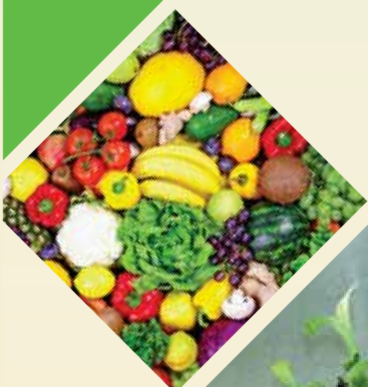
Strategy Paper

Crop Biotechnology for Ensuring Food and Nutritional Security



Dr. J.L. Karihaloo

and

Dr. R.S. Paroda

Trust for Advancement of Agricultural Sciences (TAAS)
Avenue-II, IARI, Pusa Campus,
New Delhi-110012
E-mail: taasiari@gmail.com;
Tel.: +91-11-25843243;
Website: www.taas.in

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Progress Through Science

Trust for Advancement of Agricultural Sciences (TAAS)

GOAL

Harnessing the potential of agricultural sciences for the welfare of people.

MISSION

Promoting growth and advancement of agriculture through scientific partnerships, policy advocacy and public awareness.

OBJECTIVES

- To act as a Think Tank to deliberate on key issues relating to agricultural research and innovation for development (ARI4D) and influence science based policy decisions
- To organize workshops, conferences, brainstorming sessions, policy dialogues, seminars and special lectures on emerging issues and new developments in agricultural science
- To disseminate knowledge among stakeholders through publication of proceedings, strategy papers and policy briefs
- To recognize and award scientists of Indian and foreign origin for their outstanding contributions towards Indian agriculture
- To motivate and attract youth (including women) in agriculture
- To facilitate scientific interactions and partnership at the national, regional and global level to ensure science led growth in agriculture

Strategy Paper

Crop Biotechnology for Ensuring Food and Nutritional Security

J.L. Karihaloo and R.S. Paroda
Trust for Advancement of Agricultural Sciences, New Delhi

Preamble

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO *et al*., 2017). Achieving food security would require multi-dimensional interventions that address availability and economic and physical access to food and its proper utilization. The country's past achievements in agriculture, including significant increase in the foodgrain production from mid-sixties onwards (Fig. 1), made possible primarily through breeding of high yielding semi-dwarf wheat and rice varieties and adoption of improved cultivation practices, adequately demonstrate the potential of scientific interventions for food and nutritional security. Despite these achievements, agricultural R&D is facing challenges on account of increasing demand for food, fast depleting natural resources (land, water, agrobiodiversity), rapid fragmentation of land holdings, adverse impacts of climate change, rising cost of cultivation, widening production disparities between agro-ecological regions, inefficient use of inputs, wastage of produce due to inadequate post-harvest processing and storage, and weak market linkages. These challenges have to be addressed through appropriate policy interventions and faster adoption of innovative crop production technologies that save cost on inputs, increase productivity and reduce wastage. A recent report by a committee constituted by the Principal Scientific Advisor (PSA) to the Government of India for "Agricultural Policies and Action-Plan for a Secure and

Sustainable Agriculture" (Anonymous, 2019) comprehensively deals with the diverse issues confronting Indian agriculture and recommends several measures and an action plan to accelerate agricultural growth and sustainability of farming. The present strategy paper specifically examines the role of biotechnology, highlighting a few good examples of biotechnology application that have contributed directly or indirectly to food security with proven impact. It also enumerates various challenges for harnessing the potential of biotechnology, and suggests measures to effectively address these for greater benefits to the society.

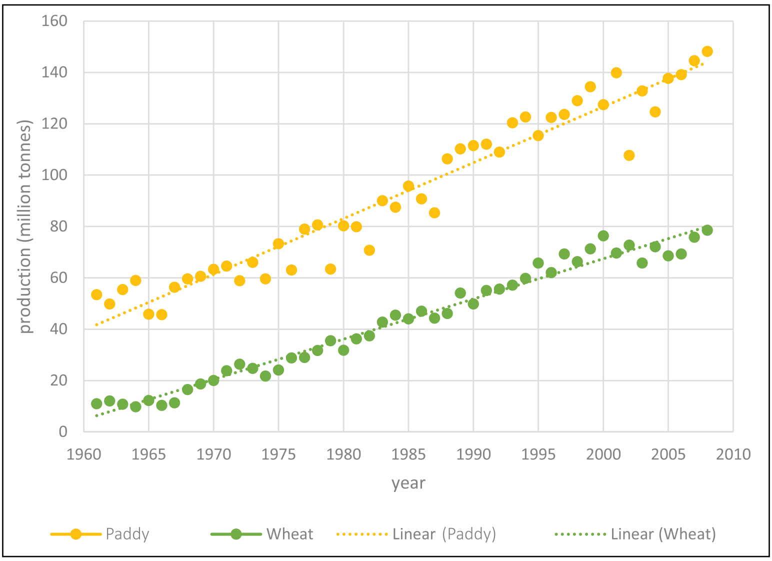

***Fig. 1.** Paddy and wheat production during 1960-2008 in India*

Source of data: http://www.fao.org/faostat/en/#data

Biotechnology encompasses a vast array of conventional and modern tools and techniques (FAO, 2011; Table 1) that have the potential to: i) increase food production, ii) improve its quality and safety, and iii) improve economic and social conditions of farmers and thereby their access to food. Such potential has been realised in several crops where biotechnological interventions have led to production of high-quality planting material; and

Table 1. Biotechnologies for crop production

Production application	Biotechnological technique
Creation of new variation	Chromosome doubling
	Tissue culture-based technologies (somatic hybridization, haploid and doubled haploids, sterile varieties)
	Mutagenesis
	Interspecific hybridization
	Genetic modification
Screening and selection	Marker-assisted selection
Production and management system	Micropropagation
	Disease diagnosis and bioprotection
	Plant nutrition
	Genetic resources conservation and management

Source: FAO (2011)

genetically improved varieties incorporating genes for yield, resistance to biotic and abiotic stresses and improved nutritional quality.

