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ADVANCES IN PEARL MILLET FODDER YIELD AND QUALITY IMPROVEMENT THROUGH BREEDING AND MANAGEMENT PRACTICES

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SUMMARY

Pearl millet is quick growing cereal as compared to maize and sorghum and it produces green fodder in short duration. It is a robust quick growing rainy season grass with large number of tillers, leaves and ear heads. Being tall vigorous with exceptional fodder yielding potential, it is indispensable fodder for the animals inhabitants in arid and semi-arid regions of world. Therefore, the development of quality fodder cultivars and management to meet out the fodder requirement for ever increasing livestock population is imperative, as the quality of the fodder is very important issue with respect to the livestock health status as well as to maximize the animal production of milk and meat. An effort has been made to review the progress done so far towards the development and production of quality fodder of pearl millet. The morphological traits, growth parameters, fodder yield and nutritional quality traits, along with toxic components have been discussed in this review.

Key words : fodder yield, fodder quality, contributing traits, pearl millet

India supports nearly 20% of the world's livestock and 16.8% human population with only 2.3% of the world's geographical area. India is the leader in cattle (16%) and buffalo (5.5%). The livestock sector contributes 32% of the agricultural output, which is 22% of the total GDP in India. Deficiency in feed and fodder has been identified as one of the major components in achieving the desired level of livestock production. The shortage in dry fodder is 21.8% compared with requirement of 560 million tons for the current livestock population (Anonymous, 2006). Pearlmillet a promising crop for green fodder supply especially in the lean period during the summer months of May to July and in combination with other fodder crops during the summer and kharif season. The dry fodder and straw of pearl millet is also used to feed the livestock in marginal production environments, particularly during the dry season when green fodder/grazing is limited. Thus, the gap in fodder demand and its supply can be bridged to some extent by developing high fodder yielding cultivars of pearl millet (Arya *et al*., 2009a).

Pearlmillet is one of the gifted crop plants of the tropical regions and that provide food, feed, stover/ dry fodder and fuel to millions of poor farmer families and their livestock. Its varieties are also cultivated for green fodder. Moreover, the inter-specific pearlmillet x napier grass hybrids are perennial and yield green fodder round the year. Pearmillet uses less water per unit of forage production, tolerates heat and drought. Therefore, it is generally grown in areas where environmental conditions, especially rainfall, temperature and soil fertility are too harsh to grow other cereals (Hanna and Cardona, 2001; Khairwal *et al*., 2009).

It is a well known fact that pearl millet is an

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excellent forage crop and it has great potential among the millets, as it is a rainy season cereal grass with large stem, leaves and heads with highly vigorous and quick growing habit. Its fodder is low in anti-quality factors like hydrocyanic acid and oxalic acid, while rich in protein, calcium, phosphorus and other minerals (Gupta, 1975; Arya *et al*., 2009a).

Low productivity of livestock in small land holding crop-livestock system in the dry regions is due to the limited quantity and low nutritional quality of the available stover (Renard, 1997). Management practices that might improve stover yield and quality, such as higher application of fertilizers are considered very risky for farmers to adopt in highly unpredictable environments due to its total dependency on rainfall. Therefore, the best option for increasing the availability of quality fodder appears to be genetic improvement of yield and quality of fodder in locally adapted as well as in new hybrids/cultivars. An effort has been made to review the progress done so far towards the development and production of quality fodder of pearlmillet.

Genetic Variability

Success in crop improvement depends mainly on the extent of desirable genetic variability available for selection. Therefore, collection, evaluation, documentation, utilization and conservation of genetic resources assume considerable significance. ICRISAT has collected more than 21000 accessions of pearlmillet having landraces and breeders' products. These accessions revealed considerable variability for various fodder components such as plant height (49-443.3cm), number of tillers/plant (1.0-9.3), stem thickness (6-31.2mm), number of leaves (4.3-37), leaf length (19.3-130cm) and leaf width (1.1-8.6cm) (Khairwal *et al*., 2009). Gupta (1969) found considerable variability for desirable fodder quality components such as protein, phosphorus, calcium and anti-nutritional factors like oxalic acid in samples of world collection of pearl millet. A number of research workers reported about the genetic variability in pearlmillet (Kulkarni *et al*., 2000; Lakshmana and Guggari, 2001; Arya *et al*., 2009a, b, 2010).

The development of high fodder yielding pearlmillet varieties for different agro-climatic conditions depends upon the nature and extent of genetic variability in the germplasm collection and the degree of transmissibility of characters. Variability in fodder productivity and quality may be of both genetic and non-genetic origin. The high yielding varieties/hybrids vary for different agro-climatic zones for different situation *e.g.* HHB 67-2 improved for rainfed, while HHB 223 for high fertility and irrigated conditions. However, the recommended agronomic practices vary with location and cultivar and can realize the maximum genetic potential determined quantity and quality of fodder (Reddy *et al.* 2003).

The estimates of variability like range, coefficient of variation, heritability and genetic advance are very useful for designing suitable selection strategy for evolving high fodder yielding genotypes in pearl millet. Kumar (2006) reported the wide variation in dry straw yield of pearlmillet ranging from 61.40 to 159.60, 114.27 to 250, 36.47 to 161.03 and 53.40 o 112.07 g/plant in four different environments. Likewise, the five hybrids *viz*. HMS 36A X 99, ICMA94222 X 94222 X 96AC 94, ICMA 94222 X ICR 161, ICMA 94222 X 78/711 and HMS 6A X H77/833-2 were found significantly superior over check (HHB 94) in all environments (Arya *et al*., 2009a). Amodu *et al*. (2007) evaluated pearlmillet genotypes for fodder yield components and nutrient composition and reported varietal differences. The Bunkure accession had the highest green and dry fodder yield. Blumel *et al*. (2007) observed significant cultivar dependent variation for all the quality traits. Yields of digestible and metabolizable stover varied among cultivars by at least 1.7 fold.

