Nainawatee, 1999; Choudhary, 2005; Sharma, 2005).

Buerkert *et al*. (2001) analyzed landraces and showed a 2.9 and 3.5 per cent higher protein concentration compared with improved varieties and hybrids without a detrimental effect on protein quality as determined by the relative amount of lysine and threonine. Landrace populations also had the highest fat concentrations and the largest micronutrient densities.

A study was carried out on nutritional qualities of pearlmillet by Singh *et al.* (2009). The estimated mean values for protein, fat, ash, fiber, carbohydrates and energy on g per cent basis were found to be ranging as 8.59 to 10.71, 5.17 to 10.28, 1.24 to 2.06, 1.86 to 3.66, 69.20 to 74.76 and 396 to 421 Kcal, respectively. The total soluble sugar, reducing sugars and non-reducing sugars ranged from 1.77 to 2.08, 1.30 to 1.80 and 0.24 to 0.79 per cent. The per cent values for calcium, phosphorus and iron ranged between 396 to 421 Kcal, 29.47 to 60.15, 256.79 to 398.84 and 5.24 to 7.94 mg per cent, respectively. Amount of anti-nutritional factors like polyphenols and phytic acids was noted to be ranging from 261.11 to 653.47 mg per cent and 48.65 to 84.75 mg per cent, respectively (Bhati and Goyal, 2012). The *in-vitro* iron bioavailability of three cultivars ranged between 3.18 to 5.24 per cent, the highest being in PCB-164 (5.24%) and the lowest in PHB-47 (3.18%). A significant difference for *in-vitro* iron bioavailability was obtained between the cultivars.

Sagar *et al*. (2005) reported that in parents, fat content ranged from 9.20 to 12.17 per cent, while that in F_1 crosses and backcrosses ranged from 10.30 to 14.25 per cent and 10.00 to 13.20 per cent, respectively. The increased performance of F_1 crosses and backcrosses indicated a heterotic response. Among the parents, fat content was highest in VCF 4827 (12.17%), followed by INB 759 (12.00%) and lowest in ICR 142 (9.20%). The fat content of backcrosses involving H 77/833-2 as recurrent parent i. e. (VCF 4827 x H 77/833-2) x H 77/833-2 and (H 77/833-2 x INB 759) x H 77/833-2 was less than their F_1 and parents, showing a trend towards the recurrent parent. On the other hand, in all other backcrosses, fat content excelled that of parents and F_1.

The phenotypic coefficient of variation (PCV) was greater than genotypic coefficient of variation (GCV)

for the quality traits, this shows the influence of environmental factors. The phosphorus content had expressed the highest phenotypic and genotypic variances (845.30 and 772.08, respectively). High estimates of genetic coefficient of variation, heritability and genetic advance were exhibited by iron and crude fat content. High value of heritability coupled with high genetic advance as per cent of means was recorded for crude protein, crude fat, phytate, phosphorus, calcium, iron and zinc content, indicating the important role of additive gene action for the expression of these characters. Therefore, selection based on these characters could bring about desired improvement in yield as well as nutritional quality of pearlmillet cultivars (Govindaraj *et al*., 2011).

Potential genotypes

The white grain colour hybrids HMS 36 x 110 in E1 and E4, HMS 36 A x 1250 in E2 and HMS 36 A x ERC in E3 and the grey grain colour hybrids HMS 16 / H 77/833-2 in E1, HMS 16A x G 73-107 in E2 and ICMA 94111 x H 77/833-2 in E3 and E4 were highest in protein content in their respective environments (Arya *et al*., 2009b).

The hybrids HMS 36A x 77/371//BSE CTCP-157 (white), ICMA 94111 x H77/833-2 (grey) for protein content and ICMA 94222 x H77/833-2 (white) and ICMA 97333 x HTP94/54 and HMS 7A x H77/29-2 (grey) for starch content and ICMA 94222 x INB 87/ 74-3-20 (white) and ICMA 95444 x G 73-107 (grey) for fat content were found to be stable in all the test environments. The hybrids viz., ICMA 94111 x INB-87/ 74, ICMA 95222 x HTP 94/54 and ICMA 96111 x 77/ 29-2 of grey grain colour were found to be stable for favourable environments for protein, starch and fat content. Two hybrids of white grain colour viz., HMS 36A x 111 and ICMA 94222 x 96AC-94 were found to be stable for poor environments for protein content only (Arya *et al*., 2008).