Some Specific Developments and Their Impact

Among conventional biotechnologies, tissue culture technology has led to the establishment of thriving commercial micropropagation industry across the globe (IAEA, 2004; Singh and Shetty, 2011). In India, about 200 commercial tissue culture companies have been established with gross installed production capacity of about 500 million plantlets and actual production of 350 million per annum (DBT, 2016). Economic analysis has revealed significant benefits accruing to the farmers adopting micropropagation based planting material. For example, in banana, there has been more than 40 per cent increase in net income per hectare (Table 2) primarily due to higher yield and quality of produce. In Jalgaon district of Maharashtra, one of

Table 2. Comparative economics of tissue culture and sucker produced banana

S. No.	Particulars	Tissue-cultured banana	Sucker-produced banana
1	Mean yield (bunches/ha)	2,663	2,416
2	Mean price received (₹/bunch)	94.47	76.42
3	Value of main product (₹/ha)	251,573	184,630
4	Value of by-product (₹/ha)	1,729	2,518
5	Gross income (₹/ha)	253,302	187,149
6	Total expenses (₹/ha)	141,040	108,294
7	Net income (₹/ha)	112,262	78,855

Source: Alagumani (2005)

the largest banana producing areas of the country, farmers who used to harvest around 20 tonnes per hectare in 1984-85 harvested over 60 tonnes after adoption of micropropagation based planting material along with improved cultivation practices (Singh *et al*., 2011). A more recent report indicates that such farmers are earning a profit of ₹240,000 to ₹325,000 per acre (₹590,000 to ₹790,000 per ha) (Dafare *et al*., 2014).

Mutation breeding is a long established method of creating genetic variations to breed improved crop varieties (FAO & IEAE, 2008). Till date, more than 3,200 induced mutation derived crop varieties have been developed globally, of which 335 have been registered in India (http://mvgs.iaea.org/AboutMutantVarities.aspx). While nearly half of these are ornamentals (Fig. 2), a number of induced mutant cereal and pulse varieties have made a significant economic impact. For example, mutant rice varieties PNR-102 and PNR-381 are estimated to have contributed US$ 1,748 million to farmers' benefit (Ahloowalia *et al.,* 2004). Mutant mungbean varieties Co-4, Pant Mung-2 and TAP-7 released in 1980's were widely cultivated in India while mutant urdbean variety TAU-1 achieved the distinction of covering over 95 per cent area

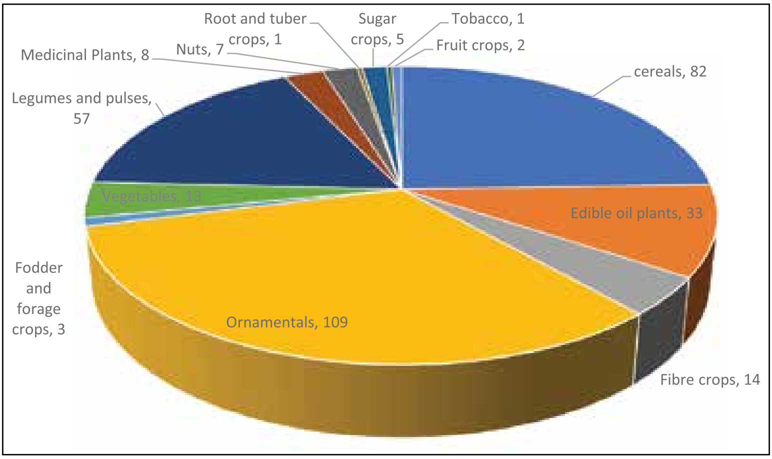

Fig. 2: *Crop varieties developed in India through induced mutagenesis*

Source of data: https://mvd.iaea.org/

in Maharashtra. The value of increased production due to cultivation of TAU-1 during-the period 1998-1999 has been estimated to be around US$ 64.7 million (Kharakwal and Shu, 2009). Presently, conventional mutation breeding has largely given way to more precise molecular tools for creating and selecting new genetic variations in the germplasm.

Among modern biotechnologies, molecular breeding techniques have been widely used to introduce useful genes in crop plants including blast and blight resistance in rice, rust resistance in wheat and mustard, downy mildew resistance in pearl millet, and tolerance to salinity and submergence in rice (Kadirvel *et al.*, 2015). Bacterial blight resistant variety Pusa Basmati 1718 developed from a very popular Basmati variety PB1121 and having an average yield of 4.64 t/ha, has been notified for growing in the states of Punjab, Haryana and Delhi (Singh *et al.*, 2018). There are plans to further improve this variety for resistance to different biotic and abiotic stresses. Quality protein maize (QPM) is a good example of marker assisted selection (MAS) for enhancing nutritional quality of staple crops. MAS developed QPM hybrids Pusa HM-4 Improved, Pusa HM-8 Improved and Pusa HM-9 Improved with enhanced endospermic lysine (48–74%) and tryptophan (55–100%), while having similar yield potential of the respective original hybrids HM-4, HM-8 and HM-9, were released for commercial cultivation in 2017 (Hossain *et al*., 2019).

