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Pearl millet stover productivity in crop-livestock farming system of arid zone: current status and opportunities for enhancement

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Abstract

Pearl millet is the most widely grown cereal in hot and arid regions of north-western India and is valued for both stover and grain. The grain is used for human consumption and its dry stover is a vital fodder resource for ruminant animals. The present paper reports trends in pearl millet stover production over a period of six decades and reviews prospects of enhancing it further. The estimated dry stover production of pearl millet has been increased from 8.8 m tons in 1950 to 21.8 m tons in 2010 due to increase in productivity at the rate of 22 kg/ha/year owing to adoption of high yielding cultivars and suitable agro-production technologies. Two approaches followed to improve quantity and qualities of pearl millet stover include crop management and genetic enhancement. Agronomic practices like fertilizer application, planting density, and time and method of harvesting have been utilized to significantly improve stover yield. A good range of genetic variation and moderate to high estimates of heritability have been observed in pearl millet for stover yield and quality suggesting that there exists good opportunities to further improve both traits. A greater emphasis is currently being laid in Indian national programme of pearl millet improvement on the development of dual-purpose pearl millet cultivars that can provide high stover productivity without compromising their grain productivity.

Key words: Arid zone, Bajra, Fodder, Livestock, Pearl millet, *Pennisetum glaucum*, Stover

Introduction

In most of the hot and arid regions of north-western India, the seasonal rainfall is low and highly erratic resulting in very frequent droughts of unpredictable intensity and duration. Elevated soil and air temperatures and high evaporational losses of soil water, invariably exceeding seasonal rainfall, further intensify the detrimental effects of drought. In addition, the soils have low water holding capacity and poor available nutrients. External organic fertilizers are rarely applied. These climatic vagaries result into extremely stressful crop growing environments and render arable cropping a highly risky preposition. Livestock, mainly consisting of bovine and small ruminants, is an integral component of existing farming system of arid zone and play very critical role in sustenance of its economy especially during drought periods. This is reflected through a high livestock to human ratio in arid zone. The livestock have traditionally been maintained on grazing lands and fodder from regional crops, trees and shrubs. With the increase in human population and intensifying cropping systems on the arable land of arid regions, the availability of fallow land and community property resources earlier used for grazing are declining and the land for forage production is becoming scarce. Hence crop residues are becoming more and more important source for sustaining the huge livestock population.

During the past 2-3 decades there has been a tremendous increase in production of cereals in India resulting into greater availability of straws and stover. While rice and wheat dominate stover production in irrigated areas, pearl millet and sorghum contribute more in arid and drier semi-arid regions. Pearl millet [*Pennisetum glaucum* (L.) R. Br.] enjoys the status of being the most important source of crop residue in the crop-livestock farming system in arid regions because no other cereal can be reliably and profitability grown here. Its stover forms a crucial fodder resource for ruminant animals during long dry seasons (October to June). Pearl millet stover accounts for over 30% of fodder resources available in this region. In addition, its grain forms the staple diet of human in these regions, though its consumption as food has been declining gradually over the past few decades (especially in urban areas) due to rising income levels, changing food preferences, cheap supply of grains such as wheat and rice through public distribution system.

Recent growth and future projections of aggregate food demand patterns suggest substantial increase in the demand for animal products (meat, milk and eggs) in India by 2020 (Bhalla et al., 1999). Clearly, there is need to improve the productivity of crop-livestock system of arid zone which is contributing significantly, and is also expected to play a vital role in future as well, in meeting such demands. An attempt is made here to assess the current situation of pearl millet stover production and to explore the means of enhancing the pearl millet stover productivity and quality (without compromising with grain productivity) in the existing crop-livestock systems in the driest rainfed parts of India.