Chaudhary *et al*. (2007) evaluated pearl millet genotypes for dry matter content, nutritional quality and digestibility. The dry matter content varied from 17.55 to 22.35 %, while crude protein 7.43 to 10.93%, crude fiber 29.3 to 35.85%, ether extract 1.7 to 2.0%, total ash 9.25 to 13.1%. They found significant difference in dry matter content, crude protein, crude fiber, total ash, nitrogen free extract and IVDMD. The per cent NDF content ranged from 60.7 to 67.75, ADF 30.7 to 35.6, ADL 5.0 to 6.85 and hemi-cellulose from 28.1 to 34.4%. Significant difference was also reported in oxalate content, which varied from1.9 to 2.5 %.

Potential Forage Yield

Hazra and Shukla (1998) reported that FMH-3, DRSB-2 for single cut, while, Gaint Bajra and FMH-3 for multi-cut systems were recorded to be most potent for fodder production. Beniwal (2009) recorded highest green forage yield of pearlmillet landrace *Mandoria Rijko Bajri* 8 (71.8t/ha), which was followed by *Jakhrana*

Bajra (71.0t/ha), *Mondoria Rijko Bajri* 15 (68.2t/ha) and *Mondoria Rijko Bajri* 9 (63.3t/ha) in summer 2007. Moreover, Maximum green forage yield was recorded in summer 2008 in MRB-8 (79.0t/ha), which was followed by MRB-9 (78.0t/ha) and MRB-15 (65.0t/ha). Among Jakharana composite bajra, JCB-2 (108t/ha) yielded highest green forage yield.

Character Association

Correlation among biological yield and nutritional quality were significant. Forage yield was associated consistently with plant height, leaf, tiller, inter-node number and stem diameter (Lopez-Dominguez *et al.*, 2001). Yadav *et al.* (2012) reported that the dry fodder yield was significantly and positively associated with effective tillers/plant, plant height, ear length, ear weight and negatively with panicle emergence.

Reddy *et al.* (2003) found a positive association between fodder and grain yield indicating possibility of simultaneous improvement in both traits. In most of cases, fodder yield and digestibility were positively correlated and showed positive association with plant height, leaf number, and number of tillers/plant in pearl millet. However, Blummel *et al.* (2007) reported that stover quality traits and grain yield of cultivars are largely unrelated, thus suggesting that high stover quality will not be achieved on the expense of grain yield.

Blummel *et al*. (2003) found significant genotypic variation for chemical, morphological and *in-vitro* fermentation characters of stover, but their relationship with digestibility and intake measurement was generally poor. They also discussed relationships between indirect animal performance measurements such as digestibility and voluntary feed intake (VFI) and animal productivity, e.g. live weight gain. VFI was shown to be a more crucial quality assessment in crop residues than digestibility and the relationship between both measurements was poor.

It is argued that pearl millet fodder crop improvement programs should validate laboratory techniques as well as indirect animal performance measurements with direct animal performance measurements such as milk or meat production before deciding on laboratory selection criteria (Blummel *et al*., 2003)

Blummel and Rai (2003) reported that stover crude protein content and grain yield and stover yields tended to be inversely associated, but relationship were not significant. Stover in vitro digestibility and grain and stover yields were not significantly associated. Stover, grain yield were not related and improvement for grain yield will not automatically affect stover yield positively or negatively.

Navale *et al*. (1995) observed significant positive association of fodder yield with tillers and plant height, ear length, ear girth, number of grains and grain yield, but significant negative association with days to 50% flowering. Thus, simultaneous improvement for both straw and grain yield could be possible. Fodder yield is significantly and positively associated with days to maturity, number of productive tillers/plant, flag leaf area, ear girth and grain yield (Harer and Karad, 1998). Dry matter yield exhibited the high positive significant correlation with plant height and negative with crude protein and intermodal length (Suresh and Suma-Bai, 1998)

Bhamre and Harinarayana (1992) also observed positive genotypic correlation with plant height, ear weight and grain yield. Dua (1986) showed that selection function of leaf traits better expected genetic gain than a combination of other traits viz. days to harvest, stem girth, plant height and tiller number. Inclusion of dry matter (%) in any selection function improved the expected genetic gain of that particular function for dry matter yield.

Berwal *et al*. (1996) studied traits association in pearl millet core-collection. The green fodder yield showed highly significant positive correlation with plant height, leaf or node number, leaf length and leaf width at phenotypic level. Path-coefficient analysis revealed that leaf or node number, leaf length, tiller number and leaf width had direct positive effect on green fodder yield. Therefore, for the genetic improvement of green fodder yield in pearl millet, the selection based on these traits was advocated.

Generally, chemical and *in-vitro* fermentation traits exhibited higher correlation with *in-vitro* measurements compared to morphological traits. For morphological traits, plant height and stem diameter and in chemical traits NDF and ADF were highly negatively correlated with OMD, OMI, DOMI and N balance. *In-vitro* digestibility and metabolizable energy content were more closely related to the *in-vivo* measurement than kinetic variables of *in-vitro* gas production. Based on the step wise MLR method, it was observed that OMD was well predicted by the matabolizable energy (R2=0.73), OMI by a combination of NDF, sheath ratio and SD (R2=0.70), DOMI by a combination of NDF, SD and extent of gas production (R2=0.84) and nitrogen balance by a combination of IVOMD, nitrogen and ADF (R2=0.82). Expcept for OMD, combinations of traits in step wise multiple regression accounted for higher parts of the variation in *in-vitro* measurements than any stover trait alone (Ravi *et al*., 2009).

The correlation studies play an important role in deciding strategy and identification of superior high yielding genotypes with better quality. The plant breeder have endovoured to identify the important traits, which when used in selection would result in yield improvement. Correlation typically results in changes to traits that were not subjected to specific selection criteria or were not under direct selection pressure. These changes called as correlated response and could occurs in one or more of mechanisms like linkage, pleotrophy, genetic drift or non-equilibrium allelic frequencies (Arya *et al*., 2009b).

