EDITORIAL COLUMN

Molecular Breeding for Mitigation of Abiotic Stress in Projected Climate Change Scenario: Potentials and Limitations for Developing and Underdeveloped Countries

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1. Introduction

If we look at the tasks to be accomplished by the farmers for survival of the mankind in the near future, a baffling situation arises. FAO projects that the global population is going to be over 9 billion by 2050, which needs at least 70% increase in crop productivity over the current scale (Alexandratos, 2006). Thus farmers have to produce almost 1½ of the current output. The projections for availability of cultivable land with good soil health and usable irrigation water are equally horrifying; both are decreasing steadily at an alarming rate. Several status reports have been published on effects of climate change on crop productivity and most of them project a shortfall of production in the future climatic conditions (Lobell et al., 2008; GOS, 2011). Moreover, predictions indicate that the difference between the rich and poor is going to increase in the near future, particularly in developing and underdeveloped countries. So, farmers, being on the poorer side of the scale, have to produce more food, fiber and fodder with less available land, irrigation and monetary input. To add to it, the methods for increasing crop production have to be sustainable, which needs use of more and more green technologies. Presently, many agricultural production technologies are unsustainable, such as indiscriminate use of nitrogenous fertilizers and pesticides. The major hindrance to crop productivity in the near future will be abiotic stresses, which are emerging as a dominant restraining factor for crop production. A lot of predictive researches are currently being carried out at national and international level to study the impact of abiotic stresses on crop loss in the near future and possible means to reduce the stress situations.

The situation worsens for developing and underdeveloped countries. The annual budget allocations of Governments and income capabilities of these countries are much lower compared to that of rich countries. Most of the annual incomes of the Government are spent to fulfill the basic needs of the people, such as food, education and health. Consequently, they have less investment capacities to initiate researches for generating solutions for these problems. Therefore, critical planning and research prioritization are very essential for getting better outputs. The researches thus have to be problem-oriented, economizing on research input side while increasing the probability of generating effective recommendations. Seemingly impossible, there is no other alternative for survival and maintaining integrity.

2. Abiotic Stresses and the Changing Climate

The abiotic stresses are generally classified into drought, salt, heat and cold stresses. While impact and magnitude of all these stresses are high in different regions of world, new abiotic stresses are coming up that deserve equal attention, such as stress from environmental pollution or soil erosion. A report on Western and Central Africa states that about 50% of the cultivated lands in this vast region face problem of soil erosion. Some more abiotic stresses that have capability to cause sporadic damage are acidification of soils and heavy metal stress, particularly where nutrient depletion is high; excessive use of ground water for irrigation; or industrial waste waters used as source of irrigation. With the global warming effects, temperature is obviously going to be the principal abiotic stress, which will aggravate other stresses including drought and dehydration stresses.

Researches have been directed in Vibha Seeds, Hyderabad, India in developing simple, novel techniques in evaluation and selection of several field crops and vegetable crop species, viz. cotton, sunflower, maize, etc. for tolerance to drought, salinity, flood, heat stress. Cultivars selected in laboratory and polyhouse for drought and salinity showed good field resistance demonstrating transfer of technology from Lab-to-Land. Further research is needed to study molecular basis of resistance which is a challenging job to the biotechnologists.