Harvest Plus, a Consultative Group on International Agricultural Research (CGIAR) research program (CRP), is a major international crop biofortification effort aimed at enhancing vitamin A, iron and zinc content of some selected food crops through breeding, including molecular breeding (https://www.harvestplus.org/what-we-do/crops). Varieties of rice biofortified with zinc, sweet potato with vitamin A, cowpea with iron and zinc, pearl millet with iron, and cassava with vitamin A have been developed and released for large scale cultivation in India and a number of countries in Africa.

An *ex ante* study carried out by the CGAIR Generation Challenge Program on the impact of marker assisted breeding (MAB) in rice and cassava in some Asian and African countries (Anonymous, 2010) concluded that though upfront costs associated with MAB were much higher compared to conventional breeding, the precision of MAB significantly slashes both breeding time and future costs resulting in substantial monetary benefits (Table 3). The technology thus contributes substantially to food security by facilitating availability of improved varieties at lower cost and in much shorter period.

Genetic modification (GM) is a powerful technology enabling transfer of desired genes across phylogenetically distant organisms. The technology has contributed to crop improvement primarily through development of varieties/hybrids with traits for pest resistance, weedicide resistance (for effective weed management), and pollination control (for hybrid production). Resistance to bollworm in cotton, fruit borer in brinjal, stem borer and sheath blight in rice that otherwise cause heavy damage to these crops has been transferred from diverse biological sources through genetic modification.

Table 3. Monetary benefits of using marker-assisted breeding

Crop, constraint, country	Incremental net present value over phenotypic selection (US$ million)
Rice	
Salinity	
Philippines	49
Bangladesh	499
India	47
Phosphorus deficiency	
Indonesia	282
Cassava	
Cassava mosaic disease, cassava green mites	
Nigeria	817
Ghana	371
Cassava mosaic disease, cassava green mites, whitefly	
Uganda	34

Source: Generation Challenge Program http://www.generationcp.org/study-3-home

Globally, genetically modified crops have been grown since 1996 and by the end of 2018 the area under these crops had reached 191.7 million hectares (mha) covering 24 countries (Table 4). The major GM crops grown around the world are maize, soybean, cotton and canola modified for herbicide tolerance, insect resistance and pollination control. Other crops developed using GM or related technologies, like genome editing and RNAi, that are under commercial cultivation/regulatory testing include β-carotene fortified rice and banana; potatoes with reduced bruising, blight resistance and, reduced acrylamide formation on frying; Bt brinjal resistant to fruit and shoot borer; drought tolerant sugarcane; browning resistant apple; high oleic soybean; and virus resistant papaya, cassava and beans. GM crops are also being developed for tolerance to heat, salinity, long spells of dryness and submergence. Regulatory approval to GM crops for consumption either as human food or animal feed

Table 4. Ten largest GM growing countries (2018)

Countries	Area (mha)	Crops
USA	75.0	Maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash, potato, apple
Brazil	51.3	Soybean, maize, cotton, sugarcane
Argentina	23.9	Soybean, maize, cotton
Canada	12.7	Canola, maize, soybean, sugar beet, alfa alfa, potato
India	11.6	Cotton
Paraguay	3.8	Soybean, maize, cotton
China	2.9	Cotton, papaya
Pakistan	2.8	Cotton
South Africa	2.7	Soybean, maize, cotton
Uruguay	1.3	Soybean
Total	**191.7**	

Source: ISAAA (2018)

and/or commercial cultivation has been granted by 70 countries (ISAAA, 2018). Among these, β-carotene fortified rice popularly called 'golden rice' deserves special mention because of its relevance in addressing vitamin A deficiency widely prevalent in developing countries, and the long history of international efforts to make it available to public (Dubock, 2019). Golden rice has been approved by regulatory authorities of Australia, Canada, New Zealand and USA for human consumption (http://www.isaaa.org/gmapprovaldatabase/).

In India, Bt cotton is the only GM crop under commercial cultivation. First released in 2002, the area under Bt cotton expanded to 11.6 mha by 2018 (ISAAA, 2018) comprising about 94 per cent of the entire cotton growing area of the country. The production of cotton has more than doubled from 15.8 million bales in 2001-02 to 36.1 million bales in 2018-19 and the productivity has increased from 302 kg/ha to 506 kg/ha during the same period, with the highest figure of 566 kg/ha having been achieved in 2013-14 (https://cotcorp.org.in/statistics.aspx, Fig. 3). The average cotton yield gain is estimated to be 30 per cent and the average farm benefits of US$ 207/ha, after deducting the cost of technology (Brookes and Barfoot, 2018a). The substantial increase in cotton production since adoption of Bt technology has turned India from a net importer to one of the largest exporters of raw cotton. Exports of cotton have registered a sharp increase from a meagre 0.05 million bales in 2001-02 to the highest figure of about 13 million bales in 2011-12 valued at about ₹234.9 billion (https://cotcorp.org.in/statistics.aspx, Fig. 4). On the basis of data collected over several years from cotton growing households in India, Qaim and Kouser (2013) concluded that the increase in family income due to adoption of Bt cotton has led to significantly improved calorie consumption and dietary quality. Adoption of Bt cotton has also led to a total reduction of 110.9 million kg (30.4%) in the use of pesticide active ingredients which has also reduced the exposure of farmers to the health hazards of pesticides.

