India needs genetic modification technology in agriculture

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India does not have a clear stand on the release and consumption of genetically modified crops (food). The only approved crop is Bt-cotton, which has put India on the global map as a cotton exporting country. Even so, Bt-brinjal is under moratorium and GM mustard is prevented from undergoing commercial trial. All these decisions are not based on sound scientific principles. Activism against has successfully prevented exploitation of a powerful technology that can contribute to India's food and nutrition security. This article attempts to give a balanced perspective of genetic modification technology as one of the serious options to be considered on case to case basis. Ambivalence will seriously affect India's food security in the future.

Keywords: *Bt*-cotton, food security, gene editing, genetically modified crops, mustard.

GENETIC modification technology in agriculture evokes strong reactions, both for and against. Even globally, a consensus has not been possible. Often the negative perceptions have not been based on sound scientific evidences, but the fact remains that the general public can easily be led on this path. India has huge challenges in terms of population growth and limitations in terms of availability of land, water and human resources for sustained agriculture to ensure long-term food and nutrition security. Therefore, the country cannot afford to miss out on any technology that can possibly help in achieving a sustainable and productive agriculture system. We do believe that genetic modification technology is worth looking at on a case-to-case basis, although it is not a magic bullet to solve all issues of agriculture. In this article, we deal with the negative perceptions in general as also discussed in a recent review[1]. These perceptions are highlighted, followed by analysis based on hardcore scientific evidences.

Bt and herbicide-tolerant crops have genotoxic effects

This perception is at variance with the consensus arrived at by major science academies of the world that include, the US National Academy of Sciences, American Association for the Advancement of Science, Royal Society (UK), African Academy of Sciences, European Academies of Science Advisory Council, French Academy of Science, American Medical Association, Union of German Academies of Science and Humanities, Indian National Science Academy and others. Briefly, the US National Academies of Sciences, Engineering and Medicine have published a 420-page document in 2016 on genetically modified (GM) crops[2]. A committee with 20 members covering the areas of plant breeding, agronomy, ecology, food science, sociology, toxicology, biochemistry,

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life science communication, molecular biology, economics, law, weed science and entomology held three public sittings, 15 webinars, heard around 80 speakers from the US, Canada, the UK, Australia, representatives from the African Union, World Trade Organization (WTO) and European Food Safety Authority, besides participating in workshops, acquiring data from other countries and analysing over 700 publications in peer-reviewed and non-peer-reviewed journals/documents. The report was reviewed by 26 other scientists and professionals. The painstaking effort of the committee to arrive at an independent, unbiased analysis is evident. The report makes the statement '*Bt* in maize and cotton from 1996 to 2015 contributed to a reduction in the gap between actual yield and potential yield under circumstances in which targeted pests caused substantial damage to non-GE varieties and synthetic chemicals could not provide practical control'. The report makes an interesting observation that use of *Bt* crop has actually increased insect biodiversity on farms compared to those of non-*Bt* crop on which insecticide was sprayed. The report adds that the emergence of secondary pests and resistant pink bollworm in India is a typical example of non-implementation of the refuge strategy. An earlier report in 2010 by the conservative European Commission states, 'The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not *per se* more risky than conventional plant breeding technologies'[3]. In 2016, 107 Nobel laureates had also appealed to Greenpeace to rethink its longstanding opposition to genetically modified organisms (GMOs). In view of all these, it is stated that the 'anti-GMO campaign is scientifically baseless and potentially harmful to poor people in the developing world. GM foods are just as safe to eat as conventional foods and don't pose an inherent risk to the environment (though, like any technology, they can be misused)'.

The positive outcomes from GM crops have also been recorded in data analysed from a large number of publications in credible, peer-reviewed journals. For instance, '147 original studies based on primary data from farm surveys anywhere in the world reporting impact of GM soybean, maize or cotton on crop yields, pesticide use, and farm profits have shown that on an average, GM technology adoption has reduced pesticide use by 37%, increased crop yields by 22% and increased farmer profits by 68%. Yield gains and pesticide reductions are larger for insect-resistant crops than for herbicide-tolerant crops. Yield and profit gains are higher in developing countries than in developed countries'[4].

Datasets on livestock from publicly available sources, starting from the year 1983 and representing over 100 billion animals did not reveal unfavourable or perturbed trends in livestock health and productivity after the introduction of GM crop-feeds[5]. The report compared the data from 1983 to 1996, a period before the introduction of GM crops and from 1997 to 2011, a period in which animal feeds were predominantly from GM crops[5].