2.1. Crop loss due to abiotic stress

It seems pertinent to obtain an assessment of crop loss caused by abiotic stresses. It is difficult to obtain a holistic view of such estimates, as the degree and nature of the stress is crop-specific, and often multiple stresses operate on the same crop during a particular period. Although such estimation suffers from generalization of complex parameters, these help us to obtain a glimpse of the tip of the iceberg. A study showed that during 1981-2002 the global loss in wheat, maize and barley due to increased temperature alone exceeds US$ 5 billion year^{-1} (Lobell and Fields, 2007). Similarly, an estimate by United States Department of Agriculture (USDA) shows that due to rise in temperature and fall in water table, the loss in global grain production in the year 2002 alone was 83 mt. In the preceding year, temperature raised to a record high for the past 134 years, lowering the wheat, maize and rice production in almost all the countries. Record crop yield loss was also observed in Europe in 2003 due to a summer heat wave. A projection map based on heat stress based modeling of crop yield loss estimates that in the years 2071-2100, a large proportion of rice cultivation in Eurasia, Eastern China and North America will face massive heat stress resulting in more than 30% yield loss. The projection statement by Lobell et al. (2008) also shows that there will be a reduction of productivity of major crops in South Asia to the tune of 5-15% by 2030 due to increased temperature. Putting together these collages, a dismal picture of effect of abiotic stress on crop failure and productivity loss is unveiled which needs immediate attention. An assessment by UK Government predicts that growth rates of crop productivity will increase slightly over the next 10-15 years and then decline gradually to 2050.

2.2. Increased yield of cereal crops?

A predictive outlook by Intergovernmental Panel on Climate Change (IPCC) estimates that changed adaptation of cereal crops will actually boost the agricultural production, particularly for wheat, maize and rice. In fact, research works have shown that an increase in CO_2 concentration in absence of temperature rise is expected to increase productivity of rice (Krishnan et al., 2007). However, if the temperature rise is near 1^{o}C, the situation reverses, particularly in the tropical climates (Ahmed et al., 2010). Lobell et al. (2008) also predicted increased yield of some specific crops in certain regions, such as sugarcane in Central America and Caribbean, but a major decline would be observed for other major crop production in most of the regions. Based on the productivity ceiling of crop plants Ainsworth and Ort (2010) doubted the yield enhancement and suggested that productivity ceiling and changed climatic pattern would obviously lower down crop yield in the future. Several predictions suggest that tropical regions will be more affected due to rise in temperature and loss of usable water for agriculture.

2.3. Adaptation of new crops/agricultural practices/food habits

With the change in the climatic pattern in the near future, the adaptations of different crops are expected to change. This will result in several changes, such as change in the management practices for increasing crop productivity (such as water saving and harvesting technologies), shift in cultivation pattern (rice to be replaced by wheat and vice-versa), identification of new genotypes better suited to the changed climate (genotypes that survive better in unexpected climate or have tolerance to abiotic stresses), change in sowing and harvesting of crops, reduction of crop growth period, better survivability of C_4 crops such as maize and sugarcane under increased CO_2 concentration, etc. are going to be important determinants for shaping future agriculture. Projection shows that crops like sugarcane, barley and maize are expected to produce more in certain regions, while crops like rice and wheat are going to face more challenges in near future (Lobell et al., 2008).

3. Molecular Breeding−a Tested Technology

In holistic sense, molecular breeding is a collection of DNA research technologies for direct application to crop improvement. It includes molecular marker assisted phenotype mapping and selection, development and implementation of genomics and transgenic technology as well as transfer of transgenes to different genotypes through conventional breeding methods after integration of the gene in a recipient genotype. Some argue that in vitro breeding technologies are a part of molecular breeding, although it is doubtful whether somaclonal variation or anther culture can be included in this group. The scope and applications of molecular breeding are quite diverse, and a large number of tested technologies and products have been developed, evaluated in farmers' field and then adopted by the farmers. Two phenomenal examples are development of Bt-cotton hybrids and adoption of Bt-cotton technology by 95% of the cotton farmers of India, and utilization of marker assisted gene introgression in widely cultivated rice varieties for better resistance to pests and diseases.

