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A Review

Achievements of agricultural biotechnology: An initiative to double the farmer's income through cutting edge technology

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The population of the world is increasing nearly exponentially over time. To feed this population following the environment conservation protocol, it is essential to enhance the agricultural productivity even in the synchronizing agrarian land use pattern. To enhance the quality and productivity in agriculture sector, introducing the cutting edge technology is need of the hour.From ancient times, traditional approaches like selective breeding, adoption of agronomic management practices and application of indigenous technical knowledge have been used to attain resilience against various abiotic and biotic stresses. However, these traditional approaches are not sufficient to tackle the increasing repercussions of climate change and feed quality food to the expanding population. Therefore, in order to address these issues of climate change, population explosion and malnutrition, biotechnological interventions can be a promising approach. In the past, biotechnology based approaches have given successful products like Herbicide-resistant Soybean, Pusa Basmati 1, Bt Cotton, Bt Brinjal, Flavr-Savr tomato, a therapeutically significant product of *Lithospermum erythrorhizon* and *Panax ginseng*. Besides that many more need based products are in pipeline which is under scrutiny of regulatory bodies, policymakers and environmentalists. It is profoundly expected that in the coming day's agricultural biotechnology applications will bring revolutionary changes to existing agricultural scenario. Therefore, in this review, we have summarized the achievement of agricultural biotechnology that is assisting to enhance the agricultural produce to double the income of farmers. However, this much is not enough; hence full utilization of all the sustainable agricultural biotechnological tools must come into the existence that definitely will boost the agricultural productivity.

Keywords: Bio-fortification, Genetic engineering, Omics, Molecular breeding, Sustainable agriculture

Introduction

Agriculture is considered as the backbone of global economy[1] because of its major contribution to gross domestic product (GDP) (39.4%) and employment (26.8%)[2]. The large variability in soil and agro-climatic regions provide us an opportunity to produce diverse range of agricultural products. The protection of diversity and natural resources is being done by native people through their traditional technical knowledge for their self-dependency. Farmers are playing very important role in conservation of biodiversity by both *in situ* and *ex situ* methods. In the current scenario, when climate change is the major issue, agrarian poverty is increasing; therefore, emerging potential agricultural technologies should be implemented[3].

Due to the lack of awareness among entrepreneur about cutting edge technologies, the situation is becoming more alarming[4]. Therefore, to meet the ever-increasing demand of food grains due to increasing population, farmers are cultivating their crop on the ecosystem land by converting it to agrarian land[5]. Current agriculture practices and technologies are not able to meet the requirement of the increasing population sustainably, therefore to enhance the agricultural production, prevent yield losses due to various abiotic and biotic stresses reduce

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the post-harvest losses, and to produce bio-fortified agricultural products, sustainable cutting edge agricultural technology is the need of the hour.

Agronomical and soil practices can utilize the potential of the field up to a certain limit which has been already exploited and any further improvement in these practices may not be statistically and environmentally viable. Further, the exploitation of available biodiversity to develop high yielding varieties[6] through breeding methods will reduce the genetic diversity by targeting only a few high-value cultivars[7]. The applications of agricultural biotechnology have been persistent, both within the agriculture sector and outside as well. Hence, sustainably increasing the bio-fortified crop production and thereby increasing the income of farmers[6] is the primary target of agricultural biotechnology.

Biotechnology provides us an opportunity to use the genetic potential of the diversity in sustainable ways to develop products thereof. It can exploit bio-prospecting of the diversity by providing us the opportunity of bio-pharming and *in vitro* cultivation. Many other sustainable methodologies have been possible due to biotechnology techniques. Therefore, the application of advance agricultural biotechnology tools like genomics, genome editing, genetic engineering, marker assisted breeding could be a way forward to boost the productivity in sustainable way. Therefore in this review our endeavour was to review and summarize the successful research activities, achievement and its effect on the socio-economic conditions of the farmers and other stake holders.

Major domain in agricultural biotechnology for crop improvement

Crop improvement drove the farmers increasingly ingenious and empowers the GDP of the country. Further enhancement of the agriculture sectors needs more new ways that can contribute to agrarian growth but at the same point it ought not to overexploit the biodiversity of the earth. Agricultural Biotechnology has different fundamental and applied effects on agriculture which can't be supplant by other options. Among several approaches, biotechnology tools *i.e.*, molecular breeding, omics, plant tissue culture and genetic engineering technology are most common. These are some major sustainable ways through which crop improvement might be enhanced for human wellbeing (Fig. 1).

i. Marker Assisted Breeding

The conventional breeding program had been a routine practice since past many years which is based on the phenotypic selection of the performing cultivar among large population[8]. It has its limitations such as season-specific, time taking *i.e.*, wait for up-to maturity of the crop for yield analysis and environmentally influenced. After the 1980s, when molecular markers came into existence[9], various limitations of conventional breeding are overcome now by the use of molecular marker technology (Fig. 2).

