Emerging research priorities in pearl millet

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Introduction

Pearl millet (*Pennisetum glaucum*) is grown on more than 27 million ha in some of the most marginal environments of Africa (17 million ha) and Asia (10 million ha) with India having the largest area (9 million ha). Based on the rainfall patterns and the latitude, pearl millet area in India is divided into three agroclimatic zones: the arid zone (A1 zone) in northwestern India, which includes parts of Rajasthan, Gujarat and Haryana, receiving <400 mm of the annual rainfall; the A zone, which includes the remainder of northern and western India; and B zone in peninsular India, receiving >400 mm annual rainfall (Yadav et al. 2011). Farmers in these three zones have varied plant and grain trait preferences, which change over time in response to changes in the farming systems, consumer needs and environmental factors. This calls for periodic reprioritization of plant and grain traits.

India has a highly organized and well-developed seed industry with a large number of seed companies involved in development and marketing of hybrids of various crops. For instance, more than 35 seed companies are involved in pearl millet hybrid development and marketing. Of these, 25 companies are members of Pearl Millet Hybrid Parents Research Consortium. As a group, the consortium seed companies represent a large human resource with expertise in diverse areas such as parental lines breeding, hybrid development, hybrid testing (both on-farm and farmer participatory), seed production and hybrid seed marketing. Being in close contact with dealers and farmers (both seed as well as grain producers), the seed companies have better perception of farmers' choice and needs, which they translate for large-scale application in a business approach. Thus, a collective feedback from seed companies on farmers' prevailing and changing requirements serves as a useful input for priority setting in hybrid parents research at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) as well as at partners' organizations, both in the public and private sectors.

As per the consortium guidelines, ICRISAT conducts Scientists' Field Days every alternate year, whereby the consortium seed companies and all the public sector pearl millet scientists are shown, among other things, the full range of breeding materials from which they select those of their specific interest. In the years alternating to Scientists' Field Days, ICRISAT holds Consortium Consultation Meeting (CCM) where consortium seed companies as a group present their views on the emerging issues requiring possible research intervention by ICRISAT. For instance, during the 2009 CCM, leaf blast caused by *Pyricularia grisea* was discussed and identified as a major problem with a serious threat to pearl millet productivity. ICRISAT rapidly incorporated blast research in its program.

In pearl millet hybrid breeding, A_1 cytoplasmic-nuclear male sterility (CMS) system continues to be the most exploited source in spite of A_4 and A_5 sources, having proven more stable and useful than A_1 source (Rai et al. 2006, 2009b). Several A-lines based on the A_4 and A_5 CMS sources have been developed (Rai et al. 2009a). However, these have not been used in hybrid development. There is a growing demand for green forage resources in India (Dikshit and Birthal 2010). Although primarily cultivated for grain production, pearl millet has been recognized as a good fodder crop due to its high biomass yield potential, fewer disease and pest problems, high fodder quality, and water use efficiency (Rai et al. 2005). There has been some concern (though unsubstantiated) about the increasing severity of smut. Thus, utilization of A_4 and A_5 CMS systems for hybrid parents development, forage hybrid breeding, and smut resistance breeding were identified by the Consortium Advisory Committees as the three emerging issues for discussion at the 2011 CCM. Based on limited consultations with consortium scientists, two experienced pearl millet breeders from the consortium seed companies (SK Gupta from JK Agri Genetics Ltd, and RS Mahala from Pioneer Overseas Corporation) prepared a presentation on these subjects, which were discussed in the CCM on 7 September 2011. It was further followed, using three questionnaires (one for each subject), to have wider consultation with consortium seed companies for structured inputs from all the consortium members. These questionnaires were sent to all the 25 consortium participants and to the coordinator of the All India Coordinated Pearl Millet Improvement Project (AICPMIP); in total 22 participants responded. In this paper, we report on the observations included in the presentation as well as the feedback received in response to the questionnaires. Leaf blast resistance research and breeding had already been initiated at ICRISAT in response to the deliberations during the 2009 CCM. However, considering the seriousness of this problem, it was suggested to have it included in the 2011 CCM as well. Thus, the issues related to leaf blast research and breeding are also included in this paper.