PHB-2168 had highest content of crude protein (13.33%), crude fat (6.01%), crude fibre (1.28%), whereas PHB-47 had the highest content of ash (2.22%) and total iron (9.42%). PCB-164 had the highest content of neutral detergent fibre (7.8 g/100 g), while polyphenols were maximum in PHB-2168 (273 mg/100 g) followed by PCB-164 (260 mg) and phytin phosphorus was highest in PHB-47 (473 mg) (Singh *et al*., 2009). Fat content was found to be maximum in RHB 121 (10.28 g) and minimum in Jaisalmeri Desi (5.17 g). Protein content was found to be higher in land races followed by composite and hybrid (Bhati and Goyal, 2012). Jambunathan and Subramanian (1988) reported that concentrations of isolucine, phenylanine, lysine, methionine and leucine contents were higher in hybrids (BJ 104 and MBH 110).

Gene effects and combining ability

Genetic analysis of grain quality characters (starch, crude protein, crude fat, calcium, phosphorus, iron and zinc and an anti-nutritional compound called phytate phosphorus) of pearlmillet was carried out in order to assess the combining ability of parents and hybrids and to understand the nature of gene action. Analysis of variance exhibited significant differences for all grain quality characters and grain yield of pearlmillet. The non-additive gene action was found to be significant in all the characters. This indicated that recurrent selection would be more appropriate breeding method for the improvement of these characters (Arulselvi *et al*., 2009).

Arya *et al*. (2009c) in their study on the mean performance of quality traits revealed the presence of partial dominance for protein content and over dominance for starch content. The magnitude of dominance gene effects was more as compared to additive gene effects for both the traits in all the three crosses, except for protein content in cross II. The protein content in cross II was governed by additive gene effects only. While, in cross I both main effects and additive x additive [i] and dominance x dominance [1] type of interaction were present, and in cross III both main effects and all the three types of gene interactions (additive x additive [i], additive x dominance [j] and dominance x dominance [l]) were present. But, for starch content in cross I, only the main effects were present and in cross II and III, main effects with all the three types of gene interactions (additive x additive [i], additive x dominance [j] and dominance x dominance [l]) were present. Duplicate type of epistasis was observed for protein content in cross I and III and for starch content in II and III.

Inheritance protein and starch in vitro digestibility

Most millet grains score over rice/wheat with

respect to one of more nutrients such as vitamins, minerals, dietary fibres and physic-chemicals. The millet grain consisted of seed coat, embryo and endosperm. The carbohydrates are the major biochemical constitutes followed by lipids and proteins (Dhomne *et al*., 2009).

Pearlmillet was higher in protein and fat, but lower in ash, fibre, nitrogen-free extract, calcium and phosphorus as compared with sorghum grain. Based upon amino acid score in both grain lysine and methionine are limiting factors (Odiba and Sanford, 1999).

The anti-nutritional content (polyphenol and phytic acid) and *in-vitro* protein and starch digestibility of 4 pearlmillet cultivars (MP-209, HHB-50, H90/4-5, and MS81-A) was compared by Archana *et al*. (2000). They found that MS81-A had the highest polyhpenol content (767.54 mg/100 g), while MP-209 had highest phytic acid content (852.30 mg/100 g). *In vitro* digestibility of protein and starch was in HHB-50, which had the highest digestibility of protein (51.77 g/100 g) and starch (17 mg maltose/g) contents.

Polyphenols limit protein and starch utilization either by binding with proteins or by inhibiting the digestive enzymes especially trypsine and amylase. In pearlmillet, the concentration of polyphenols ranging from 608 to 788 mg/100 g has been reported (Sharma, 1994). On the contrary, lower concentration (about 300 mg/ 100 g) of polyphenol in the pearlmillet has also been reported by Yadav (2003).

The combining ability for grain filling ability (GFA) was independent of combining ability for various pre-flowering effects, including grain number, but was related to the combining ability for various pre-flowering effects, including grain mass and harvest index. Improvement in individual grain mass achieved through selection for GFA should translate directly into yield improvement, whereas improvement by direct selection for individual grain mass is less-likely to do so (Bidinger *et at*., 2001).

Correlation

Sachan and Singh (2001) reported that grain yield was positively correlated with 1000-grain weight, fat and protein contents at phenotypic level among pearlmillet lines studied. Among the hybrids, 1000-grain weight was positively correlated with protein content and grain yield at phenotypic and genotypic levels, whereas fat content was negatively correlated with grain yield at genotypic level.

Total protein content was significantly higher in varieties than in hybrids. There were no large differences in fat, fibre and ash contents of hybrids and varieties, although significant differences existed among the genotypes. The soluble sugars and reducing sugars of pearlmillet hybrids and varieties showed no noticeable differences and consequently there were no significant differences in non-reducing sugar contents. The hybrids and varieties differed significantly in their calcium and iron contents. Dry-heating as a method of cooking was more beneficial in term of nutrient retention, particularly for the protein and iron content (Malik *et al*., 2002).