Marker-assisted selection is a process of selecting desirable genotype based on molecular marker tightly linked to the trait. The molecular markers have been extensively used as a powerful and reliable tool for crop improvement *i.e.*, characterization of traits, germplasm selection and evaluation, map-based gene discovery and genetic mapping of agronomically valuable crops[9]. Marker-assisted selection (MAS) has also been widely applied in breeding programs for targeted transferring and pyramiding resistance loci in different crops[10,11] for example two to four resistance genes against bacterial blight, Xa4, xa5, xa13, and Xa21 has been pyramided in rice. There are several reports where MAS has been successfully implemented to develop durable and desired varieties, some of the examples are listed in (Table 1).

ii. Plant Tissue Culture

Plant cells have ability to dedifferentiate, proliferate, and subsequently regenerate into mature plants *i.e.*, totipotency under appropriate culture conditions in a hormone-dependent manner[20]. Plant cell cultures have evolved as *in vitro* experimental models for studying cell division, differentiation and

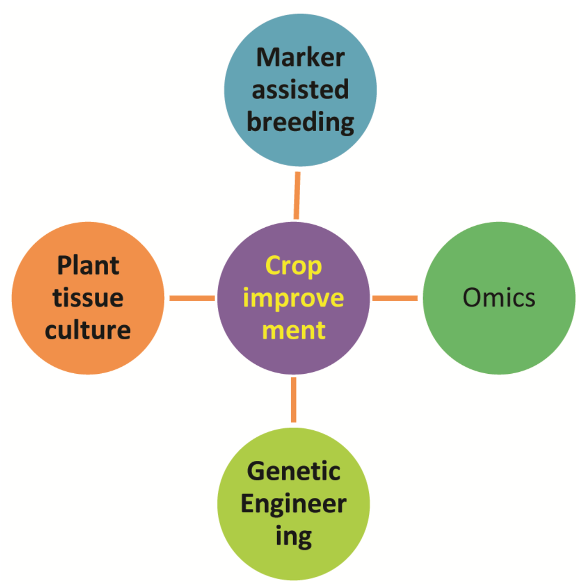

Fig. 1 — Major domains of agricultural biotechnology

morphogenesis such as meristem formation and embryogenesis and stress-related genome plasticity in plants. With the decreasing arable land, Plant tissue culture technique offers an excellent opportunity for mass propagation of plants in laboratory test tubes which can be transferred to the field later on. Several applications of the plant tissue culture such as micro-propagation, organogenesis, somatic embryogenesis protoplast culture and fusion are commonly used for various purposes.

Climate change has brought many obstacles in crop production, such as abiotic stresses, recurrent occurrences of pests and disease infestation, altered food nutrition quality which in turn leading to reduce availability and quality of agricultural produce. Plant tissue culture could help to stave-off food insecurity and hunger generated through climate change. Recent advances in plant tissue culture for crop improvement in the context of climate change are listed in (Table 2).

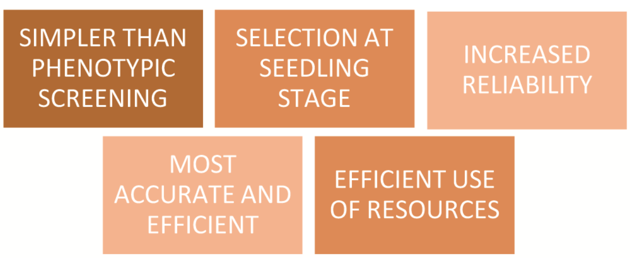

Fig. 2 — Advantage of marker assisted selection

iii. Genetic Engineering

Recombinant DNA is produced by joining together of two or more pieces of DNA segment from different organisms using genetic engineering tools. Organisms that are produced by transfer of a transgene from a distinct organism by non-breeding methods are called transgenic organisms. Various approaches are being used to transfer the transgene from one organism to another such as agrobacterium mediated transformation, gene gun method, PEG mediated DNA transfer, microinjection, macro-injection and silicon fiber mediated transformation. Transgenic plants were first developed around the 1980's. The first genetically modified crops were soybean and corn, and appeared on the US market in 1996. Since then transgenic plants have been commercialized in many countries and now a day's 28 countries are growing transgenic crop including the latest one Bangladesh. Flavr-Savr tomato, Golden rice and Bt-cotton are some successful examples of the use of recombinant DNA technology. Recent advances in Genetic Engineering for crop improvement in the context of climate change are listed in (Table 3).

iv. Omics

Genome encodes the complete set of genetic information in an organism. It includes both