Utilization of A_4 and A_5 CMS systems

Most of the strategic research on comparison of alternative CMS systems has been done at ICRISAT (Rai et al. 2006, 2009b). Based on these results and also on the observations of consortium scientists, the presentation at the CCM mentioned about varying frequency of pollen shedders as a constraint in seed parents (A-line) breeding with the A_1 CMS system. As compared to 0.1–0.6% pollen shedders mentioned for the A_1 CMS system A-lines, it was mentioned to be negligible in A_4-system A-lines and nil in A_5-system A-lines. It was also mentioned that while about 10% of the breeding lines are maintainers of the A_1 CMS system, about 40% of the lines are maintainers of the A_4 CMS system, and about 99% of the lines are maintainers of the A_5 CMS system. Thus, the A_5 CMS system provides the greatest opportunity for breeding genetically diverse and stable A-lines, followed by A_4 and A_1 CMS systems in that order. However, a large number of A_1-system restorers are available in most of the breeding programs; they are limited for A_4 CMS system and extremely rare for A_5 CMS system, implying the greater efforts that will be required to breed A_5-system restorers, followed by restorers of A_4 and A_1 CMS systems. Although results of limited studies so far show that A_1 and A_5 CMS systems have no adverse effects on grain yield, and A_4-system leads to about 5% reduction in grain yield (Rai et al. 2009b), this aspect of CMS-yield association needs to be further studied. It was mentioned that while the use of the A_1 CMS system A-lines may lead to a slow down in the genetic gain due to lesser opportunities for genetic diversification of A-lines due to lower frequency of maintainers conferring stable male sterility, there are better prospects for relatively larger genetic gains to be made with the A_4 and A_5 CMS systems. A consortium member mentioned that a beginning has been made in this direction and they have released two hybrids based on A_4 cytoplasm, one each for A and A1 zones. Further, it was also pointed out that while the use of the A_1 CMS system for breeding both A- and R-lines seems to be a matter of convenience, both A_4 and A_5 CMS systems need to be promoted in order to provide insurance against any risk associated with the use of a single CMS source, and ease seed production. The dependency on single cytoplasm can make pearl millet hybrid seed industry vulnerable to disease and insect-pest epidemics, as witnessed in case of southern leaf blight epidemic caused by *Bipolaris maydis* race T on the Texas cytoplasm based maize (*Zea mays*) hybrids in the United States (Scheifele et al. 1970).

Responding to the questionnaire, 18 respondents mentioned that there should be greater emphasis on the utilization of the A_4 and A_5 CMS systems in hybrid parents breeding, although three respondents had mentioned that ICRISAT should still have greater emphasis on the A_1 than on the A_4 and A_5 CMS systems. While 7 respondents suggested to place greater emphasis on the A_4 CMS system than on the A_5 CMS system, 9 respondents suggested equal emphasis on both CMS systems. Eighteen respondents suggested that ICRISAT should allocate 26–50% of its resources in the utilization of the A_4 and A_5 CMS sources in hybrid parents breeding. Fifteen respondents mentioned that they are planning to have their own seed parents and restorer parents breeding program for the A_4 and/or A_5 CMS systems, and 3 respondents mentioned to undertake only R-line breeding by themselves.

Forage hybrid breeding

Little targeted breeding efforts have been made to develop forage cultivars, although preliminary results have shown that some of the experimental forage hybrids made on A-lines initially bred for grain hybrid development could give up to 18 t ha^{-1} of dry forage yield, which was 44% higher than the commercial sorghum-sudan grass hybrid (Rai et al. 2005). Several positive attributes of pearl millet for forage production were highlighted in the presentation. These include excellent forage yield potential, wide adaptation, short duration, rapid growth, high tillering ability, greater drought tolerance, better water-use efficiency, absence of anti-nutritional factors like hydrocyanic acid, high regeneration potential or possibility of multi-cut cultivars, usage as green fodder and for silage, and possibility of producing male-sterile hybrids. It was mentioned that forage hybrids should be developed, both for the rainy season (single cut) as well as for the summer season (3-cuts), and the breeding objective should include high dry matter yield, low oxalates, and downy mildew resistance (for both seasons), with additional resistance to blast and rust for the rainy season hybrids. The A_5 CMS system was the unanimous choice for seed parents development, which would enable develop male-sterile F_1s much more easily due to highest frequency of maintainers and most stable male sterility (Rai et al. 2009b). Such male-sterile F_1s can be used as productive female parents of forage hybrids, which would be of distinct advantage in reducing the cost of seed production, and hence satisfy a key seed industry requirement given the high seed rate for forage crop cultivation. This, in turn, would essentially imply 3-way hybrids as the preferred cultivar option.

