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Biotechnology for Arid Land- Perspectives for the next Millennium

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Abstract: Thar region of Rajasthan, with its varied characteristics in culture, economies, the environment, governance and religion, is home to semi-urban and urban agriculture that seems to have originated in the Fertile Crescent of the homeland of the first farmers. Arid lands and deserts make up a large part of Rajasthan. Two-thirds of the state is desert or dry-lands. Half the state's population is found in these areas. Agriculture in several arid developing countries is linked to water availability and security. Vulnerability of agricultural and water resources, ecosystems, food production, utility goods, shelter and human health is high in regions with weak infrastructures. The containment of desertification in arid lands occurs in the ability to bioconvert their ecological disadvantages in to economic benefits coming from the cultivation of desert crops; development of saline agriculture and aquaculture and the rational use of water, wastewater and other water resources. Dry agriculture or the growth of salt-tolerant crops on land and of a variety of halophytic crops -grasses, shrubs and trees encountered in area is full of promise. Of economic importance in agriculture, halophytes are cultured for landscaping and use as fodder; as ornamentals; and for greening and landscaping arid soils. Against this background, the use of GM technology could make a beneficial impact through the use of improved seeds and disease-free high-quality plantlets to grow high-value commercial crops in low-rainfall areas. In addition, rural education could help promote the benefits of such technology in diversifying complementary agricultural practices such as fisheries, floriculture and growing medicinal plants.

Key words: Agricultural education · Drought · Genetic engineering · Productivity · Stress

INTRODUCTION

Agriculture in India has a long history dating back to ten thousand years. Today, India ranks second worldwide in farm output. Agriculture and allied sectors like forestry and logging accounted for 16.6% of the GDP in 2007, employed 52% of the total workforce [1] and despite a steady decline of its share in the GDP, is still the largest economic sector and plays a significant role in the overall socio-economic development of India. Around 40 years ago, green revolution in India leads to major boost in productivity with the introduction of dwarf varieties of wheat and rice. The introduction of these varieties led to a dramatic increase in the yields of the two crops. In the last 15 years the yields of rice and wheat have also plateaued out [2]. The productive agricultural a reas in the North, due to continuous rice-wheat cultivation are encountering serious problems of sub-soil water depletion, deficiency of micronutrients in the soil and increase in the use of pesticides, f ungicides and herbicides to control pests, pathogens and persistent weeds. Agricultural production is becoming more and more dependent on agrochemicals, thereby increasing input costs and causing significant damage to the environment and human health [2]. Farmers are at risk by exposure to agrochemicals and consumers due to residues of agrochemicals in the consumed food. While there is self-sufficiency in cereal grains at present, the yields and productivity of dryland crops, mostly grain legumes and oilseeds remain low and no major breakthroughs in productivity enhancement and yield stabilization have been achieved. Currently, India is importing both grain legumes and edible oils to meet internal demands. India's population is expected to reach approximately 1.5 billion by 2050. It is estimated that around 300 million (roughly 30%) of India's population is suffering from malnutrition [2]. Thus, in present scenario it is necessary to find or develop appropriate techniques for agriculture [3].

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A large fraction of the India is arid, characterized as too dry for conventional rain fed agriculture. Yet, millions of people live in such regions and if current trends in population increase continue, there will soon be millions more. These people must eat and produce their own food. Arid implies prolonged dryness and is used with respect to the climate itself and the land below it. In such regions the ability to produce agricultural crops is restricted. Usually on arid lands the potential evaporation of water from the land exceeds the rainfall. The word, "arid" does not adequately characterize the soils, however, for they may vary in many ways. Often they are alkaline or saline. Several degrees of dryness must be recognized. The first is where the dry climate is modified by seasonal rainy seasons. The arid regions of the world are often very extensive, but in the tropics it is common, even on a small island, to find arid regions not far from regions of abundant rainfall. The extreme arid region extends over about 0.32 million km^2 forming approx. 10% of the total geographic area of India. More than 60% of this area lies in the State of Rajasthan. Arid region of Rajasthan forms the eastern extremity of the great arid and semi-arid belt of the world. Owing to strong variations in climatic, physiographic, topographic and geological characteristics, the arid regions show a wide diversity of habitats. Thar Desert is home of several tribes and communities who have got a rich culture heritage and colorful traditions.

