

Plant Breeding: A Prospect in Developing World

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Abstract

Plant breeding is a vital agriculture industry that needs to be fostered and stimulated. It is an important discipline to ensure food security by developing varieties that cope with the environmental stresses and contribute towards sustainable development of agriculture. Technology amalgamation in this area can act like an incubator for scalable production of quality produce for a wider economic expansion. Developing countries with larger population have a greater responsibility to feed their present and future generation but their poor infrastructure, inadequate resources, and insufficient research and extension services question the sustainability of their plant breeding capacity. Understanding the existing challenges of plant breeding can help stakeholders as well as national and international organizations to stimulate a favorable ecosystem to develop self-resilience, less vulnerable and sustainable plant breeding industry to feed the need of the growing population across the world.

Keywords: *Plant Breeding; Developing World; Mutagenesis; Hybridization*

Introduction

In the face of growing population and uncertain climatic conditions, significant additional food required by 2050 could be a big challenge [1]. It is needed to increase agriculture output through crop improvement and crop management. Since, there is no straightforward recipe of crop improvement for a particular crop in a specific country; only important thing to consider is adoptability, uncertainty, vulnerability and resilience while developing a variety. Lot of research has been done in the area of crop improvement since last two decades which supports the fact that technology penetration is essential to make plant breeding more progressive by constant innovation for the development of environment specific improved crop varieties to increase overall productivity. The use of technologies like tissue culture (i.e. micro propagation), mutagenesis, interspecific or intergeneric hybridization, genetic modification, marker-assisted selection (MAS), disease diagnostics and bio-protection for crop improvement has been increasing continuously. Strengthening plant breeding status in developing world can be possible when all basic measures work effectively. For example, if seed supply, bank loans, transport links, market regulation and their combined effect are not in place, it can negate even the impact of most impressive technology [2,3]. It is the right time to realize the critical need of a specific country and fulfill the requisite for a continual development of crop improvement. This review is an attempt to understand the current status of plant breeding in developing countries with a focus on all possible challenges which hamper sustainable development of plant breeding and potential solution to accelerate the breeding efficiency.

Importance of Plant Breeding

Plant breeding, synonyms of 'crop improvement', is a discipline of agriculture where deliberate efforts are made by human to manipulate plant attributes, structure and composition to make them more useful for human consumption. However, manipulations of each trait are not possible hence use of technology enables plant breeder to achieve the target of intentional changes in the nature of plants and accomplish astonishing manipulation. Plant breeders aim to make crop producer's job easier by modifying plant structure for mechanical harvesting, developing resistance against pest and diseases, and improving quality and yield to meet consumer demand and other desirable changes. Before starting a breeding program, a breeder needs to understand and define a specific objective based on producer's

choice, consumer's preferences and environmental impact. Societal need is changing and so is the use of technology to meet different objectives of breeding in the areas, including food, feed, fuel, pharmaceuticals, cosmetics, and nutrition. These evolving objectives of breeding can be achieved by using sophisticated genetic tools in a more precise and effective manner. Now breeders are well equipped to undertake more dynamic alteration which were impossible to attain in past by using classical breeding approach [4].

Current Status of Plant Breeding

Plant breeding is considered as a backbone of agriculture. It is continuous evolving area encompassing basic and strategic research. Several biotechnological tools of agronomical benefits are well integrated with plant breeding programs for the creation of genetic variation, selection of favorable variants and production and management of crops. By using mutagenesis approach, more than 2700 varieties have been developed mainly from developing world in the last six decades [5,6]. Tilling, another updated version of mutation breeding [7,8] together with high-throughput robotic screening bring revolution especially for crops with large and complex genome [9].

Various useful traits have been integrated from one species to another by using interspecific hybridization, e.g. disease resistant Asian rice and new rice for Africa. However, this is very time consuming and requires significant scientific expertise and skilled labor, and thus has low popularity among breeders. Chromosome engineering technique can be a great enabler to improve wide hybridization [10-12].

Use of MAS is an effective screening method with potential to revolutionize plant breeding status in developing countries [13-16]. It is also used to uncover genetic basis of complex traits like drought/salt tolerance and pest/disease resistance [17-19] and facilitates early stage screening, scale screening, genetic resources characterization, plant gene bank management, disease diagnosis and hence save time, labor and reduce overall cost of developing elite lines [20]. However, use of MAS in developing countries is still in an early stage for key subsistence crop due to high cost of operation and technical sophistication [21].