The feedback on the questionnaire showed that only five seed companies are working on forage hybrids at present, and another 3 are planning to initiate work in the near future. However, 15 companies suggested that ICRISAT should start work on breeding forage hybrid parents with 6 suggesting <10% resource allocation, 4 suggesting 11–20% resource allocation, and 3 suggesting 25–30% resource allocation (2 being non-committal). Five respondents suggested forage hybrids only for the summer season. Eleven respondents suggested for both rainy and summer seasons, of which 6 suggested greater emphasis on summer season hybrids while 5 suggested equal emphasis on the rainy and summer season hybrids. Eight respondents suggested that ICRISAT should work on breeding inbred A-lines for use in breeding single-cross hybrids, while 9 suggested to breed male-sterile F_1s for use in breeding 3-way hybrids. Only 3 respondents mentioned that breeding topcross hybrids would be a good idea, while 7 mentioned that topcross hybrid would not be acceptable to the seed industry, but this could largely be due to the seed industry's familiarity and practice in breeding commercial 3-way sorghum-sudan grass hybrids.

Smut resistance breeding

During the late 1970s and early 1990s, extensive research on smut carried out at ICRISAT led to the development of effective screening techniques (Thakur et al. 1983), and identification of resistant sources and their utilization (Thakur et al. 1992). Results of the consultations carried out and presented at the consultation meeting indicated that although no targeted breeding for smut resistance in the recent past has been carried out in all the programs (both public and private sectors), a large proportion of hybrids under cultivation and in the AICPMIP trials appeared to be resistant. However, large variability among the locations was observed for smut severity. Hisar was suggested to be the hot-spot as none of the entries in AICPMIP's population trials were free of smut. It was mentioned that Gwalior is an equally good hot-spot location. It was suggested that AICPMIP should undertake a trend analysis of smut severity over time based on AICPMIP trial data. There is a need to carry out on-farm survey to map out geographical distribution of smut severity in the A1 and A zones and assess smut reaction of popular hybrids. Since smut severity is influenced by weather factors, trait-specific nurseries constituted by ICRISAT should be evaluated for smut severity in two dates of planting at the hot-spot locations. The consortium seed companies may seek ICRISAT's assistance in evaluation of their parental lines for smut resistance. It was mentioned that new breeding lines developed by ICRISAT should be evaluated for smut resistance before dissemination to the consortium seed companies and NARS partners. However, the number of such lines is quite large. For instance, 1954 breeding plots were selected by and disseminated to consortium seed companies and NARS partners during the 2010 Scientists' Field Day. Therefore, instead of ICRISAT evaluating such a large number of lines for smut severity, it would be appropriate for seed recipients to evaluate those lines for smut reaction at their test locations in A zone and share the results with ICRISAT and other partners to facilitate the targeted use of resistant lines in hybridization program.

Six of the 22 respondents mentioned that on-farm smut severity during the past 5–10 years has increased only marginally and 10 respondents mentioned that there has been no change, while 6 respondents mentioned that there has been significant increase in smut severity during this period. Thirteen respondents mentioned that smut is a minor problem of no consequence, while nine respondents mentioned that smut is a significant problem. With respect to smut resistance breeding, 10 respondents mentioned that ICRISAT should initiate small-scale resistance breeding work at ICRISAT, while 6 respondents suggested just to monitor the breeding lines for this trait and discard those found susceptible. Four respondents also suggested to first conduct 2–3 years of on-farm survey to assess the extent of the problem. Eighteen respondents mentioned that their seed companies market their own hybrids in northern India, but only 8 of them mentioned doing any selection against this trait even under natural conditions.