Arulselvi *et al.* (2007) observed highly significant negative correlation between grain yield and protein. Phytate phosphorus is positively associated with phosphorus and negatively associated with iron and zinc. They also reported that simultaneous improvement of both grain quality characters and grain yield was difficult. Starch had a significant positive association with grain yield. However, calcium, phosphorus, iron, zinc and phytate phosphorus had non-significant association with grain yield.

In case of white grain colour hybrids grain yield showed significant and positive correlation with starch and fat content. For quality traits protein content exhibited negative correlation for starch and fat content in case of grey grain colour hybrids. However, for white grain colour hybrids such correlation was significant only for starch content (Arya *et al*., 2009d). Correlation studies play an important role in deciding the breeding strategy and identification of superior high yielding varieties/ hybrids with better quality (Arya *et al*., 2009e).

Yadav *et al*. (2010) exhibited positive and highly significant correlation of rancidity with total phenols, C-glycosylflavones and peroxidase activity. Among the correlation coefficients for biochemical traits, fat content had positive and significant correlation with fat acidity and free fatty acid. Total phenols had positive and significant correlation with C-glycosylflavones and peroxidase activity, C-glycosylflavones with peroxidase activity, fat acidity with free fatty acid and free fatty acid with peroxide value.

6. Management of Grain Quality Enhancement

Cultural practices

Protein content in pearlmillet grain is determined by its genotypes, but agronomic practices (especially application of nitrogen) and environment conditions also affect the protein content. The grain protein of pearl-

millet grown at high fertilizer doses (120 kg N/ha) was 19 to 55 per cent higher than those at low fertilizers (12 kg N/ha) (Sawhney and Naik, 1969).

The additional protein synthesized as a result of nitrogen fertilization was mostly due to enhanced synthesis of proline fraction which is rich in tryptophan, but comparatively low in lysine. In general, only leucine and glutamic acid showed appreciable increase in the lysine and methionine contents with the increase in protein content (Balley *et al*., 1980). Chejara *et al*. (2003) observed that increase in phosphorus levels up to 30 kg/ha increased grain yield compared to control. Phosphorus at 30 kg/ha resulted in 29.9 per cent increase in grain yield over control. Further, phosphorus at 30 kg/ha also resulted in the higher N and S uptake, while phosphorus content and uptake increased significantly up to phosphorus at 45 kg/ha. However, sulphur rate up to 40 kg/ha resulted in 29.5 per cent higher grain yield compared to control.

Application of 5 t FYM/ha and 17.47 kg P/ha significantly enhanced grain yield and protein content of grain and net return. Increasing levels of zinc significantly enhanced protein content of grain only up to 5 kg Zn/ha of pearl millet (Jakhar *et al*., 2006). Satyajeet *et al*. (2007) obtained the highest grain yield, protein content and protein yield in grain with 100% RD+vermin-compost+bio-fertilizer. Blummel *et al*. (2003) reported that in pearlmillet, genotypic variation in grain yield and its quality was expressed under high fertility, but not under low fertility application.

The effects of N (0, 30, 60 and 90 kg/ha) and S (0, 20, 40 and 60 kg/ha) rates on the yield and quality of pearlmillet cv. MH-179 were studied by Jat *et al*. (2002). They observed that N at 60 and 90 kg/ha significantly increased grain yield, and protein contents, and total S uptake over 0 and 30 kg N/ha. The application of 20 kg S/ha resulted in higher grain and stover N contents, and grain S content than 0 kg S/ha. Grain protein, and total N and S uptake increased up to 40 kg S/ha. Patel *et al*. (2001) also reported that the successive increase in N application from 40 to 120 kg N/ha significantly increased plant height, ear length and grain protein content. Chaudhary *et al*. (2012) studied for genetic variability, heritability and genetic advance of grain Fe, Zn, protein and grain yield. The variability analysis revealed that grain Fe, Zn content, plant height and grain yield per plant had high magnitude of phenotypic range, genotypic coefficient of variation, phenotypic coefficient of variation, heritability and genetic advance per cent of mean, suggesting the importance of additive gene action. Hence, these characters can be improved through simple selection process.

Zong *et al*. (2011) observed that foliar Zn application exerted its impact on quality as it is an essential mineral nutrient for plant growth and development. They further observed that the Zn application increased lysine acid and soluble sugar content in the grain in both cultivars. The results of this study suggest that foliar Zn application increases yield and also improves grain quality when applied at 1.50 to 2.25 kg/hm^2 for soils with low zinc content.