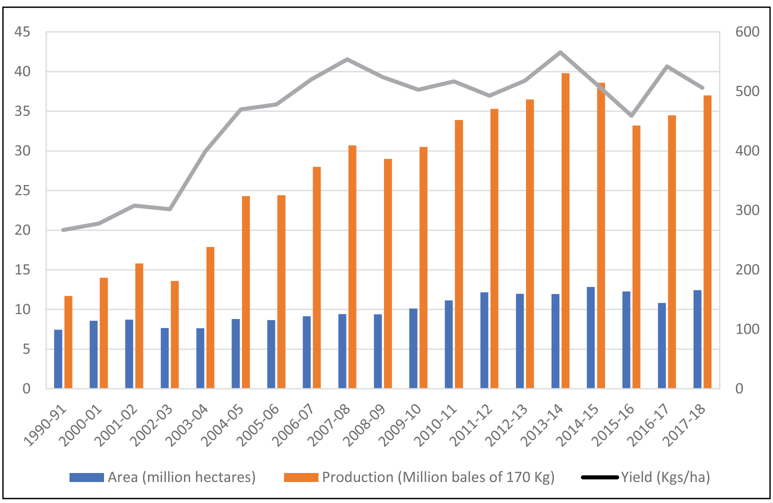

Fig. 3. *Area, production and yield of cotton in India from 2000-01 onwards*

Source of data: Cotton Corporation of India (https://cotcorp.org.in/statistics.aspx)

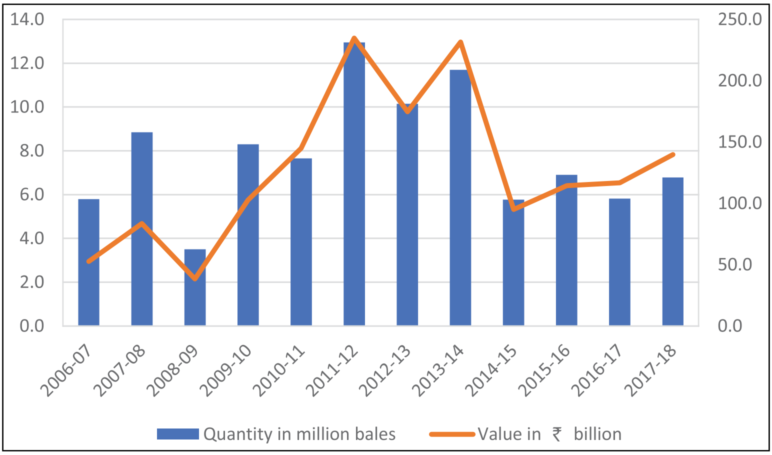

***Fig. 4.** Export of cotton from India from 2006-07 onwards*

Source of data: Cotton Corporation of India (https://cotcorp.org.in/statistics.aspx)

Harnessing New Opportunities

Highly significant advances are being made towards unravelling and manipulating genome structure and function which are enabling greater efficiency and speed in developing new crop varieties. High-throughput sequencing combined with bioinformatics has enabled rapid discovery of genes and regulatory sequences, and generated vast information regarding marker trait associations. Genome-wide association and genome-wide expression studies are uncovering molecular bases of complex traits. Genomic selection, selection based on genetic markers covering the whole genome, is emerging as an important breeding approach. Mass DNA screening of induced and natural mutants has become possible through TILLING and eco-TILLING.

Keeping pace with the huge amounts of genomic data currently being generated, large phenotyping platforms are being developed to obtain high-throughput data using non-destructive methods including advanced imaging tools and robotics. These allow quantitative studies based on numerous parameters that form the basis of complex traits, such as plant growth and architecture, pest resistance and yield (Rahaman *et al.,* 2015). Integration of modern genomic approaches, high throughput phenomics and simulation modelling are emerging as promising options to enhance crop breeding efforts (Varshney *et al.,* 2018)

Controlled environment of growth chambers is being utilized to raise up to six generations of crops per year instead of 1-3 generations possible in field or green house (Watson *et al*., 2018). The 'speed breeding' method has great potential in accelerating crop breeding research and development.

GM technology is being applied to develop biofortified crops in cereals, vegetables, fruits, oilseeds and legumes (Garg *et al*., 2018). Advanced genome engineering and editing tools enable precise genome manipulation to yield desired phenotypes and obviate the need to insert foreign genes and selectable markers that have been the main safety concerns about GM technology. Cisgenesis, intragenesis, meganucleases, zinc-finger nucleases, TALEN, and CRISPR are some of the technologies being used for inserting genes from near related taxa or to modify native gene expression by silencing, overexpression and knockout mechanism for desired results (Kamthan *et al.,* 2016, Jaganathan *et al.,* 2018). In 2016, US Department of Agriculture (USDA) decided not to regulate a mushroom and a corn modified with CRISPR/Cas9. Subsequently, in March 2018, USDA decided not to regulate any crop that has been genetically edited, as a consequence of which CRISPR edited plants are being commercially released in a short time (Waltz, 2018).

Gene drives are a class of biotechnologies that permanently alter or eliminate sexually reproducing pests through the release of relatively small number of GM organisms (Oye *et al.,* 2014). Genes in pest organisms are removed, inserted or modified in a way ensuring that when GM pests mate, all their offspring will inherit the target gene. The gene renders the pest less damaging or sterile. Success in the use of gene drive technology against crop pest *Drosophila suzukii* has been reported recently (Buchman *et al*., 2018).

