Pearl millet improvement for food and nutritional security

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Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a major warm-season cereal grown on about 30 million ha worldwide, largely in the arid and semi-arid tropical regions of Africa (18 million ha) and Asia (10 million ha) with India accounting for largest area (>9 million ha). Pearl millet in these regions is primarily grown for grain production to serve as a major source of dietary energy and nutrition, although stover is also being increasingly valued as an important fodder resource. The cross-pollinated breeding system, availability of commercially usable cytoplasmic-nuclear male-sterility (CMS) systems, and heterosis for grain and fodder yield and several other traits of agronomic and economic importance, provide for open-pollinated varieties (OPVs) and hybrids as the two broad cultivar options. Pearl millet hybrids have 25-30% grain yield advantage over OPVs. Therefore, the major emphasis in India has been on hybrid development, initially targeted to relatively better endowed agro-ecoregions, with grain yield as the highest priority trait. The diversification of cultivar base with mostly dual-purpose hybrids has led to 24 kg/ha/year of grain yield increase during the last 15 years as compared to only 5.2 kg/ha/year of yield increase during the pre-hybrid phase of 1950-1965. Dissemination of a large number and diverse range of improved breeding lines and hybrid parents developed at ICRISAT and their extensive use both by the public and private sector research organizations in hybrid development have been central to this success

The availability of commercially viable alternative cytoplasmic-nuclear male sterility (CMS) systems, with more stable male sterility and higher maintainer frequency provide opportunities for greater genetic and cytoplasmic diversification of male-sterile lines. This, of course, would also require greater efforts in breeding restorer lines of seed parents (A-lines) with these alternative CMS systems for which breeding methodologies have been developed and are now being applied. The breeding of such hybrid parents, in turn, would enable the development of higher yielding hybrids in diverse genetic backgrounds. Establishment and growth of a vibrant pearl millet seed industry has played a critical role in diversifying the cultivar base with a diverse range of productive hybrids. While pearl millet improvement for the relatively better endowed environments will continue to be of the highest priority, relatively greater emphasis than in the past is now being placed to develop parental lines and hybrids adapted to arid zone which still has unpredictable seed market, and there is not as well developed research infrastructure and germplasm base.

Breeding for resistance to downy mildew [*Sclerospora graminicola* (Sacc. Schroet.] has been an integral part of pearl mille improvement in India. Diversified parental lines with downy mildew (DM) resistance have kept at bay the periodic DM epidemics witnessed in 1960s and 1970s. Recently, leaf blast (*Pyricularia* *grisea* (Cooke) Sacc.) has emerged as serious a problem as DM in India. Pathogenic variability for this disease has been characterized, effective screening techniques have been developed, resistance sources have been identified, and resistance breeding has been initiated. There are other diseases of sporadic occurrence and minor importance for which screening techniques have been developed and resistance sources have been identified, but no substantial resistance breeding efforts have been made. In the African regions, major emphasis has been on OPV development. Considering the limited gains from OPV development, hybrid breeding work has now been initiated for Africa also. Hybrid cultivars in these regions will face the same biotic problems of DM and blast as in India. Further, there are greater problems of Striga and insect-pests such as head miner (*Heliocheilus albipunctella* de Joannis) and stem borer (*Coniesta ignefusalis* Hampson), which will pose greater challenges in pest resistant hybrid development as it has been in case of pest resistant OPV development, especially in the Western and Central African region.

Climate change and associated problems of rising temperatures, water shortages, recurrent droughts, and soil salinity are increasingly becoming more serious problems to agricultural production. Pearl millet is especially endowed with climate-change resilient attributes. For instance, among the major cereals, it is most drought tolerant, and also most salinity tolerant, next only to barley. It is also most tolerant to high air temperatures. Pearl millet is grown as a summer season crop in parts of Gujarat, Rajasthan and Uttar Pradesh states of India where air temperatures during flowering often exceed 42°C. Majority of the hybrids have very poor seed set under such environments. However, some hybrids with excellent seed set have been identified and become commercial. These give 4-5 t/ha grain yield under high management conditions as compared to the national average of just about a ton under rainfed conditions in the normal rainy season. Genetic variability for reproductive-stage heat tolerance in germplasm, and in improved populations and elite breeding lines has been identified, paving the way for heat tolerance breeding. These materials have potential uses in breeding heat tolerant cultivars in other parts of the world facing similar environmental challenges. Genetic variability for tolerance to salinity and terminal drought that has the most detrimental effect on grain yield has also been identified. No efforts so far have been made in breeding for salinity tolerance. Conventional breeding efforts in breeding for terminal drought tolerance have met with little success. Taking a recourse to biotechnological intervention, QTL for panicle harvest index, a measure of terminal drought tolerance, have been identified. These need to be validated for their effects in different genetic backgrounds and in the target drought-prone environments to set the stage for their systematic deployment in the parental lines of hybrids. Revolution in genomics technology may further accelerate the process of identification of the genomic regions associated with terminal drought tolerance and their cost-effective and rapid deployment.