Notwithstanding lower plant water potential and leaf relative water content, N-treated plants displayed significantly higher photosynthetic rates, leaf area, levels of total chlorophyll, starch, reducing sugars, soluble protein and free amino acids and nitrate reductase activity compared with control plants in all the genotypes (Kathju *et al*., 2001).

Effect of growth regulators

The foliar spray of brassinosteroid (0.1ppm), triacontanol (10 ppm), salicylic acid (100), NNA (40 ppm) and mepiquat chloride (50 ppm) on pearlmillet increased grain yield, grain protein and sugar content, due to their significant effect on plant chlorophyll, soluble protein, nitrate reductase activity, indoleacetic acid oxidase activity and N uptake. Among the growth regulators, brassinosteroid was the most effective followed by triacontanol (Sivakumar *et al*., 2001).

Impact of environment on quality

The range of protein content among various genotypes varies from 6.40 to 24.25 per cent (Sharma, 2005). Protein content is inheritant capacity of genotype, but it is also influenced by agricultural techniques especially nitrogen fertilization and many other environmental factors (Sawhney and Naik, 1969; Chugh and Bainiwal, 2002; Arya *et al.*, 2009b). Likewise, Govindara *et al*. (2001) reported that crude protein, crude fat, phytate phosphorus, calcium, iron and zinc contents were influenced by the environmental factors.

Arya *et al*. (2009b) interpreted that high protein content (%) was not only the inherent property of a genotype alone, but, it was highly influenced by environmental conditions such as temperature, humidity,

sun shine hours and rainfall distribution prevailing during the crop season. Moreover, protein content is polygenetic trait. It is considerably affected by environmental factors, especially, at grain filling stage. The water stress during the grain filling stage in pearl millet reduced the grain yield, grains per unit area and 1000-grain mass, but grain protein percentage increased. This increase in protein percentage was attributed to reduction in carbohydrates accumulation under stress (Arya *et al*., 2010). Protein content as well as its quality is influenced by cultivar genetic constitution, prevailing environmental conditions and fertilizer management (Hulse *et al*., 1980). Yadav and Kumar (2013) carried out investigation on pearlmillet genotypes HHB 67 (Improved), HHB 197, HHB 223 and HHB 234 under rainfed and irrigated. The experiment was laid down in factorial randomized block design with three replications. The results indicated that zinc and iron content in grain was significantly higher under rainfed condition (58.03 ppm) than irrigated environment (53.31 ppm). Genotype HHB 67 'Improved' recorded significantly higher zinc (63.82 ppm) and iron content (45.84 ppm) in grain compared to all other genotypes.

Processing to improve nutritional quality

Malting improved the *in-vitro* protein (14-26%) and starch (86-112%) digestibility and improved malting was significantly higher than blanching. The effect of malting with 72 h of germination was most remarkable in improving *in-vitro* protein and starch digestibility (Archana *et al*., 2001). According to Cuevas-Hernandez *et al*. (1999) fermentation of pearlmillet grains with fungus *Rhizopus oligosporus* changed their nutritional values. Protein content increased with an increase in fermentation time. The size of the pearl millet granules was also important in fermentation process.

Elyas *et al*. (2002) reported that fermentation for 36 h at room temperature was effective to reduce total polyphenols and phytic acid contents, but no change was noticed in tannin content of fermented dough in pearlmillet. Generally, malting quality parameters were significantly affected by germination temperature and time as well as by cultivar. Germination at 25-30^0 C and germination time of 3-5 days were optimum. These conditions resulted in high diastatic power, alpha- and beta-amylase activity, good free alpha-amino nitrogen and moderate malting loss. Pearlmillet malt can therefore be used for the production of sorghum type beers (Pelembe *et al*., 2002).

The qualitative factors limit the acceptability of pearl millet, such as gray colour, poor self life and astringent flavour. The techniques for processing pearlmillet, such as milling, acid treatment, dry heat treatment, malting, blanching, parboiling, and popping improves the nutritive value, digestibility, shelf life and reduces anti-nutrient content, and increases consumer acceptability on pearlmillet. In India, pearlmillet can be utilized for the development of traditional foods e.g. porridges flat beards, chips, bhakri, suhali, khichri, dalia, shakkerpara, backed products, extruded products, health products, and weaning and supplementary foods. The utilization of pearl millet for novel product development will help in diversifying their use, which can be beneficial for human health and for increasing the profits of farmers (Sehgal *et al*., 2003).

Pearlmillet is gluten-free, has unique phenolic compounds, which have been identified as having medicinal properties and contain proteins and starch characteristics that lend it to functional food uses that may impact health. Industrial setting needs stable, reliable sources of relatively inexpensive high quality grain and new market development. Without these basic requirements, development of new food market for pearl millet will be extremely difficult (Dahlberg *et al*., 2003).