In such a region it might be possible to produce a wide range of annual crops during the short rainy season, enough to sustain animals and feed mankind, although few food or feed trees might be feasible without special techniques. The second situation is a year round aridity, sometimes modified by light or irregular rains, which might make production of crops impossible. The third situation is where water is brought in by wells, canals, or other means so that normal agriculture can exist, in spite of the aridity of the climate. For some time now there has been a discussion on the potential of biotechnology for development in arid regions. It is now well established that these technologies provide valuable tools for meeting a number of developmental challenges in different areas. In agriculture for instance, the high yielding varieties which have been extensively used since the mid-sixties and ushered in green revolution are not only reaching a plateau in terms of yields but are not sustainable given their heavy dependence on chemical fertilizers, pesticides and irrigation [4]. Moreover, they are not suited to stressed arid ecosystems. Biotechnology provides tools for addressing the yield growth in a more sustainable manner by developing low cost varieties based on use of biofertilizers and integrated pest management and hence are more appropriate for small and marginal farmers in arid regions of developing countries. Biotechnological tools can also be used to improve the nutritional content of food crops so as to address the problem of malnutrition in arid regions of countries.

The Convention on Biological Diversity (CBD) defined biotechnology as “any technology application that uses biological systems, living organisms, or derivatives there of, to make or modify products or processes for specific use.” In a broad sense, the definition covers many of the tools and techniques, which have been commonly used in agriculture and food production, processing and utilization. In a narrow sense, however, it encompasses DNA techniques, molecular biology and reproductive technological applications dealing primarily with gene splicing and recombination and genomics. Biotechnology is already underpinning the sustainable development of agriculture, forestry and fisheries, as well as the food and other primary product- related industries. It has tremendous potential for impacting global food security, human and animal health, environmental health and overall livelihood of mankind [5].

Arid Stressed Ecosystems and Biotechnology: Abiotic stresses represent the most limiting environmental factors affecting agricultural productivity in arid regions of Rajasthan. To overcome these limitations and to improve production, to feed the ever-increasing population, it is imperative to develop crop cultivars that are stress tolerant. When crop plants are subjected to environmental stress conditions, they fail to express their full genetic potential for production. The effect of stress depends on the developmental stage, genotype of plant species as well as duration and intensity of the stress. Generally, plants respond to these stresses under low or moderate levels, but when the stress levels exceed a certain critical level (which varies from crop to crop), the physiological mechanisms imparting tolerance to plants start breaking down causing ultimately plant death. Consequently, the abiotic stress factors cause a massive loss to the productivity of crop plants.

Classical plant breeding methods involving inter-specific or inter-generic hybridization and *in vitro* induced variation have been applied to improve the abiotic stress tolerance of various crop plants but without much success. The conventional breeding strategies are limited by the complexity of stress tolerance traits, low genetic variance of yield components under stress condition and lack of efficient selection criteria. It is important, therefore, to look for alternative strategies to develop stress tolerant crops. Recently, marker assisted selection of specific traits that are linked to yield, e.g. osmotic adjustment, membrane stability or physiological tolerance indices, has been recommended. However, QTL that are linked to tolerance at one stage in plant development can differ from those linked to tolerance at other stages. Furthermore, desirable QTLs can require extensive breeding to restore suitable traits along with the introgressed tolerance trait. The best alternative, therefore, is the direct introduction of genes by genetic engineering to incorporate tolerance traits in target crops.

Crop biotechnology, which broadly includes areas of development of transgenic crops, structural and functional genomics and marker-assisted breeding could provide us with the vital breakthroughs to achieve improvements in both quality and quantity in a sustainable manner. With the advent of techniques of genetic engineering in the early seventies, the natural barrier to gene exchange has been removed. Sequences from varied sources like bacteria, viruses and eukaryotic systems can be transferred to plants to develop transgenic crop varieties. Achievements, to date, in plant biotechnology have surpassed all previous expectations and with the development of high throughput instruments, the future is even more promising. There are two main applications of biotechnology to arid land crop production: as an aid to conventional breeding programmes and; its ability to transfer genes between different organisms.

Physiological or morphological traits are governed by genes carried on chromosomes. The ability to monitor the presence or absence of such genes in plants is a great aid to plant breeders. This is done through the use of molecular markers, characteristic DNA sequences or fragments that are closely linked to the gene or genes in question. Molecular biological methods allowing the monitoring of such markers in many independent individuals, for example those arising from a cross between two plant varieties. This is a great aid to the selection process.