Micro-propagation and somatic embryogenesis is widely common for mass clonal propagation of elite lines or disease-free planting material in a range of subsistence crops including banana, sugarcane, cassava, sweet potato, ornamental crops, ginger, coffee, grapes and many more for easy facilitation of healthy planting material at reasonable costs [22-24]. This technology is often used by farmers to increase their yield and income by setting up micro-enterprises specialized in commercial production of disease free plantlets [25].

DNA based methods are used for the diagnosis of several vital plant diseases for which identification of causal agent is difficult. Along with this, immunodiagnostic techniques including enzyme-linked immunosorbent assay (ELISA) and monoclonal antibodies are also commercially applied in many developing countries [26].

Use of transgenic plants that express novel and useful trait in agriculture is also popular in developing countries (e.g. Bt cotton, Bt brinjal). Tissue culture technique has been a great enabler for transgenesis. Limitation for wider adoption of transgenesis is complex regulatory system for release of transgenic crop and uncertain public response [27,28].

Uses of bio-pesticides and bio-fertilizer as alternatives to chemical pesticides and nutritional supplement are commonly used in developing countries (e.g. Bt powder, *pseudomonas*, myco-pesticides).

Several other practices like cryopreservation, artificial seed production, somatic embryogenesis, and other forms of *in vitro* cell or tissue culture are also extensively used in developing countries for the crop improvement and conservation of genetic resources.

Current challenges that hamper the development of plant breeding

Proper assessment of plant breeding capacities at national level provide baseline information to different stakeholders to analyze various strength and weakness of their ecosystem, understand the complementarities and formulate long-term strategies to improve breeding capacity. A discussion of challenges and common constrains observed in developing countries follows.

- 1. Unequal distribution of resources:** Development of plant breeding is restricted by patchy resource availability. Agriculture research related activities are mostly carried out by private industries which at one side restrict the access to proprietary technologies and on the other side limit the possibility for the expansion of spillover research [29]. While other organizations which are not resourceful are unable to perform appropriate research activities.
- 2. Poor farmers:** Farmers in developing countries often have poor purchasing power to access proprietary technology. Therefore, technologies introduced by developed or developing country have a limited impact on farmer's livelihood. Sometime, useful technology or beneficial product to farmers had limited or no adoption due to poor infrastructure, awareness and poor training provisions. A solution to this problem is to have farmer participatory research coupled with wide range of extension service to the seed industries.
- 3. Unqualified and untrained breeders:** It is a threatening challenge for developing countries to have poor standard of education and training that could result in a critical shortage of skilled breeders. The number of students entering universities to be trained as plant breeders is declining continuously and those who complete their studies do not possess the level of quality required by the seed industries. This is due to the lack of motivation among students and teachers, lack of appropriate infrastructure and untrained teachers. Whole system need to be changed otherwise breeding industry will soon face a critical stage of survival.
- 4. Molecular breeding status:** Lack of appropriate infrastructure, inadequate operational support, lack of enabling policies, statutory and regulatory framework at country level are the key factors that hamper the prosperous growth of molecular breeding in developing countries.
- 5. Plant variety protection (PVP):** PVP helps seed industries to stabilize and protect companies from their competitors. However, very few developing countries have any experience with plant variety protection. This is because most companies are in mediocre range and hence may not feel worth to take the advantage of PVP.
- 6. Poor legal framework:** Lack of legal framework of bio-safety is a biggest limitation in developing world as it hampers trans-boundary movement of transgenic produce, delayed field testing and increase gene dissemination to farmer's field. Strengthening measure should be taken to regulate the trade of transgenic biotechnological product to ensure food security and maintain a healthy competitiveness in the international market.
- 7. Poor technology transfer:** Due to lack of collaborative approaches, resources, technologies and skill relevant for plant breeding are either held by the private companies or scarcely available to other organization. Also, poor regulatory framework restricts the movement of technology across the organizations.
- 8. Poor implementation of policies:** Usually policies are made appropriately but implemented poorly due to high level of corruption, short term gain, low motivation or inappropriate channeling in most of the developing countries, which undermines the success of plant breeding. An inclusive approach is required in decision making for proper resource allocation towards strengthening breeding status in the country.
- 9. High cost associated with technology:** Frequent application of technology is restrained in developing countries due to its association with high cost and skill labor. For example, use of molecular markers is apparent but the application of low-cost genetic marker could definitely improve and accelerate the efficiency of breeding programs in developing countries.
- 10. Poor plant disease management:** Due to poor disease management, around 14% of crop produce goes into waste annually. Poor understanding of disease symptoms, causal mechanism, methods to manage diseases, interaction of pathogen with environment and host, could leads to drastic depletion of quality and quantity of plant produce. Hence, serious considerable is required to improve the same.