Pearl millet has higher protein content than other major crops with more balanced amino acid profile and high protein efficiency ratio. Its gluten-free protein has therapeutic effect for those prone to gluten allergy and celiac disease. It also has high dietary fibre. Thus, foods prepared from pearl millet have low glycemic index, and are suitable to those suffering from or prone to diabetes. Phytochemicals found in pearl millet, though act as anti-nutritional factors, have anti-oxidant properties. Pearl millet also has high levels of several minerals. Of the greatest interest of these are the iron (Fe) and zinc (Zn) contents, for which widespread deficiencies with numerous adverse health effects have been found worldwide, especially in populations of the developing countries heavily dependent of cereal-based diets. ICRISAT, supported by the HarvestPlus Challenge Program of the CGIAR and in partnerships with the public and private sector research organizations, has initiated a major effort to help develop pearl millet cultivars with high levels of these micronutrients. Large variability for Fe and Zn content has been shown in commercial cultivars; in improved breeding lines, populations and hybrid parents; and in the germplasm. Cost-effective and rapid screening techniques have been identified to enhance the breeding efficiency.

Results of several multi-environment trials have shown that Fe and Zn contents are highly significantly and positively correlated, indicating that simultaneous genetic improvement of both micronutrients is likely to be highly effective. The association of these two micronutrients with grain size has been found either non-significant or positive, indicating that Fe and Zn content can be improved without compromising on grain size. Association of Fe an Zn content with grain yield has generally been found negative, but mostly low and not always significant, indicating that high grain yield can be combined with high levels of Fe and Zn density through selection in large segregating populations. This was exemplified with intra-population improvement for Fe content in a high-Fe commercial variety ICTP 8203 that has 65 ppm Fe and 39 ppm Zn content. In 42 field trials conducted during 2010 and 2011, its improved version, designated as ICTP 8203 Fe 10-2, had 9% higher Fe content and 11% higher grain yield with no changes in other traits. This improved high-Fe version variety was quickly adopted reaching 25,000 farmers in 2012. Subsequently in 2013, ICTP 8203 Fe 10-2 was released as Dhanshakti in Maharashtra state of India. Similar selection procedure applied to another commercial pearl millet variety (ICMV 221) has shown in a preliminary trial that the Fe and Zn contents increased by 22% and 16%, respectively, without any changes in agronomic traits. By using the existing hybrid parents identified for high Fe and Zn content, although initially not bred for these micronutrients as target traits, experimental hybrids have been developed which have Fe content similar to that of ICTP 8203, but have more than 30% higher grain yield. It is envisaged that by breeding parental lines with higher Fe and Zn contents as target traits, hybrids with grain yield similar to other hybrids in the market but Fe and Zn contents as high as and higher than ICTP 8203 can be produced.

Studies in India and Benin have shown that total iron and zinc absorbed from biofortified pearl millet variety with high levels of these micronutrients were higher than those from the non-biofortified variety, implying the significant contribution that biofortification can make in addressing their deficiencies in the population consuming this nutritious cereal. For instance, consumption of 200 g of Dhanshakti can meet 82% of the Recommended Daily Allowance (RDA) of Fe in adult men and 66% of the RDA in non-pregnant and non-lactating women in India. It can also meet 65% of the RDA of Zn both in men and women. The above RDAs are based on the assumption of 5% bioavailability for Fe and 25% bioavailability for Zn content. Recent pearl millet studies have shown that Fe bioavailability may be 7.0-7.5%, which would essentially lower the RDA.

Development of improved crop cultivars is just one major component of technological interventions to enhance food and nutritional security. Improved crop management technologies with potential to substantially increase pearl millet grain yield have been developed. Some of the agronomic interventions will also have significant effects on improving nutritional quality. Laboratory tested processing technologies and alternative food products have been developed, which have been shown to further enhance the bioavailability of these micronutrients. These technologies need to be tested for their commercial feasibility. Thus, an integrated approach of crop improvement backed with improved crop management, grain processing, and food products development; and appropriate policy support, will be required to enable pearl millet play its rightful role in enhancing food and nutritional security.