Eyzaguirre *et al*. (2006) reported that sisc milling of grain may add significant iron this is not necessarily *in vitro* soluble iron. Soaking of grain resulted in a 25 per cent loss of iron, but it also facilitates endogenous phytate degradation, particularly when combined with milling and cooking. Germination and lactic acid fermentation both result in partial phytate degradation. Cooking does not decompose phytates, but results in complex formation of phenolic compounds as measured by a significant reduction in reactive hydroxyl groups. Because of its different distribution in the grain, zinc is generally less attacked than iron. Phytate reduction by endogenous phytases is inhibited at low pH as caused by fermentation. Alkaline rock salt could be a functional cooking ingredient as a source of minerals and to react with phenolic substances. The relative IVS of iron was doubled by germination of grain and increased 3-fold by fermanation of wholemeal slurry. Zinc IVS tended to increase on cookng with kanwa, but decreased in cooked fermented flour.

The process variables for extraction cooking of pearlmillet were standardized and some of the physico-chemical characteristics of the pearlmillet extrudates and also the nutritional qualities of the millet and legumes-

based extruded supplementary foods were determined (Sumathi *et al*., 2007). The millet grits less than 355 micro m in size, equilibrated to 18 per cent moisture content, extruded at 150°C temperature and at 200 rpm of the barrel of a twin-screw extruder yielded the extrudates of 1.75 expansion ratio and 7.5 kg breaking strength. The cold and cooked paste viscosity, the melt energy and also the carbohydrates digestibility of the extrudates indicated that the products were pre-cooked and were of ready-to-eat nature. The millet was blended with grain legumes (30%) and also with defatted soy (15%) separately and extruded to prepare ready-to-eat nutritious food products suitable as food supplements to children and mothers. The self-life of the foods was about six months in different flexible pouches at ambient storage conditions. The study revealed that application of extrusion cooking technology to pearlmillet has promise for preparation of diversified and value-added food products from the pearlmillet.

7. Future Thrust

The nutritional quality traits are governed by both additive and non-additive gene effects. The progress in combining the high grain yield with quality traits is slow. Although, it should not be difficult to achieve fairly high levels of protein, tryptophan and lysine in high yielding genotypes, as their correlation with grain yield, though negative, are non-significant. Genotypes based on the requirements the food used in different regions have to be developed, and combine different quality traits as per needs are to be identified. The genetic information on quality traits of home-made products (snaks, noodles etc.) and industrial products (starch, alcoholic beverages etc.) are lacking. Being nutritionally rich pearlmillet needs to be improved in flour colour, flavour and keeping quality. Therefore, identification/development of suitable nutritive genotypes having good keeping quality and industrial value is needed. In future, while improving quality traits, antinutritional factors viz., polyhpenols, goitrogens, and phytic acid levels should be kept at still lower levels. Nevertheless, it should not be difficult to improve protein content, level of essential amino acids and keeping quality of flour through breeding approaches, since genetic relationship of protein content and amino acids with grain yield and factors controlling rancidity are known in pearlmillet.

Improvement in quality traits through conventional breeding gets some success. Now-a-days use of modern techniques along with conventional breeding could get more success. To obtain high quality high yielding improved varieties are prime. But in combination to this, optimum plant population, sowing time, fertilizer, irrigation and plant protection measures have found the greatest effect on grain yield and quality.

REFERENCES

Abdelrahman, A., R. C. Hoseney, and Varriano-Marston E., 1983 : *Cereal Chem.*,**60** :189-191.

Aggarwal, A . J. 1992 : Ph. D. thesis, CCSHAU, Hisar, India.

Akingbala, J. O. 1991 : *Cereal Chem*., **68** : 180-183.

Archana, S. Sehgal, A. Kawatra, and D. C. Nizhawan, 2000 : *Haryana agric. Univ. J. Res*., **30** : 45-47.

Archana, S. Sehgal, and A. Kawatra, 2001 : *Nahrung*, **45** : 25-27.

Arulselvi, S., K. Mohanasundaram, and B. Selvi, 2009 : *Crop Res.(Hisar)*, **37** : 161-167

Arulselvi, S., K. Mohanasundaram, B. Selvi, and P. Malarvizhi, 2007 : *Indian J. Genet*., **67** : 37-40.

Arya, R. K., and H. P. Yadav, 2009 : *Indian J. Agril. Sci*., **79** : 941-944.

Arya, R. K., H. P. Yadav, A. K. Yadav, and M. K. Singh, 2010 : *Forage Res.*, **36** : 176-180.

