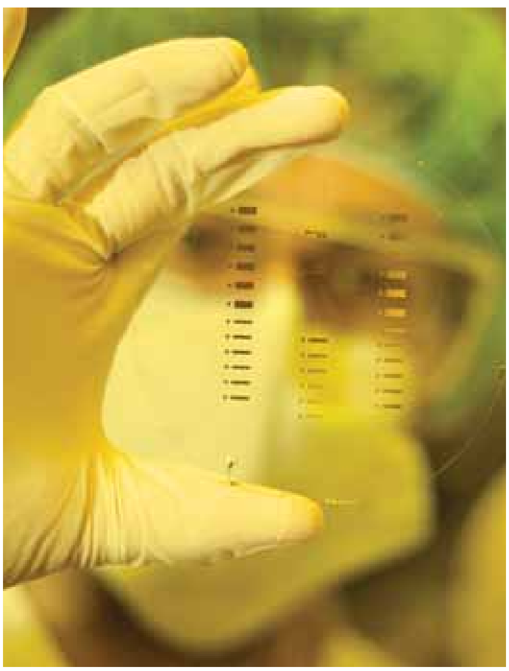
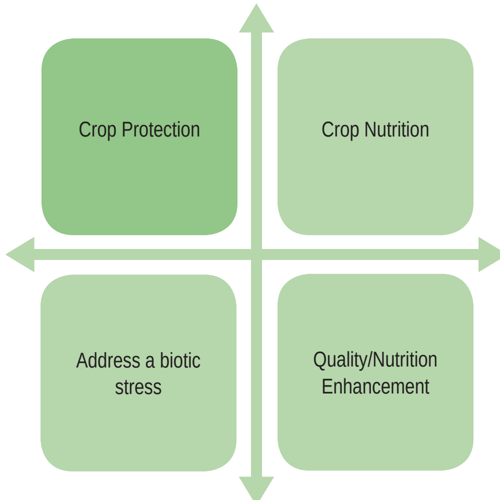
The Road to Food Security through Biotechnological Interventions in Agriculture

By Rituparna Majumder

Global population is expected to reach 9 billion by 2050 and to meet this growing demand, global agricultural production, in 2050, should be 60 percent more than what it was in 2005/2007[1]. Trends in global gains in agricultural productivity indicate a shift from heavy investments in increased fertiliser and pesticide inputs to investments in technology-driven improvements (including genetic modification) that increased yields with fewer units of input. Despite these efforts, there is lot to be done and achieved in order to meet the growing demand of food to feed the burgeoning population.

The alarming concerns of rising population, shrinking agricultural land and water bodies, declining productivity and growing environmental and agricultural problems instigate the need to adopt sustainable technological interventions in the sector to ensure global food security.





Next generation answers to address such concerns could be to develop technologically improved and high quality seeds, effective nutrients, pesticides and herbicides, to combat complexities of climatic changes causing unreliable rainfall, prolonged dry spells and extreme temperatures and address issues related to shortage of water, labour and other energy sources.

Target Areas

Agricultural biotechnology has been effectively employed over decades to augment food production and boost productivity through crop protection by developing insect, disease resistant and herbicide tolerant varieties, eco-friendly biological products reducing the use of inorganic materials and chemicals in agriculture and increasing productivity, crop nutrition through modern traits of effective nutrient uptake and yield improvement. Quality augmentation to improve standards of produce by developing bio-fortified products, facilitating enhanced ripening, and addressing abiotic stresses by adapting to adverse local agro-climatic conditions and minimising climate change impact on productivity by developing drought tolerance, salinity tolerance, submergence tolerance and heat/cold tolerance traits in various crops are the other intervention areas. These help to reduce growing concerns related to agricultural land reduction as well as preserve the natural resources by minimising the use of agrochemicals that pose hazard to the environment. Biotechnological techniques and tools have been used to address pressing agricultural issues as highlighted above through development of technologically improved biotech crops and biological inputs.