Comprising "*de novo*" synthesis of genetic material and development of components, organisms and products, synthetic biology is emerging as a new field to engineer new biological systems from scratch (Liu and Stewart, 2015). The objective is to develop substances that are difficult to obtain by other means. Synthetic biology in combination with new genome editing tools is predicted to play a transformative role towards development of biosensors, novel microbial metabolites and antimicrobials that will significantly benefit agricultural productivity and sustainability (Goold *et al*., 2018).

Concerns and Challenges

Rapid population growth

Burgeoning population and diversifying food consumption patterns continue to put severe demands on our food production systems. India's population has reached 1.37 billion which constitutes 17.79 per cent of the world population of 7.7 billion (Worldometers, 2019). With a land area of 3.28 million km^2, comprising just 2.4 per cent of the global area, the pressure on land for agricultural and other multifarious purposes is enormous. Though, foodgrain production in the country has increased from 227.32 million tonnes (mt) in 2007-08 to 285.01 mt in 2017-18 (https://eands.dacnet.nic.in/), per person foodgrain availability has been varying between 442.8 g/person/day to 518.1 g/person/day during the same period, with no consistent trend (Fig. 5). By 2030, India would need 345 mt of foodgrains which with the present production trends will be difficult to achieve. It is estimated that per person availability of food energy of 2,039 kcal, 48 g digestible protein and 49 g fat available in 2011 will by 2030 fall below that of 2011 baseline and about 75 per cent of population will receive less than the required nutritional needs (Ritchie *et al.,* 2018). On the Global Hunger Index (GHI), India ranks 102 in a list of 117 developing countries (von Grebmer *et al.,* 2019). Undernourishment is prevalent in 14.5 per cent of the population and 37.9 per cent children under the age of 5 years are stunted. In fact, the

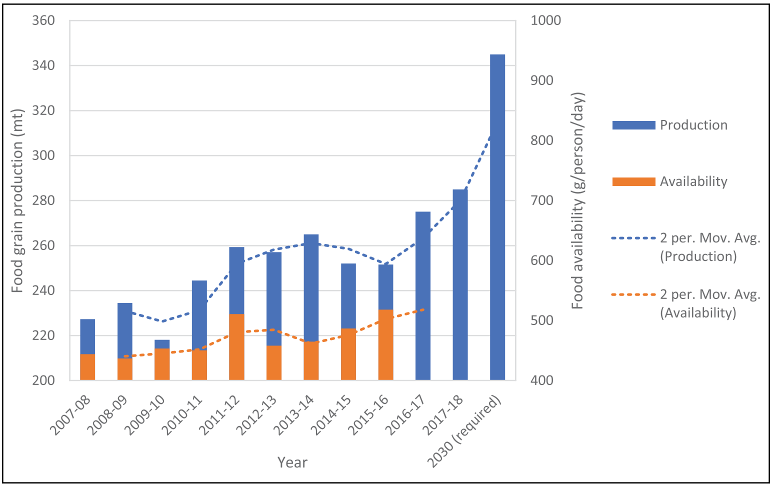

***Fig. 5.** Food grain production and food availability for the last decade in India*

Source of data: https://eands.dacnet.nic.in/

challenges of achieving food and nutrition security in the face of growing population, deteriorating and depleting environment and biological resources, and climate change are enormous. Climate change is predicted to adversely impact India on all components of crop production including area, intensity and yield. Hence, there is an urgent need to promote such practices and technologies that with minimum environmental impact enhance agricultural productivity even under adverse growing conditions.

Low R&D investments

The role of research and development in enhancing agricultural productivity and sustainability is well recognized by Indian policy makers. Public investment in agricultural R&D has been growing at more than six per cent since 1980s and during 2012-14 it averaged US$3.53 billion/year (2011 purchase power parity - PPP) (Pal, 2017). Based on full-time equivalent (FTE) scientists' involvement criteria, 63 per cent of the scientists' time share was devoted to research on foodgrain, horticulture and other crops. The budget of Department of Biotechnology, Govt. of India (DBT), which supports basic and applied research in all life science sectors, has also grown exponentially to ₹24.1 billion in 2018 (US$1.6 billion 2011 PPP) (DBT, 2018). However, when comparing the investment as per cent of agricultural GDP (termed agricultural research intensity) with that of other countries, Indian public investment in agricultural R&D is still low. During 2012-2014, India's average agricultural research intensity was 0.4 while it was 0.6 and 1.8 for China and Brazil, respectively (Pal, 2017).

Private sector investment in agricultural R&D took off since 1990s when import restrictions were removed, foreign companies were allowed to participate in input market, and subsequently in 2001 when plant breeders' rights were established. The success of Bt cotton triggered massive participation of private sector in developing new cotton hybrids using Bt genes sourced from the developers. As a result, sale of cotton seeds grew phenomenally during the following years (Fig. 6). With respect to investment in R&D, during 2008-09 private sector R&D investment in seed and biotechnology was US$ 88.6 million, of which 44.3 per cent was invested by the multinational companies (Ferroni and Zhou 2018). However,