Arya, R. K., H. P. Yadav, and A. K. Yadav, 2009a : *Natnl. J. Pl. Improv*., **11** : 65-66.

Arya, R. K., H. P. Yadav, L. K Chugh, A. K. Yadav, and Desh Raj, 2009b : *Ann. Biol*., **25** : 27-30.

Arya, R. K., H. P. Yadav, L. K Chugh, A. K. Yadav, Desh Raj, and M. K. Singh, 2009c : *Environ. & Ecol*., **27** : 1498-1502.

Arya, R. K., S. Arya, and S. K. Pahuja, 2009e : *Forage Res*., **35** :169-174.

Arya, R. K., H. P. Yadav, and L. K. Chugh, 2008 : *J. Plant Biol*., **35** : 211-214.

Arya, R. K., H. P. Yadav, Desh Raj, and A. K. Yadav, 2009d : *Agric. Sci. Digest*., **29** : 101-104.

Bailey, A. V., B. Piccoco, G. Sumrell, and G. W. Burton, 1980 : *J. Agril. & Food Chem*., **28** : 866-870.

Bangar, M. U., B. R. Bhite, D. P. Kachare, and J. K. Chavan, 1999 : *J. Fd. Sci. Tech*., **36** : 535-537.

Bhardwaj, B. L., M. Singh, and D. R. Satija, 1987 : *Indian J. Genet*., **47** : 94-98.

Bhati, D., and Madhu-Goyal, 2012 : *Asian J. Chem*. **24** : 5885-5888.

Bidinger, F. R., S. Chandra, and D. S. Raju, 2001 : *Theor. Appl. Genet*., **102** : 387-391.

Blummel, M., E. Zerbini, B. V. S. Reddy, C. T. Hash, F. Bidinger, and A. A. Khan, 2003 : *Field Crops Res*., **84** : 143-158.

Buerkert, A., M. Moser, A. K. Kumar, P. Furst, and K. Becker, 2001 : *Field Crops Res*., **69** : 1-11.

Burton, G. W., A. T. Wallace, and K. O. Rachie, 1972 : *Crop Sci*., **12** : 187-188.

Carnovale, E., and Quaglia, G. B. 1973 : *Ann. Technol. Agric*., **22** : 371.

Chaudhary. P., and A. C. Kapoor, 1984 : *J. Sci. Food and Agri.*, **35** : 1219-1224.

Chaudhary, V. P., K. K. Dhedhi, H. J. Joshi, and J. S. Sorathiya, 2012 : *Madras Agricl. J*., **99** : 465-467.

Chavan, J. K., and C. T. Hash, 1998 : Biochemical constituents related to odour generation in some ICRISAT pearl millet materials. *ISMN* **39** : 151-152.

Chejara, V. K., A. K. Gupta, and D. K. Gupta 2003 : *Ann. Biol*., **19** : 141-145.

Choudhary, S. 2005 : M. Sc. thesis, CCSHAU, Hisar.

Chugh, L. K., and C. R. Bainiwal, 2002 : Improvement of pearlmillet grain quality. In *: Proc. Seminar on Quality Improvement in Crops*, January 5, CCSHAU, Hisar. pp. 96-105.

Cuevas-Hernandez, B., J. M. Perez-Quilantan, L. J. Galan-Wong, M. G. Alanis-Guzman, and R. K. Maiti, 1999 : *Phyton-Buenos-Aires*., **65** : 91-95.

Dahlberg, J. A., J. P. Wilson, and T. Snyder, 2003 : Alternative uses of sorghum and pearl millet in Asia. Proc. of an expert meeting, ICRISAT, Patancheru (A. P.), India. pp. 42-59.

Dhillon, B. S., and V. P. Singh, 1975 : *Indian J. Farm Sci.*, **3** : 1-4.

Dhomne, M. B., S. S. Lanoe, and S. N. Deshmukh, 2009 : *Annals Pl. Phy*., **23** : 33.

Elyas, S. H. A., A. H. El-Tinay, N. E. Yousif, and E. A. E. Elsheikh, 2002 : *Food Chem*., **78** : 75-79.

Eyzaguirre, R. Z., K. Nienaltowska, L. E. Q. de- Jong, B. B. E. Hasenack, and M. J. R. Nout, 2006 : *J. Sci. Feed & Agri*., **86** : 1391-1398.

Govindaraj, M., B. Selvi, S. Rajarathinam, and P. Sumathi, 2011 : *African J. Food,-Agri,-Nutri. & Dev*., **11** : 4758-4771.