Table 1 — Examples of MAS Application

Species	Trait(s)	Gene/QTLs	Foreground selection	Background selection	References
Chickpea	Fusarium wilt	*Foc2*	SSR	SSR	19
Wheat	Drought tolerance	QChl.Ksu-3B	SSR	SSR	17
Rice	Blast resistance	Pi54, Pi1 and Pita.	SSR	SSR, STS	18
Rice	Drought, and submergence tolerance	qDTY1.1, qDTY2.1, qDTY3.1 and Sub1	SSR	SSR	12
Chickpea	Fusarium wilt	foc4	SSR	SSR	14
Peanut	Rust resistance	QTLrust01	SSR	SSR	13
Rice	Heat tolerance	RM3586,RM3735,RM241, RM468, RM554,RM26212, RM7076	SSR	SSR	16
Rice	fragrance	BADH2	SSR	SSR	15

Table 2 — Recent advances in Plant Tissue Culture for crop improvement

Techniques	Examples	References
Embryo rescue	Clubroot resistant *Brassica oleracea* line through introgressing six CR loci from *Brassica rapa*	21
Protoplast fusion	Somatic hybrids between rice (*Oryza sativa* L.) and reed (*Phragmites communis* Trin.)	22
Anther or Pollen culture	Detection of drought tolerance-related QTL in the Plainsman V./CappelleDesprez doubled haploid wheat population	23
Somaclonal variation	Obtaining Salt Stress-Tolerant Eggplant Somaclonal Variants from *in vitro* Selection	24
Shoot tip cultures	Initiation, proliferation, and improvement of a micro-propagation system for mass clonal production of banana through shoot-tip culture	25
Somatic fusion	Utilization of somatic fusion techniques for the development of HLB tolerant breeding resources employing the Australian finger lime (*Citrus australasica*)	26
Micro-propagation	Physiological response of three micro-propagated plantlets of Rhododendron hybrids for heat stress	27

chromosomal as well as organelle DNA. Gene is a set of nucleotide sequence containing coding sequences along with its regulatory units, it codes for the RNA and protein molecules required by the organism. Application of "omics" approaches has provided an integrated view of the response of plants to various abiotic stresses. Although initially genomics was in the forefront, later it was realized that the study of other omics levels, including transcriptional, proteomic, and metabolomics, is required for a more comprehensive understanding.

a) Genomics

Genomics is a branch of "omics" which deals with the study of a given genome of the organism. It mainly deals with the identification of intragenic and gene sequences, structures of genes and annotation. The advancement in genomics was expedited by rapid developments in genome sequencing technology. Functional genomics has been successfully utilized in identifying various genes involved in abiotic stress responses in plants. The advances in genomics of wild germplasm and weedy relatives of crop plants have led to the identification of several novel candidate genes for abiotic stress tolerance.

b) Transcriptomics

The transcriptomics is the branch of "omics technologies" which deals with RNA expression profiling of an organism spatially and temporally. Unlike the genome, the transcriptome is highly dynamic and changes with age, development stage, nutrient availability, or environment. Currently, RNA profiling is accomplished using RNA sequencing, microarray platforms, digital gene expression profiling, and serial analysis of gene expression (SAGE).

c) Proteomics

The proteome profile is also highly dynamic and affected by factors like age, development stage, organ, nutrient availability, or environmental conditions. Studies on proteomics, gives a plethora of knowledge about the expressed proteins. Proteome profiling is generally done using mass spectrometry and two-dimensional gel electrophoresis (2-DGE). Recently, the phosphor-proteome has received the attention of researchers because the phosphorylated proteins play an important role during abiotic stress conditions.

d) Metabolomics

Metabolomics is the advanced branch of the omics approach used to study, detect, identify, characterize and quantify the metabolic profile of cells/ tissues under particular environmental conditions. These metabolites include amino acids, peptides, lipids, organic acids, aldehydes, ketones, steroids, vitamins, hormones, and even secondary metabolites Under stress conditions in plants, the total number, concentration, and types of metabolites are significantly enhanced. This alteration in gene expression is directly reflected in the metabolite profiles of plants.

A special emphasis of agricultural biotechnology on biodiversity conservation

Biodiversity describes the variability of life forms on the earth which is the most significant factor for survivorship and human welfare. In the past numerous years, our predecessors were occupied with traditional practices to conserve this variability and utilized the assets in a reasonable manner. In due course of time with the increasing population and covetousness of the people, habitat loss, pollution, climate change and