3.1. Impact of DNA research technologies−pros and cons

A lot of debates are going on the release and cultivation of genetically modified (GM) crops, discussion of which is beyond the scope of this article. However, GM technology has entered in the area of politics and environmental concerns rather than science. Labeling GM technology thus as good or bad is difficult as lot of unforeseen potential and risks are involved in using this technology. On the one hand, no credible unsafe report has actually been published even after more than a decade of Bt-cotton technology. However, on the other hand anti-GM activities have gained stronghold which perceives unforeseen risks in commercial cultivation of GM crops. Leaving aside the debates, a lot of non-GM molecular breeding technologies have been generated for the benefit of crop improvement that are constantly being used by public and private research programs for development of improved varieties. Almost all the major public and private crop improvement programs now routinely use marker assisted selection for increasing efficiency of selection and reduction of time for developing new crops. In India, new rice varieties have been developed through MAS (marker assisted selection) and released having better resistance to diseases and insect pests (bacterial blight, blast and stem borer). However, not all the commercially successful technologies are beneficial and environment friendly. The use of polythene bags is a classic example. The polythene bags are cheap, user friendly, water resistant and thus are being indiscriminately used allover the world. But they are extremely resistant to biodegradation and within thirty years of introduction have become one of the key pollutants of the environment. Continuous use of roundup ready soybean (herbicide resistant transgenic soybean) and use of glyphosate as weedicide has led to shift of weed population towards glyphosate tolerant weed fauna. Three major glyphosate tolerant types of horseweed, waterhemp, and giant ragweed have been found to be infecting corn and soybean fields of Iowa in USA (Crop Biotech Update, 2011). Thus the potential risks of transgenic technologies have to be assessed to a certain level before using such technologies on a large-scale.

3.2. Economic impact of molecular breeding technologies

Although the volume of information on economic impact of molecular breeding technologies are less, the impact of transgenic technologies are quite clear from the rapid adoption of transgenic crops in countries which have allowed cultivation of transgenic crops. Today, the giants in the global agro-business industry are making a lot of profit from the transgenic varieties of crops like soybean, maize, cotton, canola and rice, which is a vivid statement of economic sustainability of the transgenic technology. Albeit, the costs involved in transgenic researches are high, the return has been proved to be higher.

Unlike transgenic technology, economic evaluation of MAS is difficult. The cost of MAS for a trait depends upon the nature of the trait, the target crop and the generation of population to be tested before obtaining the goal. Increment in any of these adds to the cost of the product development and vice-versa. However, in comparison to conventional breeding programs, MAS is cost effective in time and space. It has been shown that for certain objectives such as gene pyramiding, early detection of trait, low heritability of the trait and where phenotypic detection requires more time or more space, MAS are more cost effective than conventional breeding programs (William et al., 2007).

4. Prioritization of Research Needs and Areas

In the developing and underdeveloped countries, research targets are of critical concern as the research investment capabilities are less compared to developed countries. While international organizations are identifying and supporting key research priorities and extending help, such as International Crop Research Institutes and welfare foundations, a country has to prioritize its research inputs for optimizing realized outputs that will benefit farming community. Molecular breeding tools are very handy in solving specific problems that are not achievable through conventional approaches. Prioritization of research needs is more important in using these tools as it requires initial high input to develop such a tool. The example of Bt-cotton is worthwhile to consider, it has brought tremendous success in increasing global cotton productivity, particularly in India. However, a major portion of the cotton productivity improvement is due to development of cotton hybrids that are suited to different cotton growing zones of North and South India. Introduction of *cry* genes in cotton pure-lines would not have increased cotton productivity drastically, because Bt-technology is for protection of crops against pests and has no inherent productivity enhancement mechanism. Combination of *cry* genes with hybrid cotton technology has brought the record success of cotton production in India, which is a clear example of mutualism of conventional breeding and molecular breeding technologies.

There is no doubt that research inputs for agriculture has to be increased for finding solutions to the increasing problems associated with crop production in the developing countries. Assessing the gravity of the situation, Comprehensive Africa Agricultural Development Program (CAADP) has pledged the African countries to devote 10% of national budgets to agricultural development. Similarly, countries like Brazil and China have increased their budgetary allocations for agricultural researches. In many of the countries, researches on climate change and development of molecular technologies for solving agricultural problems have been set as priority (GOS, 2011).