These highlighted lists of challenges are just few examples which are responsible to limit the flourishing of plant breeding. However, several other parameters include poor characterization of germplasm, uncontrolled depletion of available germplasm, high socio-economic complexity involved in breeding activities, insufficient utilization of *in vitro* regeneration system, poor regulatory system for varietal release and commercialization are some of examples which are equally responsible to challenge the growth of breeding in developing countries.

Possible solution that can help to accelerate the breeding efficiency

Increasing understanding of ecosystem that favors plant breeding development could offer a promise to produce resilient varieties for enhanced plant breeding capacity. Some of the main applications and approaches are discussed below:

- 1. Policy improvement and effective implementation:** Countries should independently take their decision about adoption of technology and carry their risk and benefit analysis, involve relevant stakeholder in decision making and set the priorities for research activities with reference to farmer's need. Resourceful public organization should communicate effectively with society and create awareness about crop improvement/management and technology penetration and address farmer's interest that should reflect appropriateness and socio-economic impact.
- 2. Effective collaboration:** Mutually valuable partnership between different organization for sharing resources and knowledge can anticipate a brighter future of plant breeding across the globe. Although, several collaborative projects are running around the world, more rigorous efforts are required in this direction to identify the current need of breeding and develop appropriate tool to facilitate trait integration into elite varieties more efficiently. For example: effective collaboration between GOBII (Genomics and Open-Source Breeding Informatics Initiative) and Hutton Institute developed a potent molecular breeding tool 'Flapjack' which helps breeders to select the best possible parental line and perform marker-assisted backcrossing. This tool helps breeders to save 1 - 2 years to develop a new variety which can be a great accelerator for the breeding programs. Another form of collaboration can be 'professional trainings' for effective means of knowledge transfer and strengthening ecosystem for a sustainable development. Equitable partnerships between foreign and local institutions can help to acquire know-how and help to strengthen breeding status. International collaboration can be useful only when legislation system which is required to regulate activities, i.e. transfer to genetic material (i.e. plant/animal) is in place. Developing countries need assistance to develop appropriate regulatory bodies for bio-safety and legislation in agreement with evolving international policy.
- 3. Data management centre:** Data managing and developing useful information from that data is a cumbersome process. Several resourceful organizations which are rich in data management system with appropriate availability of analysis tools can support other breeders or small organization to make an impact on their crop improvement programs. These analyzed set of data can help breeders to manage their programs more effectively and efficiently to make better decision of selection and hence potentially reduce the labor and land cost required to test the lines. Though such concept exists only in terms of collaboration, open availability of such service can create a new dimension of development of plant breeding. Organizations like ICRISAT in India, IRRI in Philippine, CIMMYT in Mexico can be a pioneer organization to initiate such activities as they are resourceful, reasonable and reliable organizations.
- 4. Education and training of plant breeders:** It is very important that breeders should be well equipped with education as well as training. Education that create a conceptual framework to analyze the situation and make appropriate decision when confronted by changing circumstance ex. new crop, new disease, lack of genetic variation. While training is a hands-on practical learning that helps to focus on a particular problem [30]. In a few countries like India, China, S. Africa, education is reasonably good but their training has many shortcomings. While list of countries are long where both are in miserable condition. Capacity building to achieve these ends is considered as high priority area.
- 5. Transfer the technological product:** This kind of transboundary technology transfer is cost-effective and allows developing countries to bypass the risky and costly laboratory stages of research. Development of resistant varieties against nematode, herbicide, and bollworm can help to tackle common challenges across the world. For example, developing valuable transgenic variety into locally adopted variety by using transgenic cassette and transformation protocol developed in other country can be an effective method to accelerate the development of agriculture. Through this way, breeders can develop technological robust product to withstand the operational challenges and increase the farmer's income.
- 6. Broaden application of technology:** Technology like *in vitro* regeneration is widely used for propagation of virus free stock from elite material but still work is required to develop effective protocol for several other plant species which are recalcitrant. Application of micro-propagation techniques for *in vitro* conservation of germplasm is very low. So far, only whole plant conservation is the