Genetics of Fodder and its Quality

Hooda *et al*. (1978) studied the genetics of quantitative as well as quality traits in forage pearl millet. They reported that most of traits and governed by more of non-additive genetic variance, through additive genetic variance were also found to be significant for all the traits except leaf width and quality traits. The estimates for the number of effective genes controlling each trait were less than one for quality traits and two to four for remaining traits. Positive and negative genes were asymmetrically distributed in the parent. Heritability estimates were relatively low for leaf width and quality traits, medium for leaf length and stem girth, and high for green fodder and dry fodder yield.

Hooda and Solanki (1979) studied the genetics of protein content in fodder of pearl millet. The protein content was predominantly governed by non-additive type of gene action. The magnitude of SCA was higher. Combining ability effects were found to be significantly correlated with both the parental means and the array means.

Indu and Gupta (1981) analyzed the solubility v/s crude protein content of green fodder of pearl millet. Leaves were having high soluble protein (7.66%) and crude protein (9.96%) as compared to stem soluble protein (3.86%) and crude protein (5.23%). In leaves soluble protein content was 58 to 91 % of the crude protein, likewise in stem soluble protein content was 52 to 97 % of the crude protein. There was no specific trend of variation in soluble protein content to the crude protein content, except for a positively significant correlation of soluble protein content with crude protein content in the stems. The GCA variance and the additive gene effects were predominant for both (soluble and crude) protein contents of the stems. However, SCA and the non-additive gene effects were predominant for both (soluble and crude) protein contents of the leaves.

Dass *et al*. (1982) revealed that the dry fodder yield was under the control of both additive and non-additive type of gene effects. Mostly, dominant genes were found responsible for high dry fodder yield and at least 3-6 dominant genes or gene groups governed it. Further, combining ability studies revealed that the inbreds L111B, 5141B and P-7-3-4 were good general combiners. The best specific crosses were 5141B X L 111B, 7000251-2-1-1 x L 111B and H-702 x P-7-34.

According to Kumar *et al.* (1982) the magnitude of non-additive genetic component was higher as compared to corresponding additive. Further, the mean squares due to GCA and SCA were found to be significant for stover yield, plant height and total tillers/plant. For stover yield, H798 and H 692; H 789 for plant height and H672for tillers were identified to be good general combiners and could be used in further breeding.

Kumar and Dahiya (1989) found that additive component was predominant for tillering and non-additive component was predominant for plant height and stover yield. The parents 81A, 841A, 90/4-5MD and G 73-107-1-2 were good general combiners, while crosses 710-75-6-2 X G 73-0-107-1-2, 81A X 3014-5AI and 710-75-6-2 X 90/4-5MD were good specific combinations for stover yield and its components.

According to Kumar and Dahiya (1991), for the expression of number of tillers/plant, plant height, biological yield and dry fodder yield non-additive component of variance was predominant. The parents 78/711-1-1-3-1-3 and 77/28-2-2-2-1-4 were good general combiners for dry fodder yield and its components. Crosses 81A X 77/28-2-2-2-1-4, 841A X 77/28-2-2-2-1-4, 3383A X 77/273-5-1-2, 3383A X 77/181-4-4-3-1, 3383A X 77/786-5-221-3, 77/273-5-1-2 X 77/144-1-3-2-2 and 77/144-1-3-2-2 X 78/711-1-1-1-3-1-3 were good specific combiner for dry fodder yield and components.

Beniwal *et al.* (1999) reported that population effect was more important as compared to heterosis effect for fodder yield in pearlmillet. Moreover, Singh and Sharma (1999) investigated that mostly dominant genes were responsible for high dry fodder yield and at least four dominant genes or gene groups governed this trait and heritability was low (32.35%).

Yadav *et al.* (2002) evaluated 77 F_1 hybrids and reported high GCA effects in 92777A and 93111A (CMS) and ICR 161, 77/29-2, HP 8601 and HTP 91/32 (pollinators) for dry fodder yield. The material could be exploited by following hybrid breeding programme and/ or reciprocal recurrent selection.

Yadav *et al.* (2004) studied 42 genotypes and revealed that parents ICMA 9555, HMS 9A, HMS322A, GA 73-107 and H77/833-2 possessed high GCA effects and crosses ICMA 9555 X CSSC 46-2, HMS 9A X G 73-107 exhibited high heterosis for dry fodder yield.

Patel *et al.* (2008) evaluated 40 top cross hybrids and reported significant high heterosis for green fodder yield in crosses ICMA 95222 X IP 22269, ICMA 00999 X IP 22269, ICMA 00999 X Giant Bajra and ICMA 94 X AFB-2. Likewise, Arya *et al.* (2011) reported high positive standard heterosis for fodder yield in four hybrids viz., HMS 36A X 1250, ICMA 94222 X ICR 161, HMS 36A X 99 and ICMA 94222 X 98/711under all four test environments.

Yadav *et al*. (2012) studied the 45 cross combinations and found 31 crosses with significant positive SCA effects for dry fodder yield/plant. The cross H77/833-2 X 1305 appeared as best specific combination for fodder yield. Arya *et al*. (2008) revealed the presence of both additive and dominance gene action for dry fodder yield in three crosses *viz.* ICMA 94222 X HMS 36B, ICMA 94222 X 78/71 and ICMA 89111 X G 73-107. In cross ICMA 89111 X G 73-107 also exhibited duplicate type of epistasis for dry fodder yield.

Genetic Improvement for Fodder Quality

Pearl millet is an important forage resource for ruminants in India. However, it is poor in nutritive value because digestible energy, crude protein and mineral contents are all low. Techniques to improve the feeding value of fodder by chemical or biological means have not been adapted widely by small farmers. Therefore, genetic enhancement may provide an alternative and practical improvement strategy for nutritive value in straw and stover (Zerbini and Thomas, 2003).