Research and Development

The biotech industry is driven by a multitude of international multi-partner support programmes and initiatives promoted by national governments through substantial financial and infrastructure support, public-private consortiums, availability of skilled technical resource, accessibility of promising technologies worldwide, agro-chemical industry diversification and environmental concerns.

In the 20th century, with technological advancement, crop breeding has witnessed a paradigm shift with breeders using biotechnology for introgressing traits for increased yield, disease and pest resistance, drought resistance and enhanced flavour using specific gene sequences known to enhance or introduce new characteristics into the crops. Globally, the biological input industry has developed a better understanding of the biology of micro-organisms with US and Europe advancing towards the next generation of biological products.

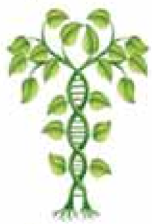
Novel Techniques

Today, innovative improvements and refinements of existing breeding methods are being deployed to develop products with enhanced efficiency and specificity of breeding, better understanding of final product by using molecular tools that addresses the public concerns related to the Genetically Modified (GM) crops especially those curtailing the use of transgenes.

In recent times, the biotech seed industry is witnessing growth of various GM and non-GM technologies for crop improvement. Companies worldwide have started investing in enabling platform technologies that would help to develop crops using non-GM techniques.

Non GM Technologies

- Marker Assissted Breeding/Selection (MAS)
- Precision Genotyping
- High Throughput Sequencing
- Enhanced Ploidy



GM Technologies

- **Transgenesis** - forgein gene
- **Gene Silencing** (RNA Interference) - prevents experession of certain genes
- **Gene shuffling** - for optimization of protein expression
- **Site specific integration** (SSI)
- Cisgenics/Intragenesis
- Genome Editing

With time, the industry has progressed with various non-GM technologies to reduce time to market products and also avoid the high costs associated with conducting regulatory studies of biotechnologically derived crops. Advancements in molecular breeding have been made through the introduction of molecular markers associated with the trait of interest (short sequence of nucleic acid which makes up a segment of DNA) to identify specific genes thereby increasing the selection efficiency. However, extremely promising technologies such as Next Generation Sequencing (NGS), Cisgenics and Genome Editing are being extensively used by the western countries.

Few of the "state-of-the-art" novel technologies used for research and development in agricultural biotechnology include:

1. Genome Sequencing Technologies for Crop Breeding: Rapid developments in NGS technologies in the previous decade have opened up new opportunities to explore the relationship between genotype and phenotype with greater resolution. As the cost of sequencing decreased, breeders begun to utilise NGS with increasing regularity to sequence large populations of plants, increase the resolution of gene and Quantitative Trait Locus (QTL) discovery and provide the basis for modelling complex genotype-phenotype relationships at the whole-genome level.

2. RNAi-based Gene Silencing Technologies: RNA Interference is an important technology used for development of biotech crops through gene silencing. Recently, numerous GM products are under development for building resistance in the crops against nematodes (Transgenic soybean[2] by targeting essential nematode genes), insects, fungi, virus, parasitic weeds, etc. RNAi-based GM plants are also developed to manipulate metabolism for improving various industrial traits as well as nutritional value (suppression of an endogenous photomorphogenesis regulatory gene, DET1, using fruit specific promoters significantly increased carotenoid and flavonoid in the fruit[3]).

3. New Plant Breeding Techniques (NPBT)[4]: Today, innovative improvements and refinements of existing breeding methods are being practiced by plant breeders and scientists to develop advanced products with enhanced efficiency, specificity of breeding and better understanding of final products. Few such techniques include:

a. Site specific mutagenesis:

i. Induced site-specific mutations: Oligonucleotide-Directed Mutagenesis (ODM) – mismatch pairing;

ii. Target specific mutation by delivering Nuclease genes into the cell for integration in the plant as a transgene - Meganuclease (MN), Zinc Finger Nuclease (ZFN), Transcription Activator-Like Effector Nuclease (TALEN), CRISPR-Cas-Nucleases.

b. Deploying genes from cross-compatible species through transgenesis (gene transfer): Specific vectors are constructed which use DNA sequences originating from the same species or related species to insert the target genes (P-DNA) instead of bacterial DNA.

