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Technologization of Agriculture through Seeds — An Indian Perspective

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ABSTRACT The millennium challenge of producing more food from less land envisages high technological intervention. Seed is the delivery system through which most of the scientific advancements get transferred to crop production. The development of a desirable seed product is the key to modern agriculture and involves conventional plant breeding, biotechnology and seed technology, aided by innovative agronomic practices. This article explores the historic and prospective technologies delivered through seed, which had and promises to have a significant impact on global agricultural scenario.

Key words: Agriculture, technology, desirable seed product, plant breeding, transgenics, seed technology

World population is projected to cross the 7 billion mark in 2013 [1]. Currently 80 per cent of it reside in the less developed regions (Table 1), whereas at the beginning of the century it was only 70 per cent. By 2050, the share of the world population living in the currently less developed regions is estimated to be 90 per cent. This unbalanced population pressure on less developed geographical areas would not only result in an increase in the demand for food, but would also reduce the availability of land for cultivation, because part of the land is being utilized for infrastructural development, thereby creating scarcity. Hence, agriculture in this century has to be different from the past and it has to be much more efficient, especially in case of developing countries where population pressure poses serious threat on food security. The challenge is to produce more food from less land which can be achieved only through technological intervention.

Table 1. Distribution of population in the world

Region	Population (%)	
	2010	2020
Africa	15.0	16.6
Asia	60.3	59.9
Europe	10.6	9.6
Latin America	8.5	8.4
North America	5.1	5.0
Oceania	0.5	0.5

Source: United Nations World Population Prospects, 2008

The term technology *per se*, has been routinely related with industry, than with agriculture. However, in today's agricultural scenario, the focus is on precise product development and its successful adoption by the end-user, *i.e.* the farmer, which grants it, undisputedly, a technology status. Adoption of technology by the farmer is directly related to its effective transfer to crop production, for which seed is the

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inevitable carrier. Being a biological entity, the performance potential of the seed, in turn, is dependent on several other physiological, biochemical and molecular factors. Hence, use of high quality seed is a pre-requisite for successful implementation of any agricultural technology.

It is estimated that if all other factors remain the same, the use of quality seeds of high-yielding varieties increases crop yield by 15-20 per cent. However, under the limited resource scenario, made further challenging by the expected climate change, there is a need for better preparedness and efficiency to produce food, feed and fuel. Multiple agricultural technologies that can counter the environmental adversities and thereby grant full expression of varietal genetic potential should be introgressed and brought to the crop production front in the form of a desirable seed product.

Plant Breeding, Biotechnology and Seed Technology are the pillar innovation for superior product development (Fig. 1). Plant breeding is the central point of this process, whereby the genetic content is determined. Biotechnological tools aid in introgression of specific trait for value-addition. Seed quality enhancement is achieved through application of various tools of seed technology. Once the desired product is developed, the aim is to maximize production which is achieved through agronomic innovations

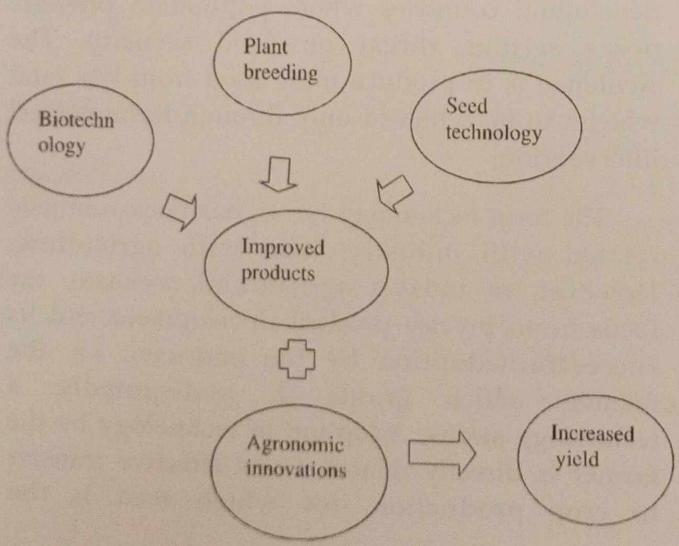

Fig. 1. Process of development of a desirable seed product

manifested through seed rate, row plant spacing, rate and dosages of fertilizer application, etc.