Sexana *et al*. (2009) registered PHB 2245 with maximum green fodder yield (233 q/ha) followed by PHB 2252 (207 q/ha) with their dry fodder yield 140 and 113 q/ha, respectively. PCB 164 with highest total mineral content (4.22%), total chlorophyll content (2.05mg/g) was promising. The sugar content of ICMA 92333 was maximum (2.63%). The chlorophyll content (total, a and b) in green leaves was maximum in PCB 164 (0.95, 1.02 and 2.05 mg/g), while reducing sugars were maximum for PIB 199 (1.01%). PCB 164 registered maximum total chlorophyll content (1.34mg/ g), while reducing, non-reducing and total sugars were maximum for ICMA94555 (0.91,4.39 and 5.30% respectively). The total sugar content of all genotypes tested was higher in leaves as compared to stalks, which imparts sweetness. From the point of view of green fodder quality, PHB 2245, PHB 2168, PHB 2252 and ICMA 92333 were promising.

Fodder quality can be further enhanced by improving tillering capacity, leafiness and sweetness of stem through genetic modifications. Pearl millet landraces are potential genetic stocks but fully no exploited for improvement of forage yield (Jindal *et al*., 2009).The nutritive value of forage is reflected by its dry matter protein, fiber and lignin composition and *in vitro* and *in vivo* dry matter digestibility (Ouendeba *et al*., 1996; Jindal *et al*., 2009).

Conventional Breeding Methods

Breeding methods used need to build favourable gene combinations to produce superior cultivars. Although significant progress has been made in improving pearl millet for quality fodder production, but the potential for further improvements still exist. The early cultivars were developed through mass selection, S_1 progeny selection, and later on through recurrent selection and backcross method.

Population breeding can effectively utilize the enormous genetic variability present in pearl millet, which holds better prospect for combining stable resistance to various biotic and abiotic stresses with better stover yield along with nutritive quality using diversity.

Dutta and Bainiwal (2002) compared the efficiency of three intra-population selection methods for improvement in fodder in pearl millet. They observed higher mean, GCV and PCV in H S progeny selection followed by FS and S_1 progenies. The estimates of heritability and expected genetic advance were also recorded higher in HS progeny selection for dry fodder yield as well as plant height. Thus, among these three intra-population improvement methods, HS selection procedure appears to be superior for improvement in these fodder traits in composite EC 91 PCV 5.

Dutt and Nirania (2005) realized genetic gain for plant height recorded in the negative direction on pooled basis in case of S_1 (-5.56%) and full-sib (-2.31%) showing dwarfness, while it was in positive direction in half-sib (0.46%) progeny selection method showing tallness. Plant height is one of the important traits as the excessive height of many varieties increases the risk of lodging and seed loss after storms. On the other hand, tallness has advantage for the varieties especially for fodder purpose. Thus, the product of half-sib might be suitable for improvement in dry fodder yield. The benefit of tallness seen in the experimental varieties obtained from half-sib progeny selection method that showed 14.33% realized genetic gain on pooled basis, whereas S_1 and full-sib progeny selection method showed -1.50 and 1.26% realized genetic respectively for dry fodder.

Khairwal *et al.* (2009) suggested the recurrent and divergent selection to improve IDVMD through decreasing cell wall concentration (measuring by NDF, more recently by *in-vitro* fiber digestibility IVFD) reducing lignin concentration (measured by ADF), increasing ready energy (measured by WSC) and/or increasing crude protein. A great deal of forage quality research work is being done in many other crops which could be adapted in pearl millet fodder quality improvement. Most of forage yield and quality traits are polygenicaly controlled and quantitatively inherited, few genes with large and direct effects could effectively improved forage quality, *albert* indirectly. Under such conditions pure line, pedigree and backcross breeding or population improvement could be exploited for fodder and its quality improvement.

Sharma *et al*. (2003) studied biochemical traits of dual purpose pearl millet such as oxalic acid content, crude protein (%), crude fiber (%), mineral, ash, calcium, sugar and fat contents, have been reported to a great variation in the quality of fodder. Various studies revealed the importance of both additive and non-additive components of variation for all the biological traits. Thus, reciprocal recurrent selection appears to be the best approach for the improvement of the biochemical quality traits of pearl millet fodder. The improved populations developed through reciprocal recurrent selection, may be exploited further through the development of composites and synthetics. Moreover, these improved populations may also be exploited by the isolation of superior inbred lines having high SCA for biochemical quality traits. The inbred with high SCA may be used to develop hybrids with superior fodder quality.

Hash *et al*. (2001) determined ruminant nutritional quality and NDF content in leaf blade and sheath and stem inter-node. GCA among the 4 male sterile line testers was not significant for fresh stover yield and quality parameters assessed. The most favourable GCA values for many agronomic and stover quality traits were observed for inbred P1449-2 and maintainer 863B.

Heritability for stover quality traits *viz*. sugar content, *in-vitro* digestibility and metabolizable energy as well as yield of digestible and metabolizable stover were high (h^2=0.73) except for stover nitrogen content (h^2=0.56).

Marker Assisted Selection (MAS)

By use of biotechnological tool, mainly the marker assisted breeding and plant engineering, it is now possible to design and produce crop varieties, which could successfully withstand biotic and abiotic stresses and could harness solar energy more efficiently. Biotechnology has provided several unique opportunities that include access to novel molecules, ability to change the level of gene expression, capability to change the expression pattern of genes, and develop transgenic with different genes of useful traits. Genetic linkage maps are created in pearmillet using DNA markers. DNA markers have been identified for important traits such as disease resistance, insect resistance, drought resistance, etc. (Boora *et al*., 2009).

Marker assisted selection (MAS) is new technique and effective to improve fodder quality. Hash *et al*. (2003) utilized quantitative traits loci (QTL) mapping and Marker assisted selection (MAS) for stover yield, forage disease resistance and in vitro estimates of the nutritive value of various stover fractions of pearl millet for ruminants.

Nepolean *et al.* (2009) developed to map drought tolerant QTLs, stover quality QTLs contributing to the improvement of metabolizable energy (ME), *in-vitro* organic matter digestibility (IVOMD), sugar content (SC) and gas volume (GAS) were mapped onto the linkage groups 9LGs) 2, 4 and 5. These QTLs were then introgressed into four parental lines of existing hybrids having good agronomic performance.