Table 3 — Recent advances in Genetic Engineering for crop improvement

Plant host	Gene source and gene	Modified trait	References
Arabidopsis thaliana	*Malusdomestica*, *MdERF100*	Resistance against powdery mildew disease	28
Triticum aestivum	Barley *HVA1 Gene*	Confers Drought and Salt Tolerance	29
Solanum lycopersicum (Tomato)	*Solanumlycopersicum,* SlDnaJ	Chloroplast-targeted DnaJ protein Protects Rubisco activity under heat stress	30
Solanum lycopersicum (Tomato)	*Solanumlycopersicum, eIF4E (eukaryotic translation initiation factor 4E)*	Creation of potyvirus potato virus Y (PVY) resistance using CRISPR/Cas9 technology.	31
Petunia hybrida	*Arabidopsis thaliana*, AtSOS3	Increase salt stress tolerance	32
Oryzasativa(Rice)	*Oryza satiava,OsERF922*	Enhanced rice salinity tolerance by CRISPR/Cas9-Targeted editing	33
Solanumlycopersicum(Tomato)	*Solanumlycopersicum, coda* gene encoding glycine betaine	Glycine betaine enhances salt toleranceby enhancing NaCl induced expression of genesencoding the K+ transporter, Na+/H+ antiporter, and H+-ATPase	34
Nicotiana tabaccum (Tobacco)	Barley*, HvSHN1*	Confers drought heat, and salt tolerance	36

intrusive species have created an alarming threat to conserve biodiversity. Several wild cultivars which are rich sources of genetic diversity are vulnerable and their overexploitation drives them toward endangered category. Therefore, several *in situ* and *ex situ* conservation methods and policies had played their key role to sustain the natural resources. Through molecular markers, various wild genotypes of crops have been characterized markers to identify several genes responsible for important traits whose introgression through marker assisted selection will be the key achievement to exploit the biodiversity in sustainable way[35-38]. At present, population bombardment is in continuation and has createda dire need to enhance agricultural production. Green revolution transformed the Asian country scenario of begging bowl to exporter of the food grain however in the current circumstance, another revolution *i.e.*, gene revolution is tremendously required. These revolutions must be economically viable, sustainable and supportive for natural resources. Biotechnology has delightfully been unravelling the mechanism of life which is by and large deliberately rearranged to serve humankind by impeding hunger and poverty. This new technology has contributed to the sustainability of the resources and agriculture through creating increased resistance/tolerance against biotic and abiotic stresses, bio-fortification, enhanced nitrogen use efficiency, improved shelf life of perishable fruits, bioremediation and biofuel technology[39]. Various tissue culture techniques, cryopreservation, gene banks, Germplasm conservation and seed banks are involved in conservation of plant diversity. Agriculture through the cutting-edge technology is more sustainable and positively influencing biodiversity rather than previous traditional ways of agriculture. Hence, biotechnology led inventions will be an effective approach in assisting the conservation of biodiversity and bio-resources and achieving self-sustainability along with high productivity.

Conclusion

In the era of modern biotechnology, high yield with quality food production in sustainable and cost effective way is the major objective of the agriculture. Apart from other aspect in agriculture sector such as agronomy, soil science, genetics and plant breeding, microbiology, plant physiology and plant pathology, which are playing significant role to enhance the agricultural produce, agricultural biotechnology cannot be avoided. In agricultural biotechnology various methods such as molecular breeding, tissue culture and genetic engineering are prominent one along with bioinformatics tools are safe and sustainable that will play major role to feed the increasing population and will create second green revolution. The urgency for higher yield and quality food production led to excessive use of agrochemicals and conversion of ecosystem land to agrarian land which ultimately resulted in biodiversity loss. Giving special emphasis on biodiversity is essential due to its high value and sustainability. Bio-prospecting is only possible when we use the cutting edge technologies that are not affecting the environment. Blind use of the technology on behalf of farmer's welfare and doubling their income is not ethical as well as successful. Therefore, implementation of new technologies that do not affect biodiversity is essential. Numerous studies suggest that biotechnological approach has a positive effect on the protection of biodiversity and environment[40]. Agricultural biotechnology is more sustainable than conventional techniques with respect to decrease in bug spray use, guaranteeing food security, biodiversity and environment protection, enhanced yield and ease strain to change over extra land into agrarian use[41]. It has also been reported that transgenic crops have fewer negative effects on biodiversity than non-transgenic crops[42].There are several traits for which a desirable gene is not present in the crossable genetic pool, in that condition genetic engineering technology is a potential tool that enhances the genetic diversity through stable integration of transgenes into the existinggenome[43]. Growing the agricultural crops which are of medicinal use can be good candidate of income to farmers and the technology will be used to isolate the secondary metabolites for pharmaceuticals[44,45]. Among several examples of success stories of biotechnology across the world, for example Bt cotton, Btbrinjal, Flavr-savr tomato, Pusa basmati 1, Golden rice, New leaf potato, Rainbow papaya, herbicide-resistant soybean and maize so forth are most common which has utilized various aspect of microbial biotechnology[46]. Thus, addressing the current problems of climate change, increasing population and malnutrition, needs technology that should be sustainable in nature.

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Conflict of interest

All authors declare no conflict of interest.

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