Role of plant breeding in development of desirable seed product

Two of the earliest seed led technologies that revolutionized global agriculture, *viz.* dwarfing gene and hybrid technology, have been achieved through conventional plant breeding, complemented by intensive agronomic practices.

Dwarfing gene

The reduced height gene (Rht) is the miracle gene of crop breeding which helped in surviving the hunger crisis that threatened mankind during the last century. The discovery of the Rht gene was originally made by European wheat breeders who identified this gene in Japanese variety Akakomugi that was well adapted to intensive agriculture. Extensive use of this technology was done two decades later, when the United States Department of Agriculture developed numerous semi-dwarf wheat varieties using another Japanese variety Norin 10.

The credit for bringing this technology to the global platform goes to International Maize and Wheat Improvement Center in Mexico (CIMMYT), where Norman Bourlog took the initiative to develop several dwarf wheat varieties. Subsequently, in the late 1960s, these varieties spread to different parts of the world and India became major beneficiary of this technology. In 1966, India imported 18,000 tonnes of dwarf wheat from CIMMYT. These cultivars ushered in the Green Revolution in the country which miraculously changed the country's status from the largest importer of wheat to that of an exporter.

Hybrid technology

The concept of hybrid vigour was first commercially exploited in corn in USA. The substantially higher yield and mechanization-friendly plant characters led to extensive adoption of these cultivars. The entry of still high-yielding and more uniform single cross maize hybrids, as compared to the initially developed double cross hybrids, led to the successful establishment of hybrid technology in agriculture, which was soon adopted in almost all other crops. India has to its credit several pioneering milestones in hybrid cultivar development. The first intra-specific cotton hybrid (H-4) was developed in India in 1970. India developed the first pearl millet grain hybrid using the Cytoplasmic Male Sterility (CMS) system, along with several high-yielding hybrids in maize and sorghum. India was also the first country to exploit hybrid vigour for the development of high-yielding castor varieties.

China was the first to achieve success in the hybrid rice when it commercially released the three-line rice hybrid for cultivation in 1976. In fact, this technology has enabled China to retain its position as the world leader in rice production even when records showed significant reduction in total rice-growing acreage in China since 1978. Now, it is reaping the benefits of the two-line hybrid rice technology which has been successfully commercialized since 1995.

India started concentrated efforts on hybrid rice development in 1989. Several hybrids from public and private sector are available for cultivation, with the private sector being the dominant player. In spite of the availability of several hybrids, a very limited area is under hybrid cultivation: about 1.5 mha out of 43.77 mha (3.4%). One major reason for this low adoption is the unattractive yield advantage that this technology offers.

It is a mere 1.0-1.5 tonnes/ha over varieties. Hence, currently the cultivation is restricted to few areas of eastern Uttar Pradesh, Bihar, Jharkhand, Chattisgarh, Punjab and Haryana. There is, in general, a lack of acceptability in southern parts of the country due to region specific grain quality requirements. It is expected that better hybrids will be evolved to give at least 3-4 q/ha advantage over the varieties with enhanced ability to fight drought and disease. Consequent to this, by the year 2015, area under hybrid rice may touch 20-25 per cent of the rice cultivated area in India.