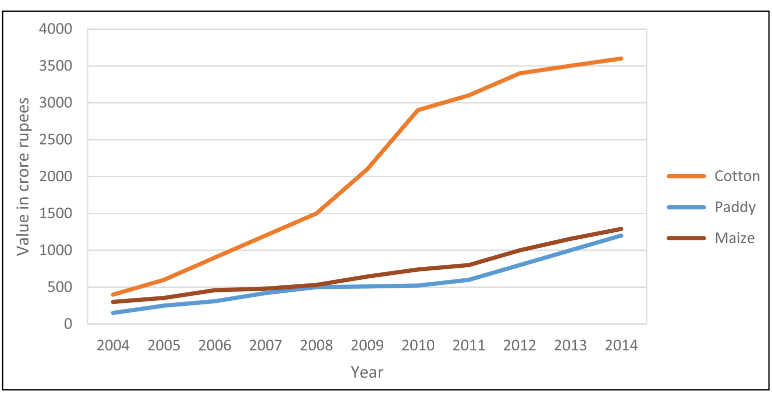

Fig. 6. *Value of seeds sold in some major crops*

Source of data: Anonymous (2015)

when compared at the global level, R&D investments of US$ 10-49 million/year (in 2014) made by individual Indian companies ranked much lower than US$ 1 billion and more/year invested by the top companies (Fuglie, 2016). Obviously, there is large scope for the public as well as private sector organizations to enhance investment in agricultural R&D, including agricultural biotechnology.

Need to improve R&D and regulatory management

NITI Ayog in its report on raising farmers' income pointed out that the Indian agricultural R&D system is under significant stress with lack of clarity on focus and inefficient use of financial resources (NITI Ayog, 2015). Collaboration among sister institutions and between laboratory and field have weakened over time and accountability declined. Consequently, there are shortfalls and delays in R&D project outputs and outcomes. Inter-institutional and public-private partnerships are hindered by similar management issues including lack of harmony between private and public R&D objectives, long gestation period and intellectual property ownership disputes.

Some initiatives of the public sector in overcoming these hurdles and encouraging innovation, translation and entrepreneurship in agriculture and biotechnology need mention. Biotechnology Industry Research Assistance Council (BIRAC) has been set-up by the Department of Biotechnology (DBT) as an Interface Agency to strengthen and empower the emerging biotechnology enterprise to undertake strategic research and innovation, addressing nationally relevant product development needs. BIRAC has supported more than 500 entrepreneurs and start-ups, including 30 biotech incubators across the country that provide incubation, nurturing and mentoring space to more than 350 biotech start-ups. The Indian Council of Agricultural Research (ICAR), through its National Agricultural Technology Project (NATP), National Agricultural Innovation Project (NAIP) and more recently, National Agricultural Science Foundation (NASF) has fostered strategic and applied research, innovation and partnership across institutions and sectors. While these have been laudable efforts, a strong need is still being felt to improve the agricultural R&D management and partnership system at various organizational levels (Mruthyunjaya and Saxena, 2017).

The need to streamline the biosafety regulatory system is evident from the cases of Bt brinjal and barnase-barstar mustard that have been long held up for approval for commercial cultivation. Biosafety evaluation of Bt brinjal started in 2000-01 with greenhouse studies (Dang *et al*., 2015). Following pollen flow, toxicity, nutritional, confined and multilocation field trials, Bt brinjal was recommended by Genetic Engineering Approval (now Appraisal) Committee (GEAC) for commercial release. However, taking cognisance of concerns expressed by some civil society ogranisations, two expert committees were set-up to examine the biosafety data. Based on the committees' reports GEAC in 2009 declared Bt brinjal safe and recommended its commercial release. However, in February 2010, the Ministry of Environment, Forests and Climate Change (MoEF&CC) imposed a moratorium on its commercial release, which continues till date. Similarly, in case of GM mustard, after years of testing and deliberations, the GEAC in May 2007 recommended its commercial release. But, the proposal is still pending with the ministry with no signs of an early release.

Cultivation of unapproved GM crops in farmers' fields is another serious issue of concern for the regulatory authorities. Cases of large-scale cultivation of herbicide tolerant GM cotton that has not been approved for commercial cultivation are being reported from time to time (Bera, 2018). To verify the authenticity of one such report, DBT constituted a committee to investigate the matter which on the basis of extensive survey concluded that 15 per cent of the cotton grown in the states of Andhra Pradesh, Gujarat, Maharashtra and Telangana contained unapproved herbicide tolerance transgene. More recently, there have been reports of unauthorized cultivation of Bt brinjal.

Intellectual property protection

Free transfer of technology from public R&D institutions to farm sector was the norm till recently, which undeniably yielded rich dividends by way of wide spread adoption of improved seeds and production technologies by farmers and the consequent boost in agricultural production. However, with the increasing participation of private sector in agricultural innovation and enterprise the need to protect proprietary material and new technologies was realised and appropriate intellectual property legislations introduced. Protection to some biological inventions like GM technology is granted under Patents Act 2005 while plant varieties are protected under Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA) 2001. It is now recognized that protection of intellectual property (IP) rights is essential to encourage innovation and entrepreneurship, the benefits of which are shared by the entire society.

An analysis of biotechnology related patents granted during 1994-2014 carried out by Menon and Jha (2015) revealed that 621 patents were granted to 13 foreign entities while just 100 patents were granted to five Indian entities, the latter including public and private sector organizations. While during the recent years, public sector R&D organizations have been laying strong emphasis on IP protection, there is obviously a vast gap between the potential and actual achievement in developing and protecting new processes and products in agricultural biotechnology.