Three QTLs were identified for dry stover yield in pearlmillet. These genomic regions were distributed across LG3, LG5 and LG6 and together controlled a significant proportion (62%) of observed phenotypic variance for stover yield among the testcrosses (Nepolean *et al.*, 2006). Favour alleles for the QTLs mapped on LG 3 and LG 6 were provided by 863B, whereas, alleles of ICMB 841 were favourable for the QTL on LG 5. This QTL on LG 5 for dry stover co-mapped with QTLs for NDF and SUGSDM.

Conventional and MAS breeding for foliar disease resistance is recommended for dual-purpose improvement, or indeed for improvement of the nutritional value of residues for any crop in which these are used as feedstuffs for ruminant livestock.

Pearlmillet X Napier Hybrid

Pearlmillet X Napier Hybrids combine the forage quality of pearlmillet with the dry matter production potential of napier grass. Commercially the inter-specific hybrid are produced by planting CMS pearlmillet and napier pollinator in 1:1 ratio. Sukanya *et al*. (2001) evaluated 30 hybrids derived by crossing three pearlmillet and 10 napier genotypes for number of leaves/plant, leaf length, leaf breadth, leaf to stem ratio and green fodder yield. Significant variation existed for all the characters. IP 6426 (pearlmillet) and FD 439 (napier) were good general combiners, and IP 6426 X FD 469 was the best performing hybrid for green fodder yield and leafiness.

Khairwal *et al*. (2009) observed that need to supply the green fodder round the year paved the way for developing perennial napier-pearlmillet hybrids in India. These hybrids known for quick re-growth, non-hairiness, narrow long leaves, thin stems, high leaf stem ratio, high forage quality, low oxalic acid and high forage yield. Moreover, these can grow on a wide variety of soil types and in mixed, relay and inter-cropping systems.

The Pearlmillet X Napier Hybrids offer tremendious opportunity for improving forage production mainly in the tropics. The pearlmillet and napier grass gene pool both have a wealth of genetic diversity for use in producing new Pearlmillet X Napier Hybrids combination. More detailed information on these hybrids reviewed by Muldoon and Pearson (1979).

Evaluation of Genotypes for Stability

Dry matter yield can be affected by genetic, environmental, cultural and management factors. Out of these environmental factors are more difficult to control therefore, multi-location/year evaluation is needed to separate cultivar, environmental and G X E interaction effects. According to Hooda and Solanki (1977) interaction for dry fodder yield in pear millet reflected both linear and non-linear types, however, relatively large portion was accounted for remainder on environmental means. Parent D 191 exhibited stability with high mean performance and average responsiveness, whereas crosses *viz.* Anand X NB 72, A296 X F 848, A 296 X NB 72 and A 296 X D 1941 depicted above average performance and were stable. The stable hybrids involved at least one stable parent.

Dass *et al.* (1983) reported the equal contribution of both linear and non-linear type of G X E interaction for stover yield in pearl millet. Inconsistent performance over environments was indicative of sensitivity of genotypes towards environment fluctuations. However, prediction was feasible for a few genotypes. Four crosses (5054B X 700851-1-1-3, 5141B X 700651-1-1-3, 5141B X700651-2-1-1 and L 111B X 1593) showed general adaptation to a range of environments. Cross 5141B X L 111B gave high stover yield and above average response indicating its suitability for favourable environments. 5141 B X P-10-3-1-5 exhibited average performance and response, but was most stable.

Sreekumar *et al*. (1991) revealed that the genotypes, PCB-15 and MBFH-1 were high in green and dry fodder yields along with unit regression coefficients and low mean square deviation from regression can be considered as stable for Kerala conditions.

Yadav *et al*. (1999) observed that the magnitude of linear component was more for plant height (85.86%), leaf area (58.18%) and dry fodder yield (65.61%) but for tiller numbers non-linear component (85.19%) was greater. The hybrids HHB 118, HHB 130 and population HP 94150 was stable for dry fodder yield and could be recommended for general cultivation.

Patel *et al*. (2010) evaluated pearl millet genotypes for stability for days to 50% flowering, plant height, leaves/plant, leaf length, tillers/plant, leaf : stem ratio, leaf width, stem diameter, inter-nodal length, green forage yield/plant, dry matter content, crude protein content and crude protein yield/plant. They identified 5054A x IP22269, PN6A x IP22269 and L 111 A x Giant Bajra top cross hybrids as stable with wider adaptability over environments hence considered as stable hybrids.

Yadav *et al*. (2010) revealed that F_1 hybrid H77/29-2 X Togo II was stable for germination, emergence rate, seedling fresh weight and seedling dry weight. While, H77/833-2 X 1305 exhibited stability for emergence rate, numbers of leaves/seedling, seedling height and dry fodder yield (Yadav *et al.,* 2009) whereas H77/29-2 X 1305 was stable for number of leaves/ seedling and seedling height only under heat stress and normal conditions.

Management Practices

To obtain high forage productivity with good quality high yielding improved varieties are prime. But, in combination to this, optimum plant population, sowing time, harvesting time, fertilizer and irrigation have been found to have the greatest effect on fodder yield and quality. It was also noticed that transplanted pearl millet produces more stover yield than direct-seeded crop, irrespective of the seedling age (Lopez-Dominguez, 2001). Further, the fodder yield components varied among cultivars, water levels, and crop cycles. Genotype x fertilization interaction was significant in all crop cycles in pearl millet.

Effect of Environment

Lopez-Dominguez *et al*. (2001) reported that the environments affected the productive behaviour and also nutritional forage quality. Thus, manipulation of environments could improve yield and quality of pearl millet forage. The optimum nutrients content of pearl millet genotype depends on the environmental conditions such as water level, fertilization, plant density and plant density and planting dates.

Arya *et al.* (2010) reported that unfavourable environment at early stages of growth and development effects were dangerous than later stages. Any kind of stress at early stages of plant growth reduced the number of tillers drastically and also provided stimulus to the plant for early flowering, resulting in reduction in size, which ultimately reduced the fodder yield. However, highly favourable environmental conditions prevailing during early growth period which stimulated plant for profuesd tillering and more speedly plant growth, delayed the flowering and more accumulation of biomass due to long life span of the plants.