Biotechnological interventions for development of desirable seed product

The first commercial biotechnological venture for development of a value-added seed product was the Flavr Savr tomato, commercialized in USA in 1994 by Calgene, a California based company. However, its production stopped in 1997. Calgene was eventually bought by Monsanto, which was primarily interested in Calgene's ventures into cotton and oilseed. The entry of dominant private players brought in a boom in the biotech crop industry which was mainly achieved through the transgenic technology. This technology entered the market through three major crops, *viz.* soybean, corn and canola, and their commercialization was mostly restricted to north America. However, introgression of transgenic traits in crops like cotton and potato led to a widespread adoption of transgenic crops in developing countries. Of the total of 29 countries, 19 have adopted transgenic crops until date, are developing countries. Currently, almost 50 per cent of the total global acreage (Table 2) under biotech crops is planted by developing countries, with India the ranking fourth (6% of the global area), next to USA (45%), Brazil (17%) and Argentina (16%) [2].

Table 2. Global area of biotech crops

Year	Million hectare
1996	1.7
2000	44.2
2004	81.0
2008	125.0
2009	134.0
2010	148.0

Source: ISAAA Brief 42: Global Status of Commercialized Biotech/GM Crops, 2010

Biotech crops in India

In 1995, Department of Biotechnology, under the Ministry of Science and Technology, GOI, gave permission to Mahyco to import Bollgard cotton. In 1996, a small quantity of seed of Coker 312

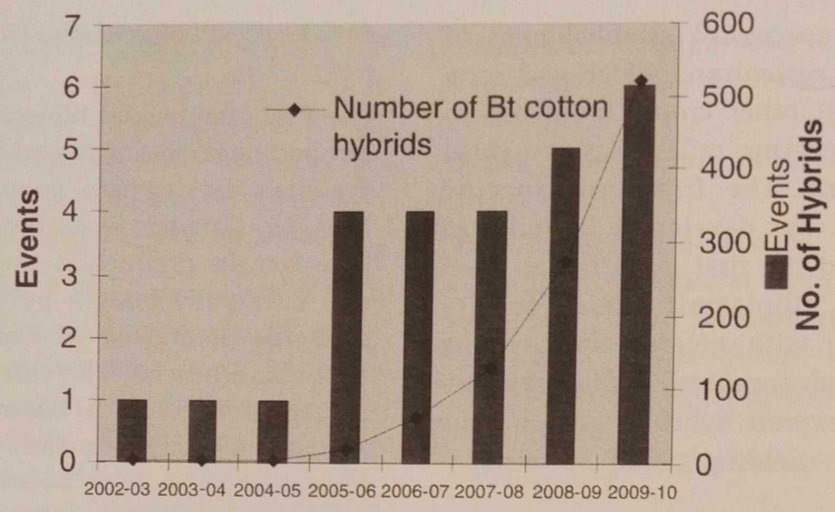

Fig. 2. Hybrids approved for cultivation in India (2002-09)
Source: ISAAA Brief 41: Global Status of Commercialized Biotech/GM Crops: 2009

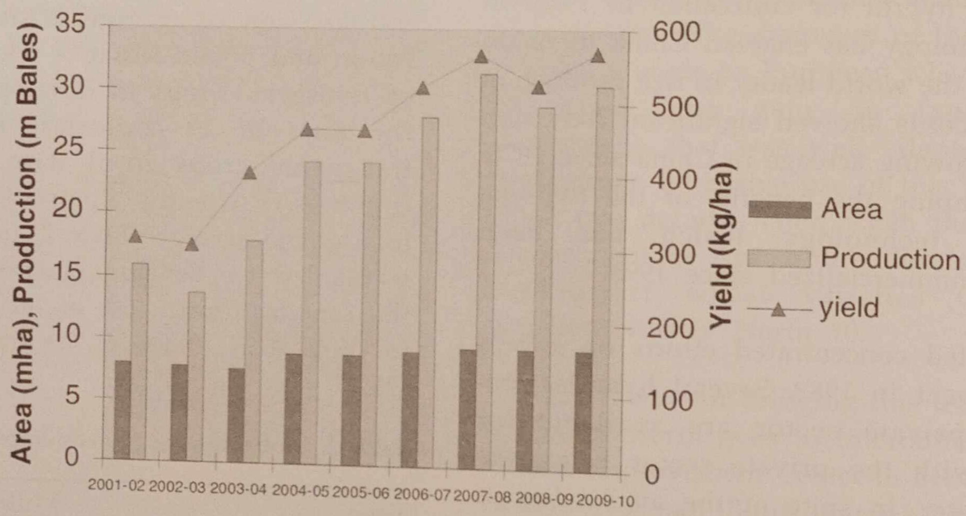

Fig. 3. Area, production and yield under cotton
Source: ISAAA Brief 41: Global Status of Commercialized Biotech/GM Crops: 2009