The ability to transfer genes means that specific genes can be added to a crop variety in one step, avoiding all the back-crossing that is normally required, providing a major saving of time and effort. Furthermore, those genes that are added need not come from a species that is sexually compatible with the crop in question. Conventional breeding is, of course, limited to the introduction of genes from plants of the same species or very near relatives. By employing the science of genetic engineering, it is possible to bring into crop plant different genes from other plants or even bacteria, fungi or animals. Genes are, simplistically, made up of two parts: the coding region which determines what the gene product is and the promoter, a set of instructions specifying where, when and to what degree a gene is expressed. Coding regions and promoters from different genes can be spliced together in the laboratory to provide genes with new and useful properties (recombinant DNA). These foreign or recombinant genes can then be introduced back into crop plants through the techniques of plant genetic transformation. The introduced genes integrate into the plant genome and will be passed on to the offspring in the normal way. In this way it is possible to enhance existing characteristics and introduce new attributes into a crop.

Research over the past two decades has provided a better understanding of the molecular biology of stress responses in plants. Many genes and gene products have been identified which get induced upon exposure of plants to various abiotic stresses-drought, salinity, low and high temperature stress, etc. Consequently, biotechnological tools have been applied to transfer some of these useful genes implicated in stress tolerance to plants. In addition to these stress-induced proteins, genes encoding enzymes of the biosynthetic pathways of different osmolytes such as proline, glycine betaine, trehalose, sorbitol, pinitol, etc. have been cloned and exploited in improving abiotic stress-tolerance in plants through genetic engineering [6-8].

Under different abiotic stress conditions, a large number of genes show elevated transcript levels in plants. Up-regulation of these genes does not always confirm their role in stress tolerance. Changes in gene expression may be due to disruption of physiological and metabolic processes of the cell. However, precise physiological function of any such gene can be studied by its altered expression (overexpression or suppression) in transgenic plants. Indeed, transgenic approach has emerged as a valuable tool in determining or confirming the precise function of the stress-induced genes and to develop stress-tolerant transgenic crop plants. Normally, genes isolated under stress conditions are first tested in model species such as tobacco and *Arabidopsis* for their role in stress tolerance before transferring them to economically important crop species. A stress tolerant genetic model will be required to delineate if stress tolerance is affected most by form or function of genes or more by differences in the expression of common genes due either to transcriptional or post-transcriptional control [9]. Stress-induced genes and gene products that accumulate under abiotic stresses have been reviewed by various workers across world [8, 10-12].

Biotechnology and Sustainable Agriculture: The continuing increase in the world's population, coupled with the limitations in the world's supply of natural resources and widespread degeneration of the environment, presents a major challenge to agricultural scientists today. Biotechnology may be able to provide an alternative to technologies that have harmful effects on the environment. Further, it has the potential of enhancing production on a sustainable basis and, since it is flexible in its applications, can be adapted for both small-scale and large-scale operations [13].

Sustainable agriculture refers to the ability of a farm to produce food indefinitely, without causing severe or irreversible damage to ecosystem health. Two key issues are biophysical (the long-term effects of various practices on soil properties and processes essential for crop productivity) and socio-economic (the long-term ability of farmers to obtain inputs and manage resources such as labor). In India's pre-independence era (before the 1950s), agriculture was a system of harnessing nature for the sustenance of human beings, similar to the presently defined organic farming. Following independence, rapid population growth placed great pressure on these traditional farming systems; huge demands for food grains led to increased use of fertilizers and pesticides, which greatly boosted production. Unfortunately, these production increases have been accompanied by gradual and negative side effects; consequently, interest in sustainable agriculture is growing at both national and global levels.

Sustainable agriculture is indeed being pursued in India. However, this initiative is aimed largely at the export market, using intensive agriculture practices inappropriate for drylands, where land degradation, lack of local food security and limited employment opportunities are already a serious issue. Meanwhile, soil and climate conditions in India's drylands make them particularly well suited to sustainable agriculture.

Biotechnology has been contributing to sustainable agriculture through the following ways:

- Increased resistance against biotic stresses (insect pests and diseases);
- Increased resistance against abiotic stresses (drought, cold, flooding and;
- problem soils);
- Bioremediation of polluted soils and biodetectors for monitoring pollution;
- Increased productivity and quality;
- Enhanced nitrogen fixation and increased nutrient uptake and use efficiency;
- Improved technologies for generating biomass-derived energy;
- Generation of high nutrient levels in nutrient-deficient staple crops such as rice.

