# GLOBAL STATUS OF COMMERCIALIZATION OF GM CROPS WITH SPECIAL REFERENCE TO INDIA

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Advances in genetics and genomics have led to the development of GM crops during the early nineties. Agricultural biotechnology is perhaps the single most significant technology that got wide acceptance after the green revolution. Agricultural biotechnology has obvious advantages in terms of higher yields, improved nutritive value, reduced pesticide consumption, enhanced stress tolerance of the crop *etc.* Though protocols are available for assessing the safety aspects of GM crops, the society at large is concerned about the safe use of such varieties. Cultivation of GM crops increased tremendously from 1996 onwards. Now GM crops are cultivated in a total area of 189.8 million hectares in 26 different countries. In terms of global area under biotech crops, the US occupies first position with an area of 75 mha, followed by Brazil (50.2 mha), Argentina (23.6 mha), Canada (13.1 mha) and India (11.4 mha). The major GM crops now cultivated globally include soybean, maize, cotton and canola. Still more GM crops such as rice and banana are in the pipeline under different stages of field testing in many countries. The only commercially grown GM crop in India is Bt cotton. India became the largest producer and exporter of cotton by the adoption of Bt technology and has the world's fifth largest area with a single GM crop. Though several countries, particularly in Europe restrict GM crop cultivation, import of the same as food/feed is permitted. It is expected that countries such as China might come up with more GM crops and will become a major player in agricultural biotechnology in near future.

**Key words**: Biotech crops, Genetic modification, GM plants, GM adoption

## INTRODUCTION

Led largely by the United States, the 1980s saw remarkable progress in plant genetic engineering and agricultural biotechnology research that led to the production and subsequent commercial cultivation of genetically modified (GM) crops. USA has approved 197 single trait events in 19 crop species since 1996. The country has the highest percentage (40%) of the global biotech crop area of 189.8 mha planted in 2017 (ISAAA, 2017). GM tobacco with antibiotic resistance and GM tomato with longer shelf-life are the early examples of GM plants. The first commercial GM crop was the Flavr Savr tomato developed by the US agro-biotech company Calgene in the early 1990's (Kramer and Redenbaugh, 1994). Antisense gene technology was successfully adopted in the GM tomato to supress

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expression of polygalacturonase gene involved in the degradation of cell wall pectin, a process that hastens fruit ripening. In 1994, Flavr Savr GM tomato cultivated in the US became the first commercially harvested GM crop in the world and this had the approval from the US Food & Drug Administration.

Elaborate protocols are in place for testing biosafety of GM crops before they are released for commercial cultivation. Even though society at large was sceptical of GM crops due to safety and ethical concerns and political and commercial reasons (and some are still sceptical, including scientists), worldwide production of GM crops has increased sharply in the last 20 years. This rapid increase makes biotech crops the fastest adopted crop technology of the last decades. But there is still considerable resistance to their widespread adoption, particularly in Europe and India. Analysis of hundreds of studies shows that GM and conventionally-bred crops are similar in risks, if any, to human and environment health and hence GM crops are safe (DeFrancesco, 2013; Nicola *et al.*, 2013), although not with criticisms, often highly opinionated to the contrary.

Today, as much as 13 per cent of the global arable land is occupied by one or the other GM crop (Lucht, 2015) and in a few cases a substantially large share of the global production is from a single GM variety clearly indicating the wide acceptance of GM technology in agriculture. Globally, 50 per cent of the total crop area for soybeans, 13 per cent for cotton, 31 per cent for maize and 5 per cent for canola were planted with GM varieties in 2017. The global market value of GM crops during 2017 was to the tune of USD 18.2 billion (ISAAA briefs 2017). This paper gives an overview of the present global status of acceptance of GM crops and briefly discusses adoption of GM crops in India.

**Major GM crops**

A large number of GM crops are commercially cultivated or at advanced stages of evaluation in many countries today (Table 1). The major GM crops that are commercially cultivated now are soybean, maize, cotton and canola (Table 2). In terms of the global share of area under GM cultivation, the crops in their decreasing order of ranking are soybean, maize, cotton and canola (Table 2). In terms of global area under biotech crops, the US occupies first position with an area of 75 mha, followed by Brazil with 50.2 mha. According to the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) briefs in 2017, the 75 mha GM acreage comprised 34.05 mha soyabean, 33.84 mh maize (corn), 4.58 mha cotton, 1.22 mh alfalfa, 0.876 mh canola, 0.458 mha sugar-beet, 3,000 hectares potato and around 1,000 hectares each of apples, squash and papaya.

Still more GM crops are in the pipeline, which are now at different stages of field testing in many countries (Stein, 2010; Parisi *et al.*, 2016). These include golden rice with more beta-carotene (Philippines and Bangladesh) and GM banana with tolerance to bunchy top virus (Uganda). Wheat is one among a number of GM crops that have been approved for experimental field planting in Australia. Similarly GM wheat (with high yield and biomass) and potato (with tolerance to leaf blight) are under field trials in Europe. Other crops in the pipe line are Maris Piper potatoes with less bruising and less acrylamide and omega-3 enriched Camelina in Europe union (EU), pest tolerant chickpea, pigeon pea and mustard in India, drought tolerant sugarcane in India and