Govindaraj, M., B. Selvi, S. Rajarathinam, and P. Sumathi, 2011 : *African J. Food, Agri., Nutri. and Develop*., **11** : 4758-4771.

Gupta, V. P. 1980 : Genetics of quality improvement. In : *Trends in Genetical Research on Pennisetum*, V. P. Gupta and J. L. Minocha (eds.). pp. 91-98.

IBPGR/ICRISAT, 1993 : Descriptor of pearlmillet (*Pennisetum glaucum* (L.) R. Br., IBPGR, Rome, Italy and ICRISAT, Patancheru, India.

Jain, R. K., and S. Bal, 1997 : *J. Agril. Eng. Res*., **66** : 85-91.

Jakhar, S. R., M. Singh, and C. M. Balai, 2006 : *Indian J. Agril. Sci*., **76** : 58-61.

Jambunthan, R., and V. Subramanian, 1988 : In : *Biotechnology in Tropical Crop Improvement*, J. M. J de Wet and T. A. Preston (eds.). ICRISAT, Patancheru, India. pp. 133-139.

Jat, R. L., O. P. Sharma, and A. C. Chaudhari, 2002 : *Annals Agril. Res*., **23** : 226-228

Kaced, I., R. C. Hoseney, and E. Varriano-Marston, 1984 : *Cereal Chem*., **61** : 187-192.

Kadlag, R. V., J. K. Chavan, and D. P. Kachare, 1995 : *Pl. Fd. Hum. Nutr*., **47** : 279-285.

Kapoor, R. and A. C. Kapoor, 1990 : *Food Chemistry*, **35** : 277-286.

Kapoor, R., and A. C. Kapoor, 1980 : *J. Fd. Chem*., **35** : 277-286.

Kathju, S., U. Burman, and B. K. Garg, 2001 *: J. Agril. Sci*., **137** : 307-318

Khangura, B. S., K. S. Gill, and P. S. Phul, 1980 : *TAG*., **56** : 91-96.

Kumar, K. A., S. C. Gupta, and D. J. Andrews, 1983 : *Crop Sci*., **23** : 232-235.

Kumar, P. D., H. M. Geetha, and H. S. Shetty, 2002 : *J. Plant Sci.*, **164** : 85-93.

Lai, C. C., and E. Varriano-Marston, 1980a *: Cereal Chem.*, **57** : 271-274.

Lai, C. C., and E. Varriano-Marston, 1980b *: Cereal Chem.*, **57** : 275-277.

Lakshmana, D., and A. K. Guggari, 2001 : *Karnataka J. agric. Sci.*, **14** : 749.

Malik, M., U. Singh, and S. Dahiya, 2002 : *J. Food Sci. & Tech. Mysore*, **39** : 463-468.

Malik, M., U. Singh, and S. Dahiya, 2002 : *J. Food Sci. and Technol*., Mysore **39** : 463-468.

Mustafa,-A-F. 2010 : *J. Dairy Sci*., **93** : 733-736.

Muyolo, N. G., K. Kamizelo, A. A. M. Kamwimba, and E. W. Wawende, 2002 : *Plant Genetic Resources Newsletter*, **131** : 23-28.

Nambiar, V. S., J. J. Dhaduk, Neha-Sareen, Tosha-Shahu, and Rujuta-Desai, 2011 : *J. Applied Pharma. Sci*., **1** : 62-67.

Nantanga, K. K. M., 2006 : M. Sc. thesis, Department of Food Science, University of Pretoria, Pretoria.

Odiba, J. Y., and P. E. Sanford, 1999 *:Bull. Animal Health & Production Africa*, **47** : 83-85.

Odiba, J. Y., and P. E. Sanford, 1999 : *Bull. Animal Health & Prod, Africa*, **47** : 83-85.

Ogunbanwo, S. T., and B. T. Ogunsanya, 2012 : *J. Applied-Biosciences*, **51** : 3608-3617.

Palande, K. B., R. V. Kadbag, D. P. Kachare, and J. K. Chavan, 1996 : *J. Fd. Sci. Tech*., **32** : 153-155.

Patel, K. V., and M. Parmeshwaran, 1992 : *J. Fd. Sci. Tech*., **29** : 51-52.

Patel, V. J., A. C. Sadhu, and J. B. Patel, 2001 : *Current Res. Univ. Agril. Sci., Bangalore*, **30** : 162-163.

Pelembe, L. A. M., J. Dewar, and J. R. N. Taylor, 2002 : *J. Inst. Brewing*, **108** : 7-12.

Phul, P. S., D. S. Athwal, and B. S. Gill, 1969 : *Indian J. Genet*., **29** : 438-445.