Trends in pearl millet productivity in arid *vis-à-vis* non-arid regions

Trends in acreage, production and estimated stover productivity of pearl millet since 1950s present interesting information (Fig. 1). Both the production and productivity are expanding but area under pearl millet is marginally declining at national level. The maximum pearl millet area in India was between 1966 and 1976, the period that coincided with beginning of pearl millet hybrid era in the country and witnessed development of several high yielding hybrids, which were widely adopted by Indian farmers. Since then area under pearl millet is continually declining due to increased area under irrigation, popularization of green revolution technologies and changes in land use and crop diversification in the country. Major decline of area has taken place in the better-endowed regions where its productivity has increased (Joshi, 1998) thus allowing the local needs of pearl millet grain and stover to be met from relatively smaller area and finally releasing additional land for other more economic and profitable crops like cotton, sunflower, maize and groundnut in better ecological regimes with provision of irrigation. In spite of the decline in area at national level, the estimated stover production has enhanced from 8.8 m tons in 1950 to 21.8 m tons in 2010 due to continuous increase in productivity owing to adoption of high yielding cultivars and suitable agro-production technologies (Govila *et al*., 1997; Bhatnagar *et al*., 1998; Khairwal and Yadav, 2005; Yadav *et al*., 2012).

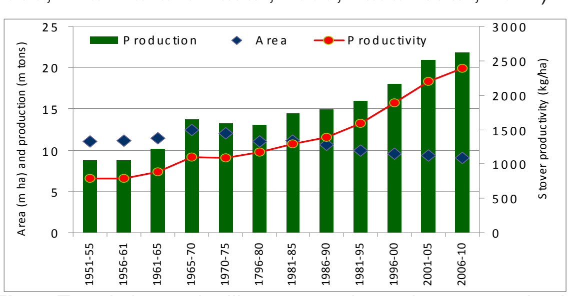

Fig 1. Trends in pearl millet area, estimated stover production and productivity in India

Unlike trends at national level, there is little change in pearl millet acreage in Rajasthan and also in the North-western arid regions since last four decades (Fig. 2) because of lack of other crop alternatives and greater importance of livestock in these regions. Similar to national level, there has been steady improvement in pearl millet stover productivity in Rajasthan as well as arid regions though there are large differences in the magnitude of improvement at these three levels. The improvement in stover productivity since 1961-66 has taken place at the rate of 16 kg/ha/year in arid regions in comparison to 22 kg/ha/year in Rajasthan and 27 kg/ha/year in India. As a result, the current levels of stover productivity in arid regions are 39% and 26% lower than that of India and Rajasthan, respectively. This is primarily due to harsh agro-climatic conditions and lower level of adoption of hybrids and varieties in arid regions (Khairwal and Yadav, 2005; Yadav *et al.,* 2012).

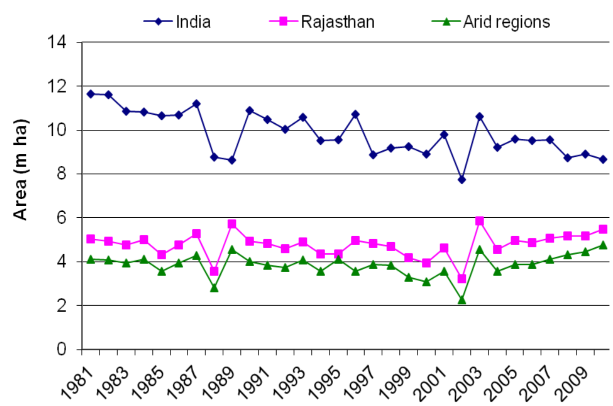

Fig 2. Trends in pearl millet area between 1981 to 2010.

Enhancing pearl millet stover productivity and quality

Pearl millet stover productivity needs to be improved considerably to bridge the gap between requirement and availability. Efforts are needed to enhance the nutritional quality of pearl millet stover as millet stover is of poor feeding value due to low digestive energy, crude protein and mineral contents. Chemical treatments have been advocated to improve stover digestibility and animal intake but there has been little adoption of such technologies by resource-poor small farmers of arid regions for economic and social reasons. Thus alternative strategy would be to increase the nutritive value of stover. There can be two approaches to improve the quantity and quality of pearl millet stover.

- Intensification of crop management alternatives for increasing production and value of stover.
- Genetic enhancement to exploit heritable differences.

Crop management alternatives

All agronomic practices that favour growth and development of pearl millet are likely to improve both stover and grain productivity. Crop management practices that have been reported to affect stover productivity and/ or quality are fertilization, plant density, time of harvesting and selective harvesting.