Failure of *Bt*-cotton

A perusal of the data on area, production and yield of cotton before and subsequent to the adoption of *Bt*-cotton provides clear evidence of the positive impact of *Bt* trait on cotton production and consequent benefits to the farmers and the country[6]. Cotton production in the years just prior to *Bt*-cotton becoming popular with the farmers (2001–03) ranged between 13.6 and 15.8 million bales with the yields ranging between 278 and 308 kg/ha. In year 2003–04, when *Bt*-cotton was adopted by many farmers, the production was 17.9 million bales and the yield was 399 kg/ha. In 2013–14, the production reached 39.8 million bales and the yield was 566 kg/ha. While there was a fall in production during the subsequent two years, it picked up later with the yield reaching 568 kg/ha in 2016–17. In 2016, 7.2 million cotton farmers adopted insect-resistant *Bt*-cotton hybrids representing 96% of estimated 11.2 m ha in India. The estimated average yield gain during this period was 30% of the total[7]. The average farm benefit after deducting the cost of technology was estimated to be US $207/ha. The consistent increase in cotton production since adoption of *Bt* technology 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 an all-time high level of 11.7 million bales in 2013–14, valued at Rs 23,153.24 crores (ref. 6). Recent statistics (2017–18) indicates that India is the largest producer of cotton (6205) followed by China (5987) and USA (4555); production figures given in parenthesis represent million metric tonnes.

Adoption of *Bt*-cotton also led to a substantial positive environmental impact due to reduction in insecticidal sprays for the control of cotton bollworm. It is estimated that there has been a reduction of 110.9 million kg, constituting 30.4% of the total in the use of pesticide-active ingredients since the adoption of *Bt*-cotton[8]. Along with reducing the load of these pollutants on the environment, *Bt*-cotton has helped in reducing the exposure of farmers and other farm workers to pesticides. It is reported that *Bt* cultivation in India has reduced pesticide poisoning in nearly 2.5 million cases[9].

An objective analysis on farmer suicides in India indicates the following: non-farmers are more likely to commit suicide than farmers in six out of nine cotton-growing states (annual suicide rates being 29/100,000 for farmers versus 35/100,000 for non-farmers)[10]. In 2001, before the introduction of *Bt*-cotton, the suicide rate was 31.7/100,000 and in 2011, after the introduction of *Bt*-cotton, it was 29.3/100,000 (ref. 11). The Indian farmer suicide story is complex, based on tragic individual anecdotes rather than on the failure of *Bt*-cotton per se. The question to be asked is, 'what would have been the cotton-yield at present, had *Bt*-cotton not been introduced in 2002?'

Although India has become the largest producer of cotton, our yield in terms of productivity is still low compared to the global average among *Bt*-cotton-growing countries. Infestation by secondary pests is also due to the use of inappropriate long-duration hybrids, and specificity of the deployed *Bt* gene towards bollworm and inability of the Indian farmers to follow the refuge strategy. The use of pesticides started increasing with the onset of secondary pests, which will require deployment of required genetic resistance through GM or non-GM means. There have been issues with productivity in rainfed areas. India is the only country using hybrids, while all other nations growing *Bt*-cotton use varieties with yields ranging from 1000 to 2500 kg/ha. India was the first country in the world to have grown hybrid cotton on a commercial scale, which led to significant increase in cotton yield. While so far *Bt* gene has been introduced in hybrids only, Punjab Agricultural University, Ludhiana has developed a true-breeding *Bt*-cotton variety (PAU Bt 1). More recently, as many as eight *Bt*-cotton varieties have been released and notified by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties in Agricultural Crops. This is a welcome development. The slightly lower yields in varieties are compensated by the ability to grow the plants densely, unlike the more spreading-type hybrids. If *Bt*-cotton varieties had been developed in time, the yield would have increased significantly, and the farmers would have also benefited from the low cost of seeds and ability to store the seeds for their own use unlike in the case of hybrids. Development of resistance is an inherent property of pests and pathogens, and is not unique to *Bt*-cotton. Adjunct strategies are always used to prolong the efficacy of the primary protectant, be it a drug used in human therapy or *Bt*-cotton to protect against pests. Therefore, there is nothing wrong in propagating traditional integrated pest management (IPM) along with the use of *Bt*-cotton. Pyramiding with genes to protect against secondary pests is also a priority. One such gene from fern has indeed been shown to protect against whitefly infestation when introduced into cotton[12]. It needs to be realized that *Bt* gene is only meant to protect against pest infestation and the associated loss, and it does not have inherent growth-promoting properties to increase the yield. Thus, *Bt* gene can work with short-term varieties and organic cotton as well to protect against pest infestation, and thus increase the net yield. Overall, while *Bt*-cotton has been a success in India to enable export and generation of revenues, strategies as outlined above are needed to further enhance and sustain high productivity levels.