i. Cisgenesis (Transfer of an intact gene between closely related species. The transferred gene is unchanged i.e. with native regulatory elements);

ii. Intragenesis (Regulatory elements of a gene may be changed).

c. Breeding with transgenic inducer line

i. **RNA-dependent DNA methylation (RdDM)** - Gene expression modified by promoter methylation without changing the genomic sequence;

ii. **Reverse Breeding -** Relies on suppression of meiotic recombination during propagation of an elite hybrid plant.

d. Agro-infiltration Techniques - Plant tissue is infiltrated with Agrobacterium suspension.

e. Grafting Techniques - Grafting on GM rootstock.

4. Technological Advancements of Biological Products: Such advancements include products with new and multiple strains, introduction of signal molecules (e.g., hairpin protein signals) to activate the defence mechanism in plants, broad spectrum, stacked products, and novel formulations. Combinational or bio-stacked product formulations have also been effective in mitigating the effect of various insects and pests on plants through combinational strains, bioactive compounds and combination of biological and chemical products. Products with improved shelf life through Encapsulation Technologies and storage stable formulations have also been developed by various industry players.

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Novel Applications

In the last two decades, globally, GM crops have focussed on crop protection traits e.g., insect resistance and herbicide tolerance. Moving over first generation crop protection traits, the industry is gradually shifting towards investing in development of second generation traits targeted towards yield improvement, crop nutrition and quality augmentation. Efforts have also been put into developing biotech traits in non-food crops. The industry is gradually moving towards deployment of new and improved techniques as well as advanced tools to develop improved biotech crops.

The latest biotech crops commercialised include Innate™ potato and Enlist™ Duo in USA, Maize (insecticide and herbicide resistance) in Vietnam, Fruit and Shoot Borer resistance Brinjal in Bangladesh and drought tolerant Sugarcane in

First Generation Traits

Insect/Pest Resistance
Herbicide Tolerance
Virus Resistance
Insect Resistance + Herbicide tolerance
Disease Tolerance/Resistance
Cytoplasmic Male Sterility

Second Generation Traits

Yield Enhancement
Nutritional quality enhancement
Nitrogen Use Efficiency (NUE)
Water Use Efficiency (WUE),
Climate resilient genotypes
Drought and Salinity tolerance,
Heat and Cold tolerance

Second generation Innate™ potato: Developed by Simplot - A food staple with lower levels of acrylamide, a potential carcinogen, resistant to late blight resistance and less wastage due to bruising; reduced browning and allows potatoes to be stored at colder temperatures longer to reduce food waste. New one gene technology was developed by silencing existing genes or adding genes from other types of potatoes.

Indonesia. Among other technologies in pipeline, second generation Innate™ potato and fortified bananas in the US, pest resistant Cow Pea in Africa, Golden Rice and late-blight resistant potatoes are being field tested in Bangladesh, Indonesia, and India. In August 2015, US Department of Agriculture's Animal and Plant Health Inspection Service granted a 'non-regulated status' to the second generation Simplot's Innate™ potato.

On the other hand, application-based biological products are now-a-days being directed towards development of products for seed treatment (Catalytic Seed Treatment), seed coating (Yield Enhancing Agent), slow release of granules, foliar spray technology and novel delivery mechanism.

Conclusion

The agri-biotech industry in the near future will be directing their work towards development of traits addressing abiotic stress, enhancing nutrient uptake and quality augmentation by emphasising on genome sequencing, gene silencing and other new plant breeding techniques for enhanced efficiency and specificity of breeding. The industry would move towards introduction of technology through Cisgenics/Intragenics to avoid public concerns related to GM crops particularly in terms of transgenes. The second generation Innate™ potato product, when approved by USEPA, will bring about another paradigm shift in agricultural biotechnology industry and open roads to commercialisation of many similar products under development in South and South East Asia. The biological input industry would move towards development of combinational products with improved formulations to address concerns of effectiveness and longevity.

References

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