Leaf blast resistance breeding

Following the 2009 CCM, ICRISAT initiated research on blast resistance. Consequently, effective field and greenhouse screening techniques of large-scale application were standardized and blast resistant sources in the breeding lines were identified (Thakur et al. 2009). Isolates of the pathogen population from various locations were collected and characterized for virulence diversity, and additional resistant sources in the core collection were identified (Sharma et al. 2011). A preliminary investigation showed single dominant gene for resistance (Gupta et al. 2012). Three blast resistant composites were also constituted, which are being used at ICRISAT to develop blast resistant lines. These composites were shared with several pearl millet breeders to accelerate their blast resistance breeding programs.

The presentation at the CCM again highlighted the growing importance of leaf blast with 20% incidence on one of the hybrids in Rajasthan and 80% incidence on another hybrid in Maharashtra. It was also pointed out that although blast severity, in general, was not very high, none of the populations in the AICPMIP's population trials during the 2010 rainy season were free of blast. In the Pearl Millet Blast Virulence Nursery conducted at four locations (Anand, Dhule, Gwalior, Patancheru) in rainy season of 2010, large variation among the locations for blast incidence was observed, with the highest incidence (mean value of 6.5) at Anand and lowest at Patancheru (mean value of 4.5). It was mentioned that there is a need to conduct on-farm survey to assess blast incidence and severity, and geographical distribution; and develop a better understanding of the genetics of resistance and spatial pathogenic variability. The need was also felt for AICPMIP to undertake a trend analysis of blast incidence and severity; and for ICRISAT and AICPMIP to develop a platform whereby the breeding materials from consortium members can be evaluated for blast resistance in the multilocational blast nurseries and in the greenhouse. Some of the consortium seed companies may want to have their hybrid parents and advanced lines screened by ICRISAT under high disease pressure using the standard greenhouse screening technique, for which ICRISAT readily agreed to provide this service on charge basis, as it is being done in screening for downy mildew resistance.

Summary and conclusions

The 2011 CCM deliberated on the utilization of the A_4 and A_5 CMS systems, forage hybrid breeding, and smut resistance breeding, which had been identified by the Hybrid Parents Research Consortium Advisory Committee as the three emerging issues in pearl millet. Further inputs on these subjects from all the 25 consortium members in pearl millet and the AICPMIP Coordinator were sought through questionnaires to which 22 participants responded. Leaf blast, identified as a serious problem at the 2009 CCM was also deliberated at the 2011 CCM. The group emphasized greater utilization of the A_4 and A_5 CMS systems (A_4 more than A_5) in hybrid parents development, but at this stage next only to the A_1 CMS system. ICRISAT should allocate 25% of its pearl millet breeding resources to hybrid parents development with the A_4 and A_5 CMS systems, gradually increasing it to 50% in the next 3–4 years. In the medium term (next 3–4 years), ICRISAT should allocate 10% of its pearl millet breeding resources to developing forage hybrid parents, making exclusive use of the A_5 CMS system, and revisit this subject again to examine if this needs to be increased to 20% depending on seed industry and farmers' requirements. The emphasis should be more on 3-cut hybrids for summer season cultivation rather than on single-cut hybrids for rainy season with 3-way hybrids as the most preferred option.

There is a lack of clear understanding of the extent of smut severity, and the majority of the farmers do not consider smut a serious problem. Therefore, it is imperative, first to undertake 2–3 years of on-farm survey to assess the distribution and severity of smut on diverse hybrids, and initiate the monitoring of smut in ICRISAT-constituted trait-specific nurseries grown as parts of ICAR-ICRISAT collaborative program at hot-spot locations in northern India. Some of the smut resistant lines and genetic stocks bred for smut resistance at ICRISAT can be used as controls to evaluate their current resistance levels. While the smut severity assessment is being done, the lines identified as resistant or less susceptible can be validated for resistance level under artificial inoculation, and those found promising for smut resistance can then be used in the hybridization program for building the higher levels of smut resistance in the breeding lines. Leaf blast, already recognized as a serious problem, requires as much attention as downy mildew, in terms of understanding the genetics of resistance and pathogenic variability; on-farm incidence and severity; trend analysis in AICPMIP trials; identification of diverse resistance sources; and targeted breeding for resistance. Both for smut resistance and blast resistance breeding, AICPMIP could coordinate the multilocational trials in disease nurseries and at hot-spot locations, and ICRISAT could coordinate screening under artificial inoculation at Patancheru in the field and in the greenhouse.

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