containing *cry 1Ac* (Event: MON 531) was imported from Monsanto, USA. Regulatory trials related to biosafety and agronomic impact were conducted for 6-7 years and Bt cotton was legally commercialized on 26 March 2002. Until date, cotton is the only Biotech crop commercialized in India, with 522 hybrids (Fig. 2) being de-regulated for cultivation by the Genetic Engineering Approval Committee (GEAC). Since 2002, when Bt cotton hybrids were introduced for farmers' fields, tremendous progress has been achieved in cotton production, resulting in phenomenal enhancement in yield (Fig. 3), thereby facilitating the rise of India to the position of one of the largest cotton producers in the world, next only to China. Currently, of the total 9.6 mha of cotton in India, 87 per cent is under Bt cotton hybrids, benefiting around 5.6 million farmers, by providing profit to the tune of 5.1 billion US dollars [3] and also transforming India from a cotton importer to a major exporter.

Around 35 private companies are the major players in Bt cotton scenario; however, first public sector Bt hybrid has entered the commercial sector in 2009. The entry of multiple gene stack products has further strengthened the cause of transgenic, with farmers adopting these products on a much larger scale as compared to single gene products. The combination of insecticide and herbicide protection in these new products makes cotton crop production a more profitable venture owing to considerable reduction in chemical inputs. It is also mentionable that simultaneous with the adoption of Bt cotton, the total pesticide consumption of the country reduced by almost 9000 tonnes within a span of 5 years [4].

The phenomenal success and adoption of Bt cotton in India led way to efforts for application of this transgenic technology in brinjal crop which is one of the most popular vegetable crops grown in India owing to its ubiquitous adaptability to almost all agroclimatic zones of the subcontinent. Bt brinjal, which offers the opportunity to provide effective control against fruit and shoot borer, was thereby developed through a successful public-private partnership venture in India. The Bt brinjal event EE-1 has been developed by M/s Maharashtra Hybrid Seeds Company Ltd (Mahyco), in collaboration with three public sector organizations. The presence of the *Cry 1Ac* protein in the transgenic crop decreases insecticide requirement by as much as 80 per cent [5]. Though the product has been approved for commercialization by the GEAC, it is still awaiting government's clearance for commercial release.

Transgenic rice

Research on transgenic rice is underway in many laboratories across the world, though no transgenic rice has yet been commercialized. Biotic-stress tolerance has been the primary focus for private sector as well as public sector organizations involved in transgenic rice research. However, one of the most promising and successful application of transgenic technology in rice has been the development of nutrient (pro-vitamin A) fortified varieties, popularly known as Golden Rice, due to the slightly yellow colour conferred to the endosperm. It is tailored to redress vitamin A deficiency among the world's poor for whom rice is the predominant source of food.

Since the initial product had a limitation in the extent of pro-vitamin A accumulation, researchers have further come out with improved varieties, requiring an intake of only 120 g (approximately two servings) rice, for meeting the vitamin A's recommended dietary allowance (RDA) of 300 micro gram/day/child [6, 7]. Currently work is progressing in many developing countries, including India, for transferring this trait into local popular cultivars. Its commercial release is soon expected. However, there are many issues still to be sorted out before it is commercialized for public good, *e.g.* reduction in beta carotene quantity in presence of light, question of consumer preference because of colour, bioavailability of pro-vitamin A when transferred to local cultivars, etc.