Poonia, B., Leela Wati, and Kushal Raj, 2010 : *J. Pure & Applied Micro*., **4** : 349-354.

Praduman, 2006 : M. Sc. thesis, CCSHAU, Hisar, India.

Rao, S. V. R., M. V. L. N. Raju, M. R. Reddy, and A. K. Panda, 2004 : *Asian-Australasian J. Anim. Sci.*, **17** : 836-842 .

Reddy, V. P., J. M. Faubion, and R. C. Hoseney, 1986 : *Cereal Chem*., **63** : 403-406.

Reichert, R. D., 1979 : *Cereal Chem*., **56** : 291-294.

Reichert, R. D., C. C. Younger, and D. A. Christensen, 1980 : In : *Polyphenols in Cereals and Legumes*, J. H. Hulse (ed.) NRCC No. 17383. International Development Center, Ottawa.

Rooney, L. W., and C. M. McDonough, 1987 : Food quality and consumers acceptance of pearl millet.Pp. 43-61. In : Proc. International Pearl millet Workshop, J. R. Witcombe, and S. R. Beckerman (eds.). ICRISAT, Patancheru, India. pp. 43-61.

Sachan, C. P., and S. K. Singh, 2001 : *Prog. Agri*., **1** : 79-81.

Sagar, P., Bal-Chandra and S. K. Gupta, 2005 : *Natl. J. Pl. Improv*. **7** : 131-132.

Satyajeet, R. K. Nanwal, V. K. Yadav, and Pawan Kumar, 2007 : *Annals Biol*., **23** : 37-40.

Sawaya, W. N., J. K. Khalil, and W. Safi, 1984 : *Plant Food and Human Nutr.* **34** : 117-125.

Sawhney, S. K., and M. S. Naik, 1969 : *Indian J. Genet*., **29** : 395-406.

Sehgal, S., A. Kawatra, and G. Singh, 2003 : Proc. An Expert Meeting, ICRISAT, Patancheru (A. P.), India. pp. 60-92.

Serna-Saldivar, S. O., C. M. McDonough and L. W. Rooney, 1991 : The Millets. In : *Handbook of Cereal Science and Technology,* K. J. Lorenz, and K. Kulp (eds.). Marcel Dekker, Inc., New York, USA. pp. 271-300.

Sharma, A., 1994 : M. Sc. thesis, CCSHAU, Hisar, India.

Sharma, S., 2005 : Ph. D. thesis, CCSHAU, Hisar.

Singh, F., and H. S. Nainawatee, 1999 : In : *Pearlmillet Breeding,* I. S. Khairwal, K. N. Rai, G. Harinarayana and D. J. Andrews (eds.). Oxford and IBH, New Delhi. pp. 156-183.

Singh, P., Singh, U., O. Bjorn, K. A. Kumar, and D. Andrews, 1987 : *J. Food Sci. and Agri*. **38** : 41-48.

Singh, T., J. K. Brar, and Kiran Bains, 2009 *: J. Pl. Sci. Res*., **25** : 79-82.

Sivakumar, R., M. K. Kalarani, V. Mallika and S. B. Sujata, 2001 : *Madras J. Res*., **88** : 256-259.

Subramanian, V., Jambunthan, R., and S. Suryaprakash, 1981 : *J. Food Sci*., **46** : 1614-1615.

Sukhchain, and P. S. Phul, 1990 : *Crop Improv.*, **17** : 70-72.

Sumathi, A., S. R. Ushakumari, and N. G. Malleshi, 2007 : *Int. J. Food Sci. & Nutri*., **58** : 350-362.

Taylor, J. R. N., 2004 : Pearl Millet. In : *Encyclopedia of Grain Science, Vol. 2,* Wrigley, C., H. Corke, and C. E. Walker. Elsevier, London. pp. 253-261.

Thiam, D. A., R. Drapron, and D. Richrd-Holard, 1976 : *Ann. Technol. Agric*., **25** : 253.

Virk, D. S., 1988 : *Crop Improv*., **15** : 1-29.

Wu, X., D. Wang, S. R. Bean, and J. P. Wilson, 2006 : *Cereal-Chem*., **83** : 127-131.

Yadav, A. K., and Anil Kumar, 2013 *: Forage Res*., **39** : (in press).

Yadav, D. K., A. K. Chhabra, H. P. Yadav, and L. K. Chugh, 2010 : *Forage Res*. **36** : 37-41.

Yadav, R. K., 2003 : M. Sc. thesis, CCSHAU, Hisar, India.

Zong-XuFang, Wang-Hong, Song-ZhenWei, Liu-DeLi, and Zhang-AiJun, 2011 : *Frontiers of Agriculture in China,* **5** : 552-555.