Biotechnology contributes to sustainable agriculture by reducing the dependence on agro-chemicals, particularly pesticides, through the deployment of genes conferring tolerance or resistance to biotic and abiotic stresses. Carefully selected genes from related or unrelated genetic resources are integrated in otherwise desirable genotypes. Systematic pyramiding of genes allows integration of desirable genes in one genotype for different traits, such as tolerance to stresses, productivity and nutritional quality. Technology, including new varieties and breeds, is an essential element of sustainable agriculture. However, it is not the only element of sustainable agriculture. Non-technological aspects such as governmental policy and will, institutional and infrastructural support, technology sharing and transfer mechanisms and peoples attitude and awareness are equally, if not more important, in providing the needed conditions for absorption and successful exploitation of the technology toward sustainable agriculture.

Biotechnology Education: Liberalization, globalization and privatization of the economy have created both new opportunities and challenges to Indian agriculture in arid regions. To meet the above challenges of the agriculture sector competent technical manpower is to be created in adequate quantity [14]. The public perception of the life sciences - including biotechnology - has in recent years drifted far from the reality. Bringing perception and reality closer together requires an open dialogue between science and society based upon a well thought-out educational policy and a better mutual understanding between scientists and media professionals. Agricultural education needs to be reoriented to cater to the needs of farming sector in terms of continuous upgradation of syllabi, introduction of need based courses in collaboration with public and private sector and introduction of innovative teaching methods.

Agricultural biotechnologies are expected to meet the needs of resource poor farmers provided the 'code' of research addresses their needs. Several national and international programmes are working towards harnessing the potential of biotechnology in agriculture. However, in the course of knowledge production and dissemination there exists a gap between developed and developing countries. Within developing countries also the nature and code of biotechnology development raises issues with regard to meeting the needs of resource poor farmers. Thus, the socio technical context (code) of research assumes greater significance in (re) designing the new paradigms in research. The problems of civil societies must be addressed through biotechnologies. However, institutionalization of this theme is still in its infancy. Liberal donor and humanitarian agencies working for the development of poor have to come forward for supporting this kind of research till the message percolates into mainstream research institutions.

CONCLUSIONS

Arid regions of India hold enormous potential for production of crops. However, in most species the yields are far below the world average. Enhancement in productivity levels is not only necessary because land is a finite resource but also to remain cost competitive in the global market. Along with productivity, it is also imperative to improve the quality of the produce. Development of crop cultivars tolerant to abiotic stresses is an important goal of national and international institutions engaged in plant research in arid regions. Both traditional plant breeding methods and transgenic technology are being employed to achieve the above objective. Since conventional breeding approaches were not found sufficient, scientists are now trying to explore the advantages of the transgenic technology to develop transgenic crops tolerant to abiotic stresses viz. drought, salinity, cold and high temperature, etc. Although numerous studies have demonstrated the feasibility of developing such transgenics in an array of crop species, substantial data are lacking on the response of these transgenics subjected to field stress conditions.

Abiotic stress tolerance is a complex trait that is controlled by multiple genes. Studies in early 1990s demonstrated that a battery of genes get up-regulated in plants that are exposed to drought or salinity stress. However, function of majority of these stress-induced genes/gene products remained largely unknown. With the advent of high throughput sequencing of genes (genomics) and proteomics, more and more ESTs/cDNA/genes or proteins are being added to the list by the global effort with little information on elucidation of their function or the mechanism of stress tolerance in plants. Genome wide approaches coupled with reverse genetics approach will surely allow deciphering the role of specific gene / gene combinations in stress tolerance. Undoubtedly, studies on stress signal perception and transduction have identified genes that play a significant role in controlling the expression of stress-induced genes. As a result, transgenic development with genes encoding transcription factors and/or protein kinases have provided tolerance to multiple stresses to significantly high levels and has increased the hope of generating transgenic crops cultivars with improved stress tolerance.

Agricultural biotechnologies have to meet the needs of resource poor farmers. Bringing perception and reality closer together requires an open dialogue between biotechnology and farmer society based upon a well thought-out educational policy and a better mutual understanding between scientists and farmers. This will not only enable the Indian farmers to compete with the imported products more effectively but also gear them to sell their produce in the international market.

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