A recent legal dispute on patentability of some aspects of GM technology highlights the need for clarity on some provisions of Patents Act and PPV&FRA. Under Section 3(j) of Patents Act, plants and animals other than microorganisms but including, varieties and species and essentially biological processes for production of plants and animals are non-patentable. Development of GM plants including multiplication of GM seed through natural reproduction has been treated as patentable. In 2017, Monsanto had filed a patent infringement case against some seed companies in India for not paying the agreed trait fees. However, Delhi High Court ruled against Monsanto holding that once Bt technology was incorporated in a plant its propagation through seed multiplication was a natural process and, therefore, could only be eligible for protection under PPV&FRA. In response to the appeal against this decision, Supreme Court of India set aside the judgement and held that the High Court should not have summarily invalidated the patent on the basis of mere examination of documents without taking inputs from experts. While the traits fee has been restored, the matter of Monsanto's patent claim remains undecided, having been remanded to the trial court.

Need to improve public perception

While the use of GM technology for crop improvement has received strong support from global scientific community, there has been stiff opposition from some other groups due to which adoption of GM crops has suffered setback in a number of countries, including India (Herring, 2009; Herring and Rao, 2012). Scientifically untenable claims of adverse impacts of GM plants and food on human and animal health and environment have created fear and suspicion in public mind. Also, many of the negative attributes of the technology expressed in public debates in fact concern general issues of modern agriculture like, consequences of intensive agriculture on environment, corporatization and foreign domination of agriculture and their impact on farmers' livelihoods and traditional practices. Due to persistent negative publicity over the years, such perceptions have gained ground despite voluminous scientific literature proving the health and environmental safety of GM crops (National Academies of Sciences, Engineering, and Medicine, 2016). In 2016, 142 Noble laureates wrote an open letter to Green Peace which is at the forefront of anti-GM campaign urging it and its supporters to "re-examine the experience of farmers and consumers worldwide with crops and foods improved through biotechnology, recognize the findings of authoritative scientific bodies and regulatory agencies, and abandon their campaign against GMOs in general and Golden Rice in particular". In India, similar efforts have been made by scientific academies like National Academy of Agricultural Sciences (NAAS), and public agencies like ICAR, DBT and MOEF&CC to convey factual information and balanced opinion about GM technology. However, such efforts have been sporadic and overall public investment in knowledge dissemination and awareness has been very limited.

Capacity development

In order to effectively fill the above mentioned gaps in application of agricultural biotechnology, the importance of appropriate infrastructural and human capacity cannot be overemphasized. Commendable support has been provided by ICAR, DBT, MoEF&CC and other organizations in building physical and organizational infrastructure and human resources, notwithstanding the paucity of funding detailed earlier in this paper. However, considering the rapid technological advancements being made globally, and scientific, legal and social issues needed to be addressed during the course of biotechnology product development and delivery, there is need for regular augmentation and modernization of physical and technical capacities. Varshney *et al.* (2012) pointed out that lack of adequate infrastructure and training makes it difficult to collect required phenotypic data for such complex traits as drought which hinders the use of genomic information for practical purposes. Similarly, regulators face the challenge of keeping abreast of rapidly advancing technologies and evaluating their bearing on biosafety regulation.

The Way Forward

The need to enhance agricultural productivity, nutritional quality of food, its accessibility to all sections of the society along with economic and social security of farmers cannot be overemphasized. While conventional crop improvement methods continue to be relevant, the food and nutrition needs of the growing population combined with depleting and deteriorating natural resources and emerging challenges of climate change necessitate adoption of new science for sustainably enhancing crop productivity and nutritional quality. Hence, to fully harness the potential of biotechnology, there is an urgent need for appropriate policy support, enabling environment and a clear Road Map to move forward. In this context, urgent action on the following recommendations is warranted:

Prioritizing biotechnology for food and nutritional security

- A national policy on agricultural biotechnology is required to be formulated highlighting its expected role in achieving food and nutritional security. A list of priority crops along with needed genetic improvements for each of them needs to be compiled and a strategic plan developed for urgent action at the national level.

- Public sector investment in agricultural biotechnology needs be doubled. To ensure delivery of expected outputs at the farm level, the funding commitments need to be long-term. Indian private sector also needs to increase substantially its investment in R&D in order to become globally competitive and come out with new innovations. For this, a conducive policy environment needs to be created by the government.

- Greater attention needs to be given to strengthening public-private partnerships to ensure timely delivery of biotechnology products from development through validation, field testing and commercialization. Public-private partnerships should also be harnessed to build agribiotechnology business enterprises, agribusiness platforms and technology parks.

- Strong coordination between different R&D funding institutions like ICAR, DBT, Department of Science and

Technology (DST) and other agencies is needed to work synergistically and avoid redundancies.

Biotechnology R&D priorities

- Development of nutritionally enhanced and biotic and abiotic stress resistant crop varieties that are well adapted to changing climate should be given high priority. Improvement of underutilized crops of high nutritional value and wide adaptation should also be taken up on priority. In states with intensive crop cultivation, adoption of herbicide tolerant genotypes needs to be considered especially in case of pulses, oilseeds, *kharif* cereals and vegetable crops.

- Given the relatively long time and expense involved in commercialization of GM crops, alternative biotechnological options should also be explored to achieve the desired improvement goals. Also, considering the huge diversity in plant genetic resources available *in situ* and in genebanks, the use of wild and weedy crop related species as sources of new genes needs to be enhanced substantially.

- The R&D programs should be executed by multidisciplinary teams with proper coordination, monitoring, evaluation and impact assessment.

Biosafety regulatory and IP management

- There is a strong need for reforming the regulatory system to make the decision making process fully science based, predictable and time bound. Taking into account the experiences since the enactment of Environment (Protection) Act, 1986, DBT had developed an elaborate blue print for reorganizing and modernizing the biotechnology regulatory system. The Biotechnology Regulatory Authority of India (BRAI) Bill which was first placed in the parliament in 2008 should be revived, further reviewed and updated, and reintroduced in the parliament on priority.