***Nitrogen fertilization*:** In chemical fertilization nitrogen assumes greater significance in improving the yield and quality of pearl millet stover. Other macro-nutrients phosphorous and potassium have not been reported to have as significant effects on stover yields and quality as nitrogen (see review by Reddy *et al.,* 2003) though there are synergistic interactions among nitrogen, phosphorous and potassium doses of fertilizers. Increased nitrogen dose increases stover yield and quality. Application of nitrogen at 80-120 kg/ha has been reported as optimum dose (Kathju *et al.*, 2001; Garg, 2003; Lakhana *et al.*, 2005; Kumar *et al.*, 2006; Satyajeet *et al.*, 2007) to enhance pearl millet stover and grain yield depending upon location and season. Bidinger and Blummel (2007) demonstrated an average improvement of 50% in biomass, stover and grain yields of pearl millet when nitrogen and phosphorous doses were respectively enhanced from 28 kg/ha and 9 kg/ha to 65 kg/ha and 18 kg/ha across a wide range of cultivars. It also significantly increased stover nitrogen concentration, *in vivo* digestibility and metabolizable energy content.

Response of nitrogen is strongly influenced by moisture status of soil. Hence optimum dose of nitrogen for arid regions is considered lower than that for non-arid regions (Jangir, 1997). Thus the economic returns to fertilizer applications in pearl millet in arid areas might be of modest degree in poor rainfall years due to overwhelming influence of drought on grain and stover yields. Even so, the improvement in both quantity and quality of stover with fertilizer should add to economic benefits to farmers whose income is more dependent on the sale of animal products. The improvement in grain yield could be an additional benefit.

***Planting density*:** Plant density is reported to influence stover and grain yields and also stover quality in crops (Caravetta *et al.,* 1990; Corleto *et al.,* 1990; Garg *et al.,* 1993; Reddy *et al.,* 2003). However plant density didn't have any significant effect on stover and grain productivity in pearl millet (Table 1) mainly because it has a great developmental plasticity to compensate for lower plant populations (Bidinger and Raju, 2000; Mahalakshmi and Bidinger, 1986). However, plant density did affect stover nitrogen concentration and stover digestibility but not sugar concentration or metabolizable energy yields (Table 1).

***Harvesting time*:** Delay in harvest is usually associated with lower stover quality primarily due to loss of leaf tissue as a result of effect of weathering and/ or foliar disease as well as progressive lignification of both leaf and stem tissues. Loss of leaf tissue might also result in a significant loss of stover nitrogen as the nitrogen concentration of leaves is higher than those of stems (Bidinger and Blummel, 2007). Staggered harvesting of landraces is a common practice in western Rajasthan. At maturity, farmers first harvest mature panicles from standing crop leaving the stover to be harvested later. Immature nodal panicles appearing later on indeterminate traditional cultivars often with partial seed set enhances the value of pearl millet stover.

The value of management factors in pearl millet production is clearly illustrated by the disparity in stover yield levels obtained under different management practices at farmers' field, demonstration plots and research stations (Table 2). The yield levels obtained under farmers' conditions through front-line demonstrations following recommended package of practices were 33% higher than current mean productivity in arid zone districts. The gap increased to 3 times when yield levels at research stations were compared with arid zone mean yield levels. Although the research station trials are far better managed and are conducted with near-optimum plant populations, the performance data explicitly demonstrates the degree of improvement that can be made in pearl millet productivity by optimizing the management conditions. This also requires a review of reasons for low yield in demonstrations at farmers' fields and appropriate interceptions to bridge the wide gap between yields at research stations and in demonstrations. Apparently, providing quality seed and fertilizers may not be adequate enough. There is need for greater efforts to ensure timely sowing, use of proper machinery, maintenance of proper plant population, timely weeding etc.

Genetic enhancement alternatives

In plant breeding programmes, improvement in grain productivity has been traditionally achieved by selection for greater partitioning to grain, but with little increase in total biomass, resulting in a trade-off in grain and stover productivity in modern cultivars (Austin *et al.*, 1993).