5. Demand-driven Technology for Addressing Key Problems–Some Examples from Developing and Underdeveloped Countries

The transgenic research program has obtained success more in the private sectors rather than public sectors. Thus impact assessment of these technologies as demand-driven technology for a country or particular region is unjustifiable. Apart from USA and China, country-led transgenic research program have not been received commercial success to a moderate scale to date. Developing and poor countries have benefited more from non-transgenic technologies till date, such as marker assisted selection (MAS) and in vitro breeding technologies.

One of the prized crops of Central and South America is Cocoa bean (*Theobroma cacao*) which is the main source of multi-billion dollar chocolate industry worldwide. However, fungal diseases (witches broom and pod rot) have been so devastating that country like Brazil, a leading exporter of Cocoa bean, has become a net importer in recent decades. An international collaborative Cacao Breeding Program using MAS has been initiated by the countries of American continent for developing resistant cultivars. Within ten years, new materials have been developed having resistance to these diseases and field trials of MAS-bred varieties are in progress in countries like Brazil, Ecuador and Costa Rica. Similar works are also in progress in African countries like Ghana, Cameroon and Nigeria (Schnell et al., 2010).

Drought is an alarming threat to rice production under predicted climatic change. Jharkhand, a state of India, is drought-prone and receives little rainfall for rice cultivation. New drought tolerant rice varieties Ashoka 200F and Ashoka 228 have been developed in India using Participatory Plant Breeding Program and MAS in collaboration with International Rice Research Institute (IRRI), University of South Wales, and Birsa Agricultural University, India. Similarly, a breeding program for developing drought tolerant rice has been initiated in Thailand.

Bacterial blight is the principal disease of rice causing substantial damage worldwide. Molecular markers linked to several resistance genes have been identified, and new lines have been developed in IRRI. These resistant genotypes have been used in breeding program in several Asian countries for incorporating resistance to popular rice varieties. In India, rice varieties having resistance to bacterial blight disease have been developed through MAS and released for cultivation through varietal trials. Resistance genes have been incorporated in leading rice varieties Swarna and Pusa Basmati-1. Some more varieties with resistance to blast disease and water logging tolerance are in pipeline.

These examples are clear enough to establish the success of using MAS in crop breeding program. Similar works are going on worldwide for development of salt tolerant varieties of rice and wheat, drought tolerant genotypes of maize and sorghum, and incorporation of specific abiotic stress tolerance in major vegetable crops in Asian, African and South American countries.

6. Conclusion

Scientific solution of a problem requires research to obtain the goal. Being a multi-faceted activity the research on crop production is diverse and needs prioritization. Crop improvement is a crucial component for productivity enhancement and securing food supply. New technologies like molecular breeding are going to be helpful for increasing production of crops by delivering improved varieties in shorter time. However, initial investments for setting up molecular breeding programs are high and needs expertise. Research prioritization and identification of key problems in each crop are thus essential that would need molecular breeding as an essential component. Apart from the transgenic technologies, other molecular breeding technologies deliver rapid results, involve lower cost and at long run are more economic than conventional breeding programs. A strong molecular breeding network thus is essential for improvement of major target crops in developing and underdeveloped countries to sustain productivity and mitigate hunger in the future. However, a single technology is seldom sufficient to tackle a problem effectively and deliver a sustainable solution. Thus an armory of several technologies would be required for fighting hunger in the coming decades, in which molecular breeding is expected to play a key role. Some points are worthy consideration for developing policies and key strategies for crop improvement using molecular breeding technologies. These are as follows:

- Estimation of long term sustainability of current crops under changed climate and adopting cropping sequence that will fit better to the changed climate.
- Identification of key traits for sustaining the existing crops in cropping sequence and identifying possible sources for the traits. Traits that are difficult to detect by phenotypic screening should be given priority for MAS, while novel and high impact traits should be targeted for gene transfer.
- Use of combination of conventional and molecular breeding for rapid introgression of the traits into existing cultivated genotypes.
- Investment in research of new molecular technologies for higher return and sustainability in the future crop production.
- Developing partnership with developed countries and international institutions for enhancing technical knowledge base in molecular breeding.

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