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Prospects of breeding sorghum, pearl millet and pigeonpea for high forage yield and quality

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Abstract

Sorghum, pearl millet and pigeonpea are major warm-season dryland crops adapted to and grown primarily for grain production in the semi-arid tropical regions of Asia and Africa. With the increasing demand for livestock products and a realization of the impact of livestock in improving rural livelihoods, the value of forage (both green forage and stover) has considerably increased in recent years. Both sorghum and pearl millet are high water-use-efficient crops and belong to C_4 species with high photosynthetic efficiency and dry matter accumulation rates. Based on the mean performance of several varieties at common test locations in the All India trials, higher green fodder yields were obtained for sorghum (32.7 t/ha) and pearl millet (37.6 t/ha) than for maize (30.9 t/ha). Both sorghum and pearl millet produce good quality forage, with crude protein in pearl millet (8.7 %) being higher than those in sorghum (6.0%) and maize (5.5%). Pigeonpea is a perennial and bushy plant with still higher green forage yield (40.6 t/ha) and crude protein content (23.7%). Several other forage quality traits have been identified in these crops. With the large genetic variability identified in the germplasm and improved breeding materials, opportunities exist to develop forage cultivars with high forage yield and quality, and improved adaptation to diverse agro-ecological environments.

Media summary

Sorghum, pearl millet and pigeonpea have the potential of becoming useful forage crops for stress environments, characterized by drought, high temperatures and degraded soils.

Key Words

Breeding lines, populations, tolerance, stress environments.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) are the most important warm-season cereals in the semi-arid tropical regions of Asia and Africa, primarily grown for grain production and used as a major source of dietary energy. Pigeonpea (*Cajanus cajan,* Millsp.) is one of the most important pulse crops and a major source of protein in the vegetarian diets, especially in south Asia. In view of global climate change, rising temperatures, increasing water shortages and salinity, and increased demand for animal products (meat and milk), these three crops have recently gained added importance for their forage value. Despite their differences, these crops have five key things in common: (i) wide agro-ecologial adaptation, (ii) drought tolerance, (iii) wide range of germplasm with varying degrees of photoperiod sensitivity associated with forage yield, (iv) excellent regenerative ability, permitting multi-cut forage production and grazing, and (v) diverse sources of cytoplasmic-nuclear male sterility that enhances the possibility of exploiting heterosis for forage production. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), initially mandated to undertake genetic enhancement for increasing grain production of these crops (along with chickpea and groundnut), has recently added the forage aspects in its research agenda. In this paper, we highlight forage yield and quality as well as adaptation of these crops to stress environments, and opportunities that exist for genetic improvement to further enhance these attributes.

Adaptation to stress

Sorghum, pearl millet and pigeonpea have evolved as leafy structures, destined more to be forage crops rather than grain crops. These crops have high water-use efficiency (WUE) and are well adapted to dry areas. For instance, the WUE of sorghum and pearl millet has been reported to be, respectively, 27% and 93% greater than maize, when grown under water-limited environments (Singh and Singh 1995). These crops also have a high degree of heat tolerance, with pearl millet being the most tolerant, where some genotypes have been shown to emerge and survive at soil surface temperatures up to 64^{O}C (Peacock et al. 1993). Adaptation of these crops to problem soils and degraded lands further broadens their adaptation range. Elite breeding lines, open-pollinated varieties and hybrid parents have been identified in pearl millet and sorghum that have performed well at high salinity levels (15dS m^{-1}). Preliminary results indicate variability for salinity tolerance in pigeonpea as well. Additionally, both sorghum and pearl millet have also been found to be well adapted to acid soils. Several sorghum breeding lines, populations and hybrid parents; and relatively larger proportion of pearl millet populations have been identified that have performed well at pH levels varying from 4.1 to 4.8 and Al^{3+} saturation levels varying from 55 to 85% (Reddy et al. 2000).

Forage yield

Both sorghum and pearl millet are C_4 species with high photosynthetic potential and dry matter production ability. Pigeonpea, by nature, is a perennial and bushy plant with still higher forage production ability. In an experiment conducted under severe water stress, sorghum and pearl millet gave 4.1 t/ha dry matter that was 37% more than that of maize (Singh and Singh 1995). In another study where maize gave a green forage yield of 27.8 t/ha, sorghum had 44% higher yield and pearl millet had 54% higher yield than maize (Vyas and Rai 1985). Research in Korea showed sorghum giving 7% more dry matter and pearl millet giving 32% more dry matter than maize that produced a dry matter yield of 15.5 t/ha (Kim et al. 1990). In another Korean study, a pearl millet hybrid, *Chungaecho (= Suwon 1*) that grows more than 4 m tall has been reported to give a total green forage yield of 150 t/ha in three cuttings, which was 35% more than a sorghum-sudangrass hybrid *GW 9110* (Choi et al. 1993). There are reports of green forage yields of about 45 t/ha in single-cut sorghum hybrids. Forage yields of pearl millet cultivars seem to be 15-20% less than those for sorghum. All these studies used only one genotype to represent each species and not necessarily the best available. Based on multi-location performance of several genotypes of each crop in dry areas in All India Coordinated Forage trials, it was observed that maize gave an average green forage yield of 30.9 t/ha and dry forage yield of 6.5 t/ha (Table 1). In comparison, sorghum gave 6% higher green forage and 18% higher dry forage yield, while pearl millet gave 22% higher green forage yield and 31% higher dry forage yield.

Table 1. Dry forage yield and crude protein in sorghum, pearl millet, maize and pigeonpea.