Table 1. Effects of planting density on pearl millet pearl millet grain and stover yields and stover quality variables (Source: Bidinger and Blummel, 2007)

Trait	High planting density	Low planting density	Standard Error
Grain yield (q/ha)	19.6	20.6	0.44
Stover dry matter yield (q/ha)	31.3	29.8	0.61
Digestible dry matter yield (q/ha)	12.5	12.0	0.25
Metabolizable yield (MJ)	1.64	1.51	0.03
Leaf percentage	31.9	32.2	0.26
Stover nitrogen percentage	0.79	0.87	0.02
Digestible percentage	40.8	41.3	0.12
Soluble sugar (%)	3.28	3.41	0.05

Table 2. Mean pearl millet dry stover yield under different levels of managements in western Rajasthan

Management level	No. of location x year combinations	Dry stover yield (q/ha)
Potential yield at research station[1]	7	32.57
Achievable yield at research station[2]	33	30.15
Yield at farmers field[3]	210	13.54
Arid districts yield average[4]		10.16

[1]Yield of best entry in AICPMIP trials of A_1 zone during 1998-2005

[2] Mean of all entries in AICPMIP trials of A_1 zone during 1998-2005

[3] Yields (estimated from grain yield assuming harvest index of 30%) obtained in the front-line demonstrations at farmers' field in Jodhpur district across a wide range of cultivars

[4] Arid zone districts average yields estimated from grain yield assuming harvest index of 30% (Source: Statistical Abstracts 1998-2005, Government of Rajasthan)

This strategy for increasing grain yield is not as much applicable for arid zone environments as in other regions considering the value of pearl millet both as a fodder and grain crop (Bidinger *et al.*, 2003). Thus the improvement of pearl millet stover yield and quality by genetic means without compromising grain productivity is perhaps the most realistic way to improve the productivity and economic returns of the rainfed crop-livestock production system in arid areas without substantial public and/or private investments in irrigation and other infrastructure. Given a large deficit in the availability of fodder in the arid regions even during normal rainfall years, the improvement in the stover quantity might be the first priority but the nutritive value of pearl millet stover needs to be increased so as to improve the animal productivity of crop-livestock systems in arid regions. Breeding efforts have given little attention, to date, to the improvement of stover quality of pearl millet. The genetic approach to improve dual-purposeness of pearl millet needs to assess the genotypic variation for stover productivity and quality together with grain yield available in germplasm, breeding materials and cultivars. The relationships among traits determining stover quantity and quality and extent of genotype x environment interaction must be examined and heritability of traits determined.

Genetic variation: During the last five decades, lesser emphasis was given to the improvement of pearl millet stover as compared to grain through plant breeding and selection programmes (Khairwal and Yadav, 2005). Obviously, most of the genetic studies targeted grain yield rather than stover to assess the genotypic variation available in pearl millet germplasm and breeding materials and have been reviewed earlier (Virk, 1988; Khairwal and Singh, 1999). There are only a few studies that evaluated the materials for either stover productivity or for their dual-purposeness (Yadav and Singh, 2012) and still fewer addressed the traits affecting stover quality.

Blummel and Rai (2003) evaluated seven pearl millet populations and their 42 top cross hybrids based on six fodder type male-sterile lines for productivity and quality parameters and found significant and wide differences for stover crude protein, *in vitro* stover digestibility in addition to significant variation for stover and grain yields. Using another set of 30 diverse pearl millet cultivars, Hash *et al.* (2006) observed significant differences in grain and dry stover yields and *in vitro* stover digestibility and metabolizable energy content but not for stover nitrogen. The differences in stover quality traits were largely stable across environments and years (Hash *et al.*, 2006).

Blummel *et al.* (2003) investigated variation in six genotypes of pearl millet for stover and grain yields and fodder quality of stover. Highly significant genotype-dependent variation was found in stover and grain yields and fodder quality measurements. Similarly, Hall *et al.* (2004) reported highly significant differences among 30 pearl millet genotypes for stover yield, stover *in vitro* digestibility, digestible stover yield and grain yield. In a wide range of cultivars including landraces, hybrids and open-pollinated varieties Blummel *et al.* (2007) found significant genotypic effects on pearl millet stover yield and fodder quality and observed that landrace cultivars produced higher quality fodder than modern hybrids, but at a significant cost in grain yield. Dual-purpose, open-pollinated cultivars were generally intermediate between the landraces and hybrids, in terms of both stover quality and grain yield, but produced the highest yields of both digestible and metabolizable stover. The range of variation in various stover quality traits in addition to total grain and stover yields quantities have been summarized in Table 3.