Selection of Cultivar

Fodder quality is paramount to palatability or acceptability and animal intake. Plant morphology, anatomical components, digestibility, protein, mineral, cellulose and lignin contents and anti-nutritional factor like oxalic acid determine animal performance- milk and meat production (Khairwal *et al*., 2009). Further, pearl millet breeders, biochemists and animal health and nutrition experts have a role to play in good quality forage research and cultivar development. Inter-institutional partnership forage research and development.

Joshi *et al*. (2009) reported the crude protein per cent and crude protein yield (q/ha) in forage pearl millet *i.e.* varied from 4.82 to 10.28 per cent and from 1.65 to 13.79 q/ha, respectively. IVDMD and dry matter digestibility (DDM) yield ranged from 45.4 to 58.0 per cent and from 15.09 to 78.18 q/ha, respectively. Among promising genotypes JHPM-05-02 yielded maximum crude protein (8.56 q/ha) and NDFB-9 yielded maximum DDM (73.79 q/ha). The genotypes viz. AVKB 58, Gaint Bajra, Raj Bajra, PHB 2172, NDFB-9, AVKB 19, AVKB 69 and Bajri Bawal(H) were promising genotypes. Range of variability in crude protein and IDVDMD was in accordance with finding of Das *et al.* (1974).

Narwal *et al*. (2009) reported that the hybrid HHB 117 has the stay-green characteristics i.e. plant leaf remain green at maturity. Such genotypes partition more carbon and nitrogen to the leaves during early growth compared to their senescent type resulting in greater specific leaf nitrogen. It sustains about 20 per cent high chlorophyll content over the senescent types. It provides better quality having less cellulose and lignin, and higher crude protein (8.93) and ADF (44.32). It also has early vigour heat tolerance and high biomass.

Bhardwaj *et al*. (2009) developed multi-cut fodder hybrid, PHBF-1 at PAU, Ludhiana. It is 200 cm tall with succulent stem and thick leaves, resistance to downy mildew and produce high dry matter and crude protein (10.7%) and low crude fiber (23.5%), NDF (64.4%) and ADF (40.1%).

Biofertilizers Innoculation

Biofertilizers enhanced crop production by enhancing the soil fertility, soil enzymes and soil microbs. Which may play important role in minimizing our dependence on inorganic fertilizers. The occurance of nitrogen fixing and phosphorus solublizing bacteria such as *Azotobactor*, *Azospirillum* and *Pseudomonas* etc. in the rhizosphere of plants of economic importance is being recently harvested in agriculture (Kumar *et al*., 2012). Inoculation of biofertilizers has synergic and additive effects on plant growth, biomass production, besides reducing the cost of cultivation. The encouraging role of *Azotobacter* as bioferilizer to supplement N to pearlmillet was first reported by Gautam (1979). Dalavi *et al*. (1993) reported significant increase in the stover yields of pearlmillet when the seeds were inoculated with *A. brasilense*. Bhatnagar *et al*. (1998) reported that *A. brasilense* was among free living bacteria, which showed associated symbiosis when present in the rhizosphere.

Singh *et al*. (1997) observed that the use of biofertilizers increased the stover yield by 27 and 14 per cent over control. Further, the stover yield obtained by inoculation were almost similar to those produced with application of 20kg N and 10kg P_2O_5/ha. However, Tiwana *et al.* (1992) reported that biofertilizers alone had no effect on green and dry matter yield and found that *Azospirillum* and *Azotobacter* produced similar yield of green and dry fodder matter.

Rathore *et al*. (2003) reported that inoculation of seed with the mixed biofertilizers significantly increased the grain and stover yields over control. Neelam *et al.* (2009) observed that grain and stover yields with *Azotobacter* inoculation were 10.5 and 5.8 per cent higher over control. However, grain and stover yields with Biomix (*Azotobacter* + PSB) application were 14.7 and 10.8 per cent higher, respectively, over control. Likewise, *Azospirillum* + PSB+ 75-100RDF gave significantly higher grain and stover yield of pearl millet than absolute control (Kumar *et al*., 2007). The highest protein content and protein yield in grain and stover were obtained with 100% RDF +vermicompost +biofertilizers (Satyajeet *et al.*, 2007). Inoculation of pearl millet seed with N fixing bacteria such as *Azotobactor* decrease fertilizer needs and improve the crude protein and IVDMD of fodder (Reddy *et al*., 2003).

Soil Fertility

Pearlmillet generally grown as rainfed crop on marginal and sub-marginal land, poor in organic matter, low in available nitrogen, phosphorus and zinc, which result in low yield. The judicious use of organic and inorganic combination of fertilizers help to maintain long-term soil fertility and sustained higher levels of productivity (Jakhar *et al*., 2006)

The inherent low availability of plant nutrients, coupled with fast depletion in the emergence of deficiency of micronutrients (Nayyan, 1999). Micronutrients have not only responsible for the nutritional disorder in plant but are also known to improve the yield and quality (Katyal, 2004).

In pearl millet increase the stover yield with the application of FYM has been reported by Jakhar *et al*. (2006). The enhancement in fodder yield may be attributed to the better nutrient availability and favourable effect on soil physical and biological properties resulting in increased growth and yield attributes and finally higher fodder yield.

Nitrogen Management

Tiwana *et al*. (2003) recorded 35.50, 44.82 and 19.68 % green fodder and 30.46, 45.08 and 24.46% dry matter in the first, second and third cuttings, respectively. Each increase of nitrogen (up to 100kg N/ha/cut) increased the green fodder yield of pearl millet. The magnitude of increase with 100kg N/ha/cut was 105.2, 46.5, 16.4 and 7.8 % in green fodder and 108.4, 55.2, 30.2 and 14.6 % in dry matter yield over 0, 25, 50 and 75 kg N/ha. Tiwana and Puri (2005) indicated that the variety Gaint Bajra was significantly higher fodder yielder than others and responded upto 90kg N/ha. Shekara and Lohithaswa (2009) recorded the significant higher green forage yield (520.58q/ha), dry matter yield (104.34q/ha) and crude protein yield (8.013 q/ha) in genotype JHPM-05-1 with 100 kg N/ha.