Moratorium on *Bt*-brinjal is justified

Moratorium on *Bt*-brinjal is the most unfortunate step taken by the Government of India in 2010. This singular act has crippled the R&D on transgenic crops. Brinjal is a striking example where toxic pesticide sprays can be as high as 80 and more to protect against fruit and shoot borer. The development of *Bt*-brinjal took a decade of safety and yield studies by public-funded and private institutions in India. It is ironical that Bangladesh has taken up the technology based on data generated in India and has made it a success. Reports indicate that more than 25,000 Bangladeshi farmers are cultivating *Bt*-brinjal. The crop was given to farmers in Bangladesh free of royalty charges and they were allowed to keep the seeds for the next season. It is a possibility that *Bt*-brinjal could have crossed over the international borders into India. One feels aghast at the way anti-GMO campaigners have attempted to scuttle *Bt*-brinjal cultivation in the Philippines and Bangladesh through false propaganda. These include: destroying *Bt*-brinjal-growing sites; bringing an injunction through courts; *Bt*-brinjal crop that has reached the end of its growing season after several harvests shown as an example of failed crop; children consuming *Bt*-brinjal would get paralysis; if insects do not eat *Bt*-brinjal, then it cannot be suitable for human consumption[13]. The fact remains that Bangladesh has been able to reap the benefits due to the hard stance taken by its Minister for Agriculture, and by 2017, 7500 farmers in 36 districts were growing *Bt*-brinjal and pesticide sprays have been dramatically cut down. *Bt*-brinjal in Bangladesh is an encouraging success story with great economic impact[14].

It is well known that certain publications in journals that are not popular, or even predatory journals were used by activists to spread fear psychosis among the public that GM crops and food are not safe. It is a fact that that the report by Seralini on the toxicity of GMOs to experimental animals had to be withdrawn. Food Standards Australia/New Zealand, European Food Safety Authority (EFSA), German Federal Institute for Risk Assessment, and Health Canada have all rejected the findings of Seralini on the basis of faulty experimental design and wrong choice of experimental animals[15].

Herbicide-tolerant crops using glyphosate linked to cancer and other health hazards

Breeding of hybrids to exploit the phenomenon of heterosis between divergent parental lines has been a major development in the field of plant breeding in the 20th century. Hybrid breeding has two components – a pollination control system and good combiners (parental lines). In a self-pollinated crop like mustard, a good pollination control system is essential for hybrid seed production, which could be useful for all times to come –

combiners will keep on changing. The barnase and barstar system has already been proven to be an excellent pollination control system in rapeseed and has been in use since 1996. The same set of genes has been used in mustard. The mandate of the Biosafety Research Level (BRL) trials is to conduct biosafety studies on the transgenic events and to test the efficacy of the introduced traits in the field. These trials have been successfully conducted on the barnase, barstar lines of mustard. DMH-11 is the first hybrid – many will follow if the technology is allowed to be adopted. Yield increase is not due to the pollination control system, but due to the combiners used. Herbicide gluphosinate needs to be used only in the hybrid seed production plots, though it is true that the resulting hybrids would also be tolerant to the herbicide. The concern is whether the farmers would start using herbicide in the fields. In such a case, the use of an approved herbicide by the mustard farmers to control notorious weeds may become a necessity. It is important to note that this pollination control system for mustard has been developed by a public sector organization in India, and is an excellent demonstrator of our capabilities in this field. The positive effects on yield of mustard will be observed in the years to come as newer hybrids that have the requisite yield potentials are developed. The recommendation is that mustard breeders should be allowed to use this technology to generate newer generation of hybrids that will contribute greatly to enhancing farmers' income and our national exchequer. Why is there so much anxiety among activists to scuttle the technology?

There is a question mark on the use of herbicide-tolerant crops because glyphosate is linked to cancer. The perception that glyphosate is a dangerous herbicide based on the International Agency for Research on Cancer report does not take into account that this judgement was opposed by all other scientific agencies in the world, including EFSA[16]. An elaborate discussion on glyphosate safety and the vested interests involved in the decision-making process is given elsewhere[13].

Another area where genetic modification technology can make a major impact is in the improvement of nutritive quality of our grains/vegetables. Golden rice with provitamin A in rice seed, which took close to two decades of development and trials by Ingo Potrykus and Peter Beyer is available[17]. While India is struggling to do the field experimentation, Bangladesh is now in advanced stage for its release for commercial use. The Prime Minister of India has catalysed import of gene constructs for provitamin A, iron, Fusarium wilt and virus resistance from Australia to develop beta-carotene-rich, disease-resistant transgenic banana as an affordable source of vitamin A that can prevent blindness in millions of children. Similarly, there is scope to improve micronutrient status of grains/vegetables.