Traditional landrace cultivars from arid zone, which are considered to have evolved a high degree of adaptation to various environmental stresses that characterize arid zone environments, might be good sources for producing dual purpose cultivars. A large number of such landraces were assessed for the stover and grain productivity (Yadav and Bidinger, 2008) which showed significant genetic variation for stover and grain yields and other phenotypic traits. More than two-thirds of 169 landraces produced higher stover yields than two check cultivars viz., HHB 67 and CZP 923. Ten highest yielding landraces had far greater (28% to 236%) capacity than checks to provide higher stover and grain yields which reflected the reason for continuing farmer preference for local landraces over improved cultivars in the mixed crop-livestock farming system in North-western India (Kelley *et al.*, 1996). The landraces thus form good sources for improving stover yield in arid zone pearl millet breeding programs, without adversely affecting grain yield (Yadav *et al.*, 2009).

Pearl millet national improvement programme has also recognized the need of dual-purpose cultivars in view of growing importance of pearl millet stover to support livestock. In a recent study, Yadav and Khairwal (2007) assessed the genotypic variation for stover and grain productivity in most recently developed pearl millet experimental cultivars by the Indian national programme and concluded that a considerable scope existed for the selection of genotypes with higher stover yield. Around 7.5 t/ha of stover could be obtained with grain yield levels between 2-3 t/ha in the hybrids. At moderate levels of grain yield (1.7 t/ha) in the composite varieties, the stover yield differed from 5.5 t/ha to more than 8.0 t/ha demonstrating that there existed a good choice of selection of cultivars with higher stover yield without sacrificing grain yield, or vice-versa, depending upon the need of diverse crop-livestock farming systems. The results showed that there are excellent opportunities to enhance stover production and to meet future expectations.

***Trait relationship*:** Nature of relationship between stover yield and its fodder value and grain yield has direct implications in improving stover quantity and quality. In order to simultaneously improve the stover and grain yields the positive association or at least lack of negative association between these two traits is very essential. Based on previous studies two most important traits that influence stover productivity have been identified as plant height and crop duration. The greater plant height contributed directly to higher stover production (Yadav *et al.*, 1994) and cultivars with later maturity tend to produce more stover yield (Yadav *et al.*, 1993, Yadav and Bhatnagar, 2001; Yadav and Bidinger, 2008). But increasing stover yield by extending crop duration beyond a particular limit tend to significantly increase the risk of drought to the pearl millet crop in the arid areas of North-western India (van Oosterom *et al.*, 1996).

Different magnitude of relationship between grain yield and stover yield has been reported in pearl millet. For example, Blummel *et al.* (2003, 2007) found positive (though non-significant) relationship between these two traits. In a larger number of hybrids and composite Yadav and Khairwal (2007) observed positive and significant associations between stover and grain productivity. However, Hash *et al.* (2006) observed slightly negative associations between stover and grain yields across a wider range of genotypes but correlations were still non-significant. The relationship between grain and stover productivity in arid zone dual purpose landraces is of particular interest and the grain yield is significantly and positively correlated to stover productivity (Yadav and Bidinger, 2008).