Tiwana *et al*. (2012) reported that green fodder yield increased significantly with increase in N levels upto 75 kg N/ha. Further increase in N level to 125 kg N/ha, the fodder yield increase was non-significant. The highest nitrogen level (150 kg N/ha) caused lodging of the crop and reduction in fodder yield. They further reported that fodder quality of pearl millet was influenced appreciably with the application of nitrogen levels. Application of nitrogen increased crude protein content upto the highest dose (150 kg N/ha). The crude protein content under irrigated conditions increased from 7.05 in control to 9.46% with 150 kg N/ha. Increase in crude protein with each increment in nitrogen dose might be due to increased absorption of nitrogen from the soil. Since nitrogen is main constituent of amino acids, it ultimately increased crude protein content of plants. Similar results were obtained by Sheoran *et al.* (2008).

The green fodder yield increased with increased in N rate. Nitrogen promotes vegetative growth and it was observed that higher N rate of 150kg/ha was required to release maximum green fodder yield (Sharma *et al*., 1996; Tiwana *et al*., 2003; Chaurasia *et al*., 2006 and Sheta *et al*., 2009). Likewise, the N requirement of forage pearl millet varied from 100 to 150 kgN/ha. The results on dry fodder yield were similar to that of green fodder yield.

Heringer and Moojen (2002a) showed positive linear relations of the crude protein of stem and dead dry material with nitrogen levels from top to base of pasture and for leaf blade until 30 cm height. *In-vitro* organic matter digestibility was indifferent to nitrogen levels, except for leaf blades taller than 10 cm, which showed a quadratic relation with nitrogen levels. Tiwana *et al*. (2003) observed increase in crude protein, crude fat, mineral matter and nitrogen free extract, but decrease in crude fiber content with increase in N levels up to 100kgN/ha/cut. Heringer and Moojen (2002b) revealed that application of nitrogen increase crude protein and decreased *in-vitro* organic matter digestibility of the components.

Yadav and Solanki (2002) revealed that application of nitrogen up to 120kg/ha significantly increased green fodder yield of pearl millet representing 174.20% increase over control. Application of nitrogen in three splits proved to be a superior practice as green fodder recorded with this treatment (262.96q/ha) was significantly higher over rest of the treatments. Likewise, nitrogen application in splits significantly increased the dry matter production (57.99q/ha) as compared basal application. According to Joshi *et al*. (2009) crude protein content, IVDMD and DDM increased with level of nitrogen from 50 to 100 kg N /ha.

Phosphorus Management

Indian soils (about 98%) are low in available P (Tiwana, 2000). Therefore, the application of increasing levels of phosphorus brought substantial improvement in stover yield of pearl millet up to 17.47 kg P/ha (Jakhar *et al*., 2006).

Chejara *et al.* (2003) observed that increasing P levels up to 30kg/ha increased grain (29.2%) and stover (32.9%) yields compared to control. Application of P at 30kg/ha also resulted in the highest N and S uptake, while P content and uptake increased significantly up to 45kg/ha.

Phosphorus application also improved the quality parameters (crude protein, crude fat, crude fiber, mineral matter and nitrogen free extract) of multi-cut pearl millet (Tiwana *et al*., 2003).

Potassium Management

The green and fodder yield increased significantly with the application of K_2O, 50% as basal and remaining in two equal splits after first and second cuts produced higher yield (Sheta *et al*., 2009). Opposite to this, the *goradu* soils of middle Gujarat region are generally medium or high in available K application (Patel *et al*., 1993) and being a multicut forage crop, pearl millet exhibited higher requirement of K fertilizer. Heidari and Jamshidi (2011) found that potassium treatment increased antioxidant activity in perl millet plants, though it had no significant effect on proline content in leaves.

Micro-nutrient Management

The response of Zn application may be attributed to the low available Zn in the soil and also its role in various enzymatic reactions and it acts as a catalyst in various growth processes and in hormone production and protein synthesis which results in increasing the growth and yield attributes and ultimately the stover and grain yield (Jakhar *et al*., 2006).

Kumar (2012) reported that the increase in green forage yield in HHB 197 with 10kg $ZnSO_4$ as basal treatments was 9.6 and 17.9 per cent, respectively, whereas these values were 10.2 and 17.6 for green fodder in HHB 223(Hooda *et al*.,2004; Sarita (2007). Within crop species, individual varieties can often vary considerably in their response to Zn application might be ascribed to Zn deficiency in the experimental plot. (Kumar, 2012).

The effect of sulphure (S) on green and dry fodder yield has been reported as significant (Jat *et al*., 2002; Dadhich and Gupta, 2003 and Sheta *et al*., 2009). The application of S up to 40kg/ha as a basal dose increased stover yield 32.5% compared to the control. Increasing S rates up to 40kg/ha resulted in a significant increase in N, P and S content of grain and stover, and in a significant increase in total N and P uptake. P and S interaction was significant for grain and stover yields (Chejara *et al*., 2003)

Application of 40kg S/ha significantly increased crude protein and crude fiber over control, but ether extract and ash content increased significantly only up to 5kg Zn/ha (Dadhich and Gupta, 2005).

Sowing Dates and Planting Method

Guideli *et al*. (2000) reported that in the first cut from November sowing, there was high leaf production with contents of crude protein higher than 20% and value of IVDMD around 70% application of 150 kg N/ha was considered adequate.

High density cultivation of landraces offers single cut and staggered planting ensure continuous supply of fodder during off-season. On the other hand, improved varieties are amenable for multi-cut management. A single variety Rijko of pearl millet dominated the multi-cut forage scenario (Khairwal *et al.*, 2009). Planting method and planting rate recommendations should be followed to maximize forage productivity. Although low density planting improved fodder quality, but declined fodder yield (Reddy *et al.*, 2003).