Crop	Green forage yield (t/ ha)	Dry forage yield (t/ ha)[1]	Crude protein (%)[2]
Sorghum	32.7	7.7	6.0
Pearl millet	37.6	8.5	8.7
Maize	30.9	6.5	5.5
Pigeonpea	40.6	12.6	23.7

[1] Sorghum, pearl millet and maize data from All India Coordinated Initial Forage Trial conducted at six locations (mean of 21 sorghum, 9 pearl millet, and 5 maize varieties). Pigeonpea data mean of three varieties across three years at one location in Oklahoma, USA (Rao et al. 2002)
[2] Sorghum, pearl millet and maize data from the above coordinated trial (mean of 11 sorghum, 6 pearl millet and 10 maize varieties across 3 locations), Pigeonpea data (Saxena et al. 2002).

Pigeonpea takes longer to build its biomass, but produces much higher dry matter. Late-maturing pigeonpeas maturing in 265-340 days have given 46-52 t/ha of dry matter yields (Rao et al. 2002) of which about 50% is edible forage. In an experiment conducted with medium-maturing genotypes, harvest at 135 days after planting gave 40.6 t/ha of green forage in a summer-season dryland crop in Oklahoma, USA (Table 1).

Inter-specific hybrids provide additional opportunities to increase forage yield. Thus, multi-cut sorghum-sudan hybrids have been reported to produce 60-80 t/ha of green forage yield. In case of pearl millet, a high-yielding multi-cut inter-specific hybrid NB 21, produced from a cross between pearl millet x napier grass (*P. purpureum*) gave 296 t/ha of green forage yield with an average of 43 t/ha/cut in seven years of All India trials (Gupta 1974).

Forage quality

Generally, a good quality forage is high in protein and digestible nutrients, and low in fiber and lignin. Results from All India Coordinated Forage Project trials showed that pearl millet forage had 8.7% of crude protein, which was 45% more than that in sorghum and 58% more than that in maize (Table 1). Pigeonpea has much higher levels of crude protein (23.7%). Choi et al. (1993) showed that the digestibility of pearl millet hybrid *Chungaecho* varied from 63.4% (one cut) to 57.6% (four cut) as compared to 57.6% and 47.3%, respectively, for the sorghum-sudan grass hybrid. Digestibility up to 69% has been reported in pigeonpea forage.

Animal performance that also takes into account the forage intake is a better indicator of forage quality. Research results from Tifton in the USA showed that body gains in beef cattle grazing both early and late planted *Gahi 1* pearl millet were higher than those grazing sorghum-sudan grass. The live weight gains of over 1120 kg/ha/year in cattle grazing pigeonpea have been reported, indicating that this crop produces high quality forage and could carry a higher stocking rate as compared to those of the grasses.

A high-yielding experimental forage hybrid of pearl millet

Cattle grazing forage pigeonpea

Both sorghum and pearl millet contain anti-nutritional factors that reduce their forage quality. These include hydrocyanic acid (HCN) in sorghum that becomes dangerous at the concentration levels exceeding 750 ppm; and nitrate (especially in pearl millet) that becomes toxic at the level exceeding 9.3 g of nitrate/kg of dry forage. Oxalic acid in pearl millet is another anti-nutritional factor, which reduces the bio-availability of calcium and hence has a negative impact on milk production and fat content. Tannins as anti-nutritional factor in pigeonpea remains to be investigated. These problems, however, are amenable to solution to varying degrees through genetic enhancement and crop management.

Prospects

In view of global warming, increasing water shortages, deteriorating natural resource base, and growing demand for alternative forage resources of high quality to meet the forage requirements of increasing livestock population, sorghum, pearl millet and pigeonpea provide useful crop options. In all these crops, hybrids have 20-40% yield advantage over varieties. Stable cytoplasmic-nuclear male sterility (CMS) sources for which the maintainer frequency in the germplasm are very high (>90%), have been identified in all three crops. This increases the opportunity for genetic diversification of male sterile lines, leading to high probability for developing high-yielding hybrids.

Several simply inherited traits identified in these crops can be used to breed cultivars with improved forage quality. This is illustrated with two traits governed by single recessive genes. A d_2 dwarfing gene in pearl millet that reduces plant height by 50% and total plant dry matter by 22%, has been shown to increase the proportion of leaves by 50% and protein content by 15%, and reduce lignin by 17%, thus leading to 21% more forage consumption and 40% more body gain in 51-d cattle feeding trials (Johnson et al. 1968). Similarly, a brown mid-rib (*bmr*) mutant reported in pearl millet (Cherney et al. 1991) that increases forage palatability and its digestibility by 10% can have a great impact on forage quality improvement provided its adverse effect related to reduced dry matter production and lodging can be resolved. A *bmr* gene identified in sorghum has similar effect on reducing the lignin concentration, and thus contributing to increased *in vitro* dry matter digestibility (IVDMD).

Large genetic variability detected for several highly heritable traits (e.g., plant height, tiller/branch number, leaf number and leaf length, photosensitivity) that show significant and positive association with forage yield provides opportunities to develop forage hybrids with higher yield potential. Similarly, genetic variability for the anti-nutritional traits (HCN in sorghum, nitrates and oxalic acid in pearl millet and tannins in pigenpea) and cost-effective screening procedures available for these traits provide opportunities to improve forage quality. Large variability identified for heat tolerance, and tolerance to acid and saline soils provide opportunities to develop forage cultivars for cultivation in the otherwise unusable lands.

Conclusion

Sorghum, pearl millet and pigeonpea will continue to be important food grain crops. Their wide adaptation, owing to tolerance to numerous abiotic stress factors, and their ability to produce high forage yield with better quality have the potential of making them important forage crops for diverse agro-ecological conditions. Available genetic materials and screening/breeding technologies provide opportunities to further improve their yield and quality through crop breeding.

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