Table 3. Stover and grain productivity and stover quality traits in pearl millet

Trait	Mean	Maximum	Minimum	Reference
Stover yield (q/ha)	30.4	37.6	22.3	Blummel *et al.* (2007)
	55.4	63.5	39.3	Blummel *et al.* (2003)
	34.8	44.4	23.5	Hall *et al.* (2004)
	20.3	32.1	10.0	Nepolean *et al.* (2006)
	36.2	48.5	26.8	Hash *et al.* (2006)
	52.5	76.9	40.6	Yadav *et al.* (2005)
	28.3	34.2	22.9	Yadav *et al.* (2001)
	74.2	108.0	43.6	Yadav and Khairwal (2007)
	38.4	52.9	29.3	Blummel and Rai (2003)
Digestible dry matter (q/ha)	12.2	15.5	8.5	Blummel *et al.* (2007)
	16.0	22.5	11.3	Hash *et al.* (2006)
	13.8	18.4	9.0	Hall *et al.* (2004)
Metabolizable energy yields (q/ha)	0.18	0.20	0.11	Blummel *et al.* (2007)
Stover *in vitro* digestibility (%)	40.5	41.9	39.2	Hall *et al.* (2004)
	41.1	42.7	38.9	Blummel *et al.* (2007)
	45.5	48.1	40.1	Blummel *et al.* (2003)
	44.5	46.5	42.9	Hash *et al.* (2006)
	42.5	48.0	36.6	Nepolean *et al.* (2006)
	43.2	46.7	38.5	Blummel and Rai (2003)
Stover nitrogen (%)	0.67	1.20	0.33	Nepolean *et al.* (2006)
	0.89	0.97	0.82	Hash *et al.* (2006)
	0.83	0.93	0.74	Blummel *et al.* (2007)
Stover crude protein (%)	4.40	6.30	3.6	Blummel and Rai (2003)
Soluble sugars (%)	3.34	4.29	2.40	Blummel *et al.* (2007)
	3.71	8.17	0.83	Nepolean *et al.* (2006)
Leaf (%)	32.2	34.5	28.6	Blummel *et al.* (2007)
Metabolizabel energy (MJ/kg)	5.34	5.87	5.12	Blummel *et al.* (2007)
	6.27	6.47	5.93	Hash *et al.* (2006)
	6.11	6.93	5.23	Nepolean *et al.* (2006)
Organic matter intake (g/kg)	45.1	49.3	41.3	Blummel *et al.* (2003)
Cell wall digestibility	53.3	55.2	48.0	Blummel *et al.* (2003)
Digestible organic matter	20.6	23.8	17.9	Blummel *et al.* (2003)
intake (g/kgLW$^{0.75}$/day)	27.8	31.7	24.5	Hall *et al.* (2004)
Digestible stover yield (q/ha)	13.8	18.4	9.0	Hall *et al.* (2004)
	16.0	22.5	11.3	Hash *et al.*(2006)
	12.2	15.5	8.5	Blummel *et al.* (2007)
Grain yield (q/ha)	20.1	26.7	11.8	Blummel *et al.* (2007)
	30.2	42.2	24.2	Blummel *et al.* (2003)
	17.6	22.3	10.7	Hall *et al.* (2004)
	19.2	29.9	9.9	Nepolean *et al.* (2006)
	37.5	39.6	28.5	Blummel and Rai (2003)
	17.0	22.8	9.8	Hash *et al.* (2006)
	21.3	25.9	15.1	Yadav *et al.* (2005)
	18.0	22.1	15.5	Yadav *et al.* (2001)
	23.7	31.7	11.6	Yadav and Khairwal (2007)

In a set of selected landraces and exotic populations the correlation between stover and grain yields was positive and significant (Yadav *et al.*, 2001, 2005). Thus there is one commonality in all these studies that none of them found grain and stover productivity as contrasting traits, rather they were compatible traits which suggested that both the traits can be expected to be improved together and improvement in one should not adversely affect other trait.

Stover yield was reported to have positive association with digestibility, soluble sugars and metabolizable energy (Hall *et al.*, 2004; Blummel *et al.*, 2007) and significantly and negative with stover nitrogen content (Blummel *et al.*, 2007). These results suggest that selection for increased stover yield would also result in increased digestibility, soluble sugars and metabolizable energy but with a significant loss in stover nitrogen. Blummel *et al.* (2007) thus opined that scope for breeding for high nitrogen content would be limited. Since application of nitrogen fertilizer resulted into significant increase in stover nitrogen content, management intervention would be preferable to genetic intervention.

Heritability

In breeding programmes for stover yield improvement the heritability estimates for traits affecting stover productivity and quality must be determined in order to assess the relative role of genetic and environmental variances. Heritability estimates of various stover quality traits and stover production are summarized in Table 4 which are moderate to high suggesting that genetic differences were considerably larger than differences due to environments or genotype x environment interactions.