- In view of the fact that genetic modification related technologies are evolving rapidly, regular review of biosafety regulations should be carried out to harmonise these with the new developments and knowledge.

- In order to fully evaluate the prerelease performance of newly developed GM crop varieties/hybrids, confined field trials should be undertaken in collaboration with ICAR institutes and SAUs following the well-established system of multilocation testing for the release of conventionally developed new varieties along with appropriate safety protocols.

- To encourage researchers to think more creatively and develop innovative technologies and products, IP in development of new varieties/hybrids and introduction of desirable traits through GM and related technologies should continue to receive protection under PPV&FRA and Patents Act. Appropriate clarifications may be made in the two Acts, if needed.

- Several important biotechnological processes, like those related to CRISPR, are protected by patents. Government agencies should facilitate their availability to the country's scientists through a centralized system of license negotiations.

Capacity development

- Infrastructure for large scale phenotyping under controlled and open environments should be developed on priority, preferably in different agroclimatic zones of the country. This would also include efficient systems for storage, analysis, protection and sharing of the data.

- Greater thrust needs to be given on training and skill development programs especially in advanced molecular breeding, gene editing, genomics, phenomics and related information acquisition and handling tools. Since biotechnology R&D capacity differs widely across laboratories and institutions, it is desirable to conduct project-based capacity development needs assessments taking into account individual and institutional capacities, objectives and expected outputs of the projects. Equal attention also needs to be given to capacity development in biosafety research and regulation, intellectual property management, partnership building and public communication.

Public awareness

- Public awareness efforts need to be considerably enhanced to effectively communicate among various sections of the society factual information on the benefits and concerns about biotechnology and its regulation. Proactive strategies involving science-based messages suited to different audiences need to be developed to promote constructive dialogue with stakeholders ranging from policy makers to producers, traders and consumers.

- Existing public extension system like ICAR Krishi Vigyan Kendras also need to be involved and suitably equipped to take up the responsibility of information dissemination and advice to farmers, particularly about field management of GM crops.

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- Horticulture for Food and Nutritional Security - Strategy Paper by Dr. K.L. Chadha and Dr. V.B. Patel, October, 2019.

Brief Resume

Dr. J. L. Karihaloo, former Director, ICAR-National Research Centre on Plant DNA Fingerprinting and ICAR-National Bureau of Plant Genetic Resources, New Delhi, did his M.Sc. in Botany from Jammu & Kashmir University, and Ph.D. in Botany (cytogenetics and cytotaxonomy) from Jammu University. He was also trained in biochemical and molecular systematics at University of California, Davis. Dr. Karihaloo joined Indian Council of Agricultural Research (ICAR) in 1978 and served the organization in different capacities at ICAR-Grassland and Fodder Research Institute, Jhansi, ICAR-Indian Institute of Horticultural Research Institute, Bengaluru, and ICAR-National Bureau of Plant Genetic Resources. He joined Asia-Pacific Association of Agricultural Institutions (APAARI) in 2006 as Coordinator of its biotechnology programme and as Senior Consultant, APAARI in 2015 where he served till 2017.

Dr. Karihaloo is a recipient of Rafi Ahmed Kidwai Award of ICAR, and Prof. V. Puri Medal of Indian Botanical Society. He has been Editor-in-Chief, Indian Journal of Plant Genetic Resources and Vice-President, Indian Society of Plant Genetic Resources. He has published over 120 research and review articles, book chapters and books including on agricultural biotechnology development and policy issues. Dr. Karihaloo has been a faculty member of three universities and is currently a member of a number of R&D advisory and technical expert committees.

Dr. Raj Paroda, former Director General, Indian Council of Agricultural Research (ICAR) & Secretary, Department of Agricultural Research and Education (DARE), Government of India, holds a unique perspective as an accomplished scientist, able research administrator and development practitioner. He is well known for modernization and strengthening of the national agricultural research system (NARS) in India as well as in many other countries. Government of India has recognized his contributions to the advancement of agriculture by bestowing on him the prestigious national Padma Bhusan Award. He is recipient of several awards and recognitions - Rafi Ahmad Kidwai Award, ICAR Team Research Award, FICCI Award, Om Prakash Bhasin Award, BP Pal Gold Medal, Borlaug Award, Mahendra Shiromani Award, Dr. AB Joshi Award and US Awasthi IFFCO Award. Dr. Paroda had been the founder chairman of Global Forum on Agricultural Research (GFAR) based at FAO, Rome. He also served as President of the Indian Science Congress and President of the National Academy of Agricultural Sciences. Seventeen universities have awarded him D.Sc. (Honoris Causa) degree including Ohio State University and Indian Agricultural Research Institute. He is Fellow of all science academies in India, Third World Academy of Sciences, Russian Academy of Agricultural Sciences, and Honorary Member of American Society of Crop Science and American Society of Agronomy. He also served for more than two decades as Executive Secretary of Asia-Pacific Association of Agricultural Research Institutions (APAARI), FAO, Bangkok. Till recently, Dr. Paroda worked as Chairman, Farmers Commission of Haryana. He had also served on ACIAR, CABI and WMO Advisory Committees, was Chairman of Board of Trustees of ICRISAT and member of finance committee of CGIAR. He is a member of CGIAR-SIMEC and Board Director of International Fertilizer Development Center (IFDC). Currently, he is the Founder Chairman of the Trust for Advancement of Agricultural Sciences (TAAS), New Delhi.