Application of Growth Regulators

Sivakumar *et al.* (2001) reported that foliar application of growth regulators and chemicals increased the chlorophyll content. Foliar spray of brassinosteriod showed highest chlorophyll content (3.80 and 1.56mg/g on 60and 80 DAS, respectively) followed by triacontanol. Foliar spray of brassinosteriod, triacontanol, salicylic acid, naphthalene acetic acid, and mepiquat-chloride on pearl millet increased soluble protein at all the stages of observation, but, brassinosteriod and triacontanol showed their effect on increasing soluble protein content (15.14 and 15.05mg/g on 60 and 80 DAS, respectively). Brassinosteriod, triacontanol, and naphthalene acetic acid spray could increase the uptake of nitrogen. Brassinosteriod stimulates fraction 1-protein synthesis (Braun and Wild, 1984). Thus, it is possible that besides affecting various bio-chemical activities, it also enhance water and nutrient uptake (Sivakumar *et al.*, 2001). Salicylic acid was also found to have direct effect on the nutrient uptake by altering the root physiology, growth rate and root hair production, thus affecting soil activities related to nutrient availability (Jose-Siqueira *et al.*, 1991).

Water Management

Green fodder and dry matter yields were influenced significantly with irrigation. The irrigated crop gave significantly higher fodder yield than un-irrigated and the magnitude of increase was 15.9%. Irrigation contributed towards higher yield because it helps in the absorption and translocation of nutrients from the soil to the growing parts of the plants and increases moisture content of the plant parts (Tiwana *et al.*, 2012). Further they observed that NO_3-N concentration was higher under un-irrigated conditions than under irrigated conditions in whole plants. Under un-irrigated conditions, the mean value of NO_3-N was 615 ppm as compared to 501 ppm under irrigated conditions. More over the concentration of NO_3-N was less in leaves as compared to stems. The low concentration of NO_3-N under irrigated conditions might be due to the dilution effect of nitrogen fertilizer. The crude protein content of the irrigated crop was less than the un-irrigated crop. The higher crude protein content (8.50%) was obtained in unirrigated crop as compared to 8.01% in irrigated. Higher crude protein content under un-irrigated conditions was due to more concentration of absorbed nitrogen and less water content in plants than under irrigated conditions.

Irrigation at more frequent intervals by splitting the same quantity of water into smaller irrigations and at critical stages improved dry matter and crude protein yields (Reddy *et al.*, 2003). Kachhadiya *et al.* (2010) registered significantly high values of grain and dry fodder yields as well as proteins with 1 OIW: CPE ratio.

Weed Management

Hand weeding resulted in better weed control efficiency than application of herbicides. However, application of herbicides resulted in the greatest benefit: cost ratio (Reddy *et al.*, 2003). Weed control measures significantly increased the protein content in grain and stover over unweeded (control). However, weed control measures did not differ significantly in protein content but maximum values was recorded by hand weeding twice at 30 and 45 days after sowing followed by pendimethaline and oxadiazon each at 1 kg/ha + one hand weeding at 45 days after sowing (Ram *et al.*, 2005).

Cutting Management

Kollet *et al.* (2006) observed that dry matter yield among the varieties were 4360, 4204 and 3247 kg/DM/ha for African, American and BN-2 varieties, respectively. The crude protein (15.36, 16.71 and 16.3%), NDF (60.55, 56.29 and 55.93) and ADF (34.55, 30.04 and 30.98) concentrations as well as the leaf blade/stem per cent differed among the African, American and BN-2 varieties. Dry matter productivity, NDF and ADF concentrations increased as the cutting age was prolonged, while leaf blade/stem ratio and crude protein decreased linearly. Productivity was reduced during regrowth, however, the average crude protein 19.75, 20.21 and 20.43%), NDF (52.45, 53.19 and 53.42%) and ADF (27.44, 26.72 and 27.06) concentrations did not differ among the African, American and BN-2 varieties. The leaf blade/stem ratio, however, differed among during regrowth. Forage nutritive value at regrowth was higher than first growth period. American and BN-2 varieties had the highest stem percentage. American and BN-2 considered best forage varieties and best cutting age in 49 days.

Hooda *et al*. (2004b) revealed that pearl millet when cut for green fodder at 45 days after sowing, and ratoon allowed to set grains though recorded significantly lower grain and stover/dry fodder yield over no cut for fodder treatment, but gave additional fodder yield of 112.71q/ha and improved the economics of cultivation in terms of gross and net returns. Among pearl millet genotypes, composite (HC10 and HC 20) yielded higher green fodder and stover than hybrids.

Pearl millet forage yields were highest when harvested at the milk stage. Crude protein declined from 8.2% at flowering to 5.3% at dough stage, while crude fibers increase from 32.7 to 35.4%. Harvesting of pearl millet at milk or dough stage is recommended. Nutrient changes with advancing maturity were small and forage yields increased with age (Amodu *et al*., 2001). Hegde *et al*. (2004) revealed that harvesting at milk stage recorded a higher dry forage yield of seed crop (14.05) and significantly lower dry forage yield in ratoon crop (3.6t/ha), while it was reverse when harvested at flag leaf stage.

Future Vision

Pearl millet is grown as sole crop or in mixed/ inter-cropping with other crops for stover and forage production. For the continuous supply of green fodder, there is a need to develop annual multi-cut high yielding pearl millet varieties/hybrids.

The limited ratoonability of pearl millet can be overcome by repeated planting for sustaining the continuous green fodder supply chain. High yield, thinner stem and more palatability can be achieved by maintaining high plant density.

Seed industries are interested to develop multi-cut hybrid rather than varieties. Pearl millet being a cross pollinated crop, there is a vast scope for the development of intra and inter-specific forage hybrids.

The nutritional quantity of fodder is determined by crude protein, IVDMD, NDF and ADF, which are reflecting degradability of proteins, carbohydrates, lignin and celluloses and anti-nutritional traits such as oxalic acid, HCN, tannins and phenols. Forage quality research is more complex, expensive and laboratory dependent, which needs multi-disciplinary approach and multi-institutional alliances.

To obtain high forage productivity with good quality high yielding improved varieties are prime. But in combination to this, optimum plant population, sowing time, cutting management, fertilizer, irrigation and plant protection measures have found the greatest effect on fodder yield and quality.

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