Breeding for enhanced stover productivity and quality

The magnitude of genetic variation and moderate to high levels of heritability suggest that genetic improvement of stover quantity and quality should be most effective way to deal with shortage of good quality of pearl millet stover in arid zones. So far pearl millet breeding has been very successful in developing high yielding grain cultivars. Priority is to be given to the development of improved dual-purpose cultivars of high biomass with a minimum trade-off in grain yield for arid zone conditions. It has been demonstrated by Bidinger *et al.* (2003) that this can be most conveniently achieved through exploitation of heterosis in hybrids for biomass by a careful selection of male-sterile lines and adapted landraces as pollinators. The most critical requirements include use of landrace-based pollinators with a significant positive general combining ability (GCA) for total biomass productivity, with A-lines with a non-negative GCA for both grain and stover production. Blummel and Rai (2003) also found good heterosis for stover quality traits in top cross hybrids based on diverse male sterile lines populations. The approach of hybridization of Indian pearl millet landraces and African elite composites has also been examined in order to enhance stover yield of pearl millet under arid zone conditions (Yadav and Rai, 2011). They found that crosses between Indian pearl millet landraces and African elite composites, had significantly higher biomass and stover yield than both landraces and composites. Heterosis in crosses was positive for both biomass (10%) and stover yield (12%) but negative for harvest index (-7%) which indicated that hybridization of Indian landraces with elite composites based on African germplasm is an attractive and useful strategy to enhance biomass and stover productivity under drought-prone conditions.

Yadav and Singh (2012) examined the prospects of enhancing biomass yield to improve both stover and grain yields of arid zone pearl millet in a set of testcrosses based on 232 F_5 lines derived from a cross (J28 × RIB 335/18). Stover yield of testcrosses accounted for 72% of differences in total biomass with remaining accounted for by grain yield. Mean superiority of best 5% testcrosses over early checks was 58% for biomass, 68% for stover yield and 53% for grain yield.

Expression of stover quality traits in pearl millet is complex and selection based on conventional breeding methods is potentially difficult given that wet-lab analysis of nutritive value of large number of lines and breeding progenies is tedious and time consuming. Identification of quantitative trait loci (QTL) associated with stover quality traits followed by marker-assisted-selection would circumvent some of these difficulties.

At International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), two QTLs one each on LG 2 and LG 6 have been identified which govern several quality traits. Fortunately, QTL on LG 2 was also associated with improved drought tolerance. Thus transferring this stover quality QTL is also likely to improve drought tolerance which would be additional benefit for arid zone environments (Nepolean *et al.*, 2006).

Table 4. Heritability estimates for stover and grain yields and various traits associated with stover value

Trait	Heritability (%) range	References
In vitro digestibility	51-94	Hall *et al.* (2004); Hash *et al.* (2006); Nepolean *et al.* (2006); Blummel *et al.* (2007)
Digestible stover yield	67-69	Hall *et al.* (2004); Hash *et al.* (2006)
Stover nitrogen	40-56	Nepolean *et al.* (2006); Blummel *et al.* (2007)
Metabolizable energy	55-85	Hash *et al.* (2006); Nepolean *et al.* (2006); Blummel *et al.* (2007)
Stover yield	31-88	Yadav *et al.* (2001); Hall *et al.* (2004); Hash *et al.* (2006); Nepolean *et al.* (2006); Blummel *et al.* (2007); Yadav and Bidinger (2008)
Grain yield	25-88	Yadav *et al.* (2001); Hall *et al.* (2004); Nepolean *et al.* (2006); Hash *et al.* (2006); Blummel *et al.* (2007); Yadav and Bidinger (2008)

Conclusions

Pearl millet would continue it to be very important cereal in arid and drier semi-arid regions primarily because it is the only cereal crop that is capable of producing a reliable yield under the marginal growing conditions prevailing in these regions. The available data suggest that there exists considerable scope to improve the pearl millet stover productivity and quality. The quickest approach is the management intervention especially nitrogen fertilization but this involves some risk under arid zone conditions. Existence of sufficient genetic variation for stover productivity and quality and the positive association between stover quantity and quality traits (except stover nitrogen content) and moderate to high levels of heritability certainly appear to make the case for breeding programmes for improved stover quality. But selection would be difficult with conventional breeding methodology. Marker-assisted breeding can circumvent some of the limitations. The most immediate objective could be to improve the stover productivity of pearl millet for arid zone environments where there is still a wide gap between stover requirements and availability. However, genetic improvement of nutritional quality of stover is most cost effective and permanent means to improve the productivity of crop livestock system of arid zones. Value addition and appropriate storage methods and can further help meeting the increasing demand of fodder in arid regions.

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