Seed technological interventions for development of desirable seed product

Seed technology has a very critical role in the value-addition chain of the seed product. They are mainly applied as pre-sowing seed treatments for enhancing seed vigour (quality), thereby, ensuring quick and uniform field establishment which is a pre-requisite for effective expression of its genetic and introgressed traits. Estimation of seed vigour though standardized vigour tests and relating it to stand establishment and field performance is a priority area in seed research. In high-value low-volume crops, where a farmer cannot afford to have a single un-sprouted seed, a precise estimation of seed vigour followed by suitable invigoration treatments is essential for ensuring desirable returns. Amongst the various pre-sowing seed treatments, seed coating has a major place in the seed industry.

Innovative seed coating approaches like, film coating (the application of a thin, durable, water permeable seed coat, usually a polymer binder, which can be effectively used to contain pesticides, nutrients and other products) and green coating technologies using botanicals and inert dusts have been widely studied, with many giving promising results [8]. Such technologies are being used by seed firms for branding and increasing the aesthetic value of their products as well. Presently, commercialization of these technologies is restricted to the private seed sector and much of the information regarding the products is patented. With effective public-private partnership, there is ample scope for large-scale commercialization of such precision technologies which is essentially required for meeting the future challenges.

Innovative agronomic practices to complement Bt technology

The fact that Bt cotton has saturated almost 90 per cent of India's cotton area also arouses serious concern regarding the scope of expansion of this technology in the country. However, an innovative agronomic approach holds great promise in further yield enhancement. Multi locational trials conducted in 3 different states of India (Maharashtra, Andhra Pradesh and Karnataka) for 2 years demonstrated that even at varied (between-row and between-plant) spacing whereby the number of plants per acre was almost doubled, there were no significant reduction in per plant productivity. Rather, a 2-4 q/acre yield benefits were recorded owing to more plant per unit area. Hence, it is obvious that there is provision for increasing the crop seed rate from the recommended 450 g/acre to even up to 700-800 g/acre, with the benefit of a much higher yield. Hence, the key to ensure progressive returns from such advanced technologies lie in development of innovative agronomic practices at the user end.

Technologies in pipeline

There are several promising products in research pipeline of mostly private organizations, which merits due mention here. Traits like heat tolerance, drought tolerance, salinity tolerance, lodging resistance etc are useful not only for sustainable yield but also to withstand the adverse effects of climate change. Most of these technologies are being developed in private sector and likely to be commercialized by 2015 (Table 3).

Table 3. Promising technologies in pipeline for major crops

Crop	Trait category
Maize	Herbicide tolerance Pest resistance Product quality (Modified amylase, enhanced lysine) Agronomic (Drought tolerance and yield/improved nitrogen efficiency)
Soybean	Herbicide tolerance Pest resistance (Nematode resistance and fungal resistance) Product quality (Modified oil) Agronomic (Yield and drought tolerance)
Rapeseed	Herbicide tolerance Product quality (Modified oil) Agronomic (Improved yield)
Cotton	Herbicide tolerance Pest resistance Agronomic (Drought tolerance)
Rice	Pest resistance (Stem borer) Nutritional improvement, Golden rice
Alfalfa	Herbicide tolerance Product quality (Modified oil)
Wheat	Herbicide tolerance Pest resistance Agronomic (Stress tolerance and higher yield) Drought tolerance

Source: Arundale and Sawaya (2009) with minor additions

CONCLUSIONS

The future of agriculture lies in effective utilization of technology for development of precise end products, which can be successfully transferred to crop production. Seed, being the converging point of biology, technology and crop production, is the key to the value-addition process wherein, desirable traits are integrated for enhancing crop yield. In the previous century, plant breeding played a central role in successful yield enhancement and it revived the agricultural scenario through production and distribution of quality seeds of high-yielding varieties and hybrids. Currently, it is the era of transgenics, duly complemented by innovative agronomic practices and precise seed technology whereby, the foundation of plant breeding is further strengthened for ensuring better yield through use of quality seed.

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