Yet another technology that has already made inroads in agriculture is gene editing, where existing genes can be precisely modified. It is also possible to introduce a new gene with precision. Non-browning apple, potato resistant to late blight, high-iron rice and others have become a reality. This technology can bring desired changes by altering the existing genes in a crop. The application of CRISPR-Cas technology in editing banana genes has also been reported from an Indian laboratory[18]. Mutation breeding of seeds has been an accepted norm in the country. The United States is treating gene editing as one among the technologies to modify the existing genes and therefore, it would not require any regulatory approval. Europe has decided to treat gene-edited crop/plant as a GMO, needing regulatory trials for approval. It is important that India formulates regulatory norms at the earliest on the use of gene editing in agriculture as a potential tool for a variety of applications. Furthermore, it is important to ensure that Indian scientists have 'freedom to operate this technology' and appropriate strategies have to be developed in this regard, as the enabling technologies are patented.

Regulatory bodies have conflict of interest and lack of expertise

Reports of Parliamentary Sub-committees on Agriculture (PSCs) and Technical Expert Committee (TEC) appointed by the Supreme Court, critical of these bodies, are generally used by activists to criticize the regulatory bodies. The five-member TEC recommended an indefinite moratorium on field trials of GM crops and a complete ban on their commercial release. However, critics in general omit the fact that R. S. Paroda (former Director-General of ICAR and member of the committee) was not part of the report submitted in 2013. He has made it clear to the Court that the report was submitted without his consent and was 'neither transparent nor objective', and submitted a separate report recommending continuation of field trials[19]. While there is always scope for improvement in any institution, indictment of the regulatory bodies is an insult to the integrity of a large body of scientists who have toiled hard for years to monitor the trials and be part of the approval process. After all, the trials, be it GM mustard or *Bt*-brinjal, have lasted for over a decade and have been carried out in earnest.

Our appeal

The recent statement of M. S. Swaminathan, father of the Green Revolution in India, 'I wish to … reiterate my total commitment and support to modern technologies including genetic modification and gene editing. Also, my emphasis has been on generating synergy between technology and public policy' (*The Hindu* dated 19 December 2018, and personal e-mails) is encouraging and is a harbinger for acceptance of the policy for the application of modern technologies to Indian agriculture. We only want to reiterate that the genetic modification technology is definitely one of the options to ensure food and nutrition security in the country, including biotic and abiotic stresses. The obsession with endless debates on *Bt*-cotton is scuttling initiatives to explore modern technologies in other areas such as saving fertilizer use and utilizing photosynthetic efficiency for greater productivity. It would not be appropriate to discard the technology based on propaganda without a scientific basis. This is discouraging even for research students to get into the area on gene modification in agriculture. It is not a good augury for a developing country like India, with aspirations to ensure food and nutrition security to over 1.3 billion people and more than 500 million livestock (excluding poultry).

One needs to assess rationally on a case-to-case basis and adopt the most appropriate technology. We are also clear that each case has to be assessed based on the source of transgene, trait to be introduced, path of gene expression, phenotypic expression, effect on the environment, safety trials required and economic viability in relation to other technologies available. The public-sector institutions have a major role to play in the development of GM crops, so that the interests of farmers and public are top priority.

Challenges would always arise in sustaining productivity, and scientists should have the space and access to address the concerns and come up with newer solutions. No one is championing to dispense with regulatory issues of safety to health and environment. Our regulatory bodies follow one of the strictest protocols for evaluation. There is always scope for improvement and more innovative ways of informing and involving the farmers and public in the development and use of modern technologies. While scientists can develop the technologies and experts can work out an appropriate regulatory regimen, the political decision to accept GM crops/plants, whether it is a case of bringing a gene from outside or precisely changing an existing gene, on a case-to-case basis, is essential. To start with, on a rational scientific basis, it is time to deregulate *Bt* genes in use, based on a huge amount of data attesting to their safety, and lift the moratorium on *Bt*-brinjal cultivation. This is also in tune with the recommendation of the National Academy of Agricultural Sciences (India), which states 'It is high time to approve environmental release of the GE varieties, which have been tested to be bio-safe, to extend the benefit of growing these varieties to the farmers and consumers without further delay'[20].

Finally, it is our considered view that it is time enough for India to employ and adopt genetic modification technologies for improved agricultural productivity and profitability, and contributing to sustainable food and nutrition security. Ambivalence and indecision will hurt us deeply, and ultimately the country would be the loser.

Conflict of interest: The authors have worked or are working with genetically modified crops funded by various agencies over several years.

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