main attention. However, both means of conservation: whole plant and *in vitro* can increase the existing plant collection. Another example of widening application of technology is by improving nitrogen-fixation efficiency of leguminous and non-leguminous crop. Since plant Rhizobium symbiosis is a complex association between two organisms that influence the environment of soil micro-flora. High-throughput genomic research will help to understand the genetic basis of nitrogen fixation capability in legume symbionts and help to develop crops that can enhance nitrogen use efficiency. To create more examples like these, more research efforts are required to broaden the application and acceptance of technology.

7. **Public-Private-Partnership (PPPs):** It is an effective way to strengthen overall capacity of plant breeding. PPP is an equitable mechanism that should be applicable where possible to share the technology, skill and knowledge with each other by effective collaboration. For example, PPPs have developed cheaper and easier MAS breeding system [31]. Partnership between public and private sector or between developed and developing countries can be very promising to achieve the potential benefit of technology to foster plant breeding [32,33].
8. **Broad genetic basis of crop production:** From all the available plant species (around 7000), only four crops: rice, wheat, maize and potatoes provide more than 60 percent of human food energy while remaining crops are not much domesticated. The harness of new species by advance breeding technique is a potential prospect for broadening the genetic base of crop production and extending the food basket of agricultural products for human consumption. Manipulation of complex trait can have direct impact on domestication of new crops and help to accelerate the breeding programs by improving agronomic performance and enable the faster and reliable seed production/multiplication for dissemination to growers [15,34,35].
9. **Investment in research and development:** Built up a regional unit, maintain an advisory capacity to perform the assessment and adopt the technology in plant breeding by assuring adequate, consistent, stable investment for regular research and development of plant breeding.
10. **Uptake and acceptance of technology:** Any technology which is well established or presented in miniscule or merely a concept can be exploited when complemented by cross-sectoral measure to ensure efficient uptake by all kind of farmers and used practically in well-regulated manner both locally and globally. Participatory research approach is also an effective means to introduce technology at community level. Connecting high-tech scientist with the most subsistence farmers is participatory plant breeding approaches which help to accelerate the breeding efficiency in developing world. Uptake of improved varieties or technology by smallholder farmers depends not only on the performance of variety but also on their easy accessibility, adequate infrastructure to grow, appropriate extension capacities and involvement of all relevant stakeholders. Stronger extension service linked with participatory crop improvement programs should be well integrated with research activities for wider acceptance of technology by the farming community.
11. **More start-up seed companies:** Start-up national seed companies engage not only local talent pool but also give more focus to improve local commodities. Future development of crop improvement in most developing countries depends upon success of start-up seed companies and their long-term commitment to meet the need of local community.
12. **Robust legal framework:** Overall development of seed sector in developing countries depends not only on quality of produce but also upon other enabling environment that regulate growth of agribusiness. Countries that use technology or work on transgene will need to ensure proper protection through right combination of seed laws, PVP, biosafety regulation especially at the early stage of varieties.
13. **Effective disease management:** Disease management has played its role in doubling food production in the last 40 years: however, increasing awareness for environment and human health, effective disease management is turning into more complex area than before. Though integrated disease management that combines biological, cultural, physical and chemical work holistically to control pest, people are more inclined to use chemicals as a cheap alternative to have quick relief against pest. Now, responsibility is increasing to develop new innovation in diagnostic kits for early and precise diagnosis, discover new mode of chemicals with low environmental impact, find effective biological control with reliable and persistent activity and develop varieties with durable disease resistance. Successful implementation of appropriate strategies for disease management can be achieved at a broader scale by positioning enabling policies at national level for agriculture production and protection [36].

Conclusion

Developing countries are improving with their capacity for the deployment of technology in plant breeding but yet not mature and self-sustainable. More attention is needed in the direction of capacity building that includes policy development, strengthening institutional status, adequate and continual availability of funding, strong research and extension activities, capacity building for researchers and technicians, establishment of cross-sectoral regulatory measures across the boundaries to create a new dimension of plant breeding to enhance food security and improve living standard.

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