Table 1. **GM crops, traits modified and cultivated/tested countries**

| GM crop | Traits modified | Countries testing/growing |
|---|---|---|
| Alfalfa | Herbicide tolerance | US., Canada, Mexico |
| Argentine | Herbicide tolerance | Canada, US, Japan, Australia |
| Carnation canola | Modified flower colour and herbicide tolerance | Australia, European Union |
| Chicory | Herbicide tolerance, weed resistance and higher yields | European Union |
| Cotton | Improved insect protection, herbicide tolerance and resistance to weedicides | Australia, US, China, Mexico South Africa, Argentina India, Indonesia, Philippines, Brazil |
| Maize | Herbicide tolerance Insect resistance | Canada, Japan, US, Argentina, EU, South Africa, China, UK Russia, Korea, Uruguway |
| Flax | Herbicide tolerance, antibiotic resistance | Canada, US |
| Linseed | improved weed protection | |
| Green pepper | Virus resistance | China |
| Melon | Delayed ripening | US |
| Papaya | Virus resistance | US, Canada |
| Polish Cenola | Herbicide tolerance and improved weed control | Canada |
| Potato | Improved protection from insect and leaf roll virus | US, Canada, Japan, Australia, Philippines |
| Rice | Herbicide resistance | US |
| Soybean | Improved weed control and herbicide tolerance | US, Argentina, Japan, Canada, Uruguay, Mexico, Brazil, South Africa, Czech Republic, European Union, Korea, Russia, Switzerland, Taiwan, U.K., Philippines and Australia |
| Squash | Resistance against watermelon mosaic virus | US, Canada |
| Sugar beet | Herbicide tolerance | Australia ,US, Canada, Japan, Philippines |
| Sunflower | Herbicide tolerance | Canada |
| Tobacco | Herbicide tolerance | US |
| Tomato | Improved shelf life, taste, color and texture, insect and virus resistance | China, US, Mexico, Japan, Canada |

**Source:** Mishra *et al.* (2006)

Table 2. **Major GM crops, their cultivated area and share of total production**

| Crop species | Global area under GM (m ha) | % share of total cultivated area | % share of total global production |
|---|---|---|---|
| Soybean | 94.1 | 23 | 77 |
| Maize | 59.7 | 32 | 32 |
| Cotton | 24.1 | 20 | 80 |
| Canola | 10.2 | 30 | 30 |

Indonesia *etc*. In 2017, farmers in the USA and Canada planted biotech alfalfa. Approximately 1.14 million hectares of herbicide tolerant alfalfa and 80,000 hectares of low lignin alfalfa were planted in the US, while Canada planted 3,000 hectares low lignin alfalfa. Other than soybean, maize, cotton, canola, and alfalfa, the following biotech crops were also planted in different countries: sugar beet, squash, papaya, eggplant, potato and apple.

Higher nutrient content of the food product is emphasized in the second generation GM crops. Golden rice enriched with vitamin A and iron could address the problem of malnutrition in developing countries, including India where rice is a staple food (Stein *et al*., 2006).

**Area under GM crops**

Globally, there has been steady increase in the area under cultivation of GM crops (Fig. 1).

Between 1996 and 2017, area under GM crops increased 112-fold, largely due to

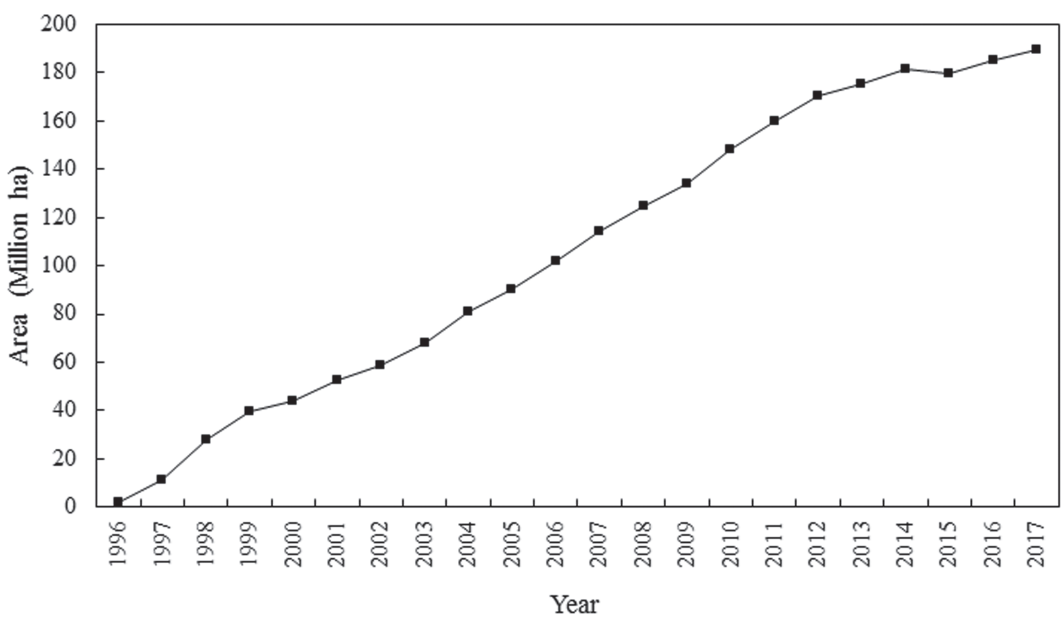


Fig.1. Increase in area under cultivation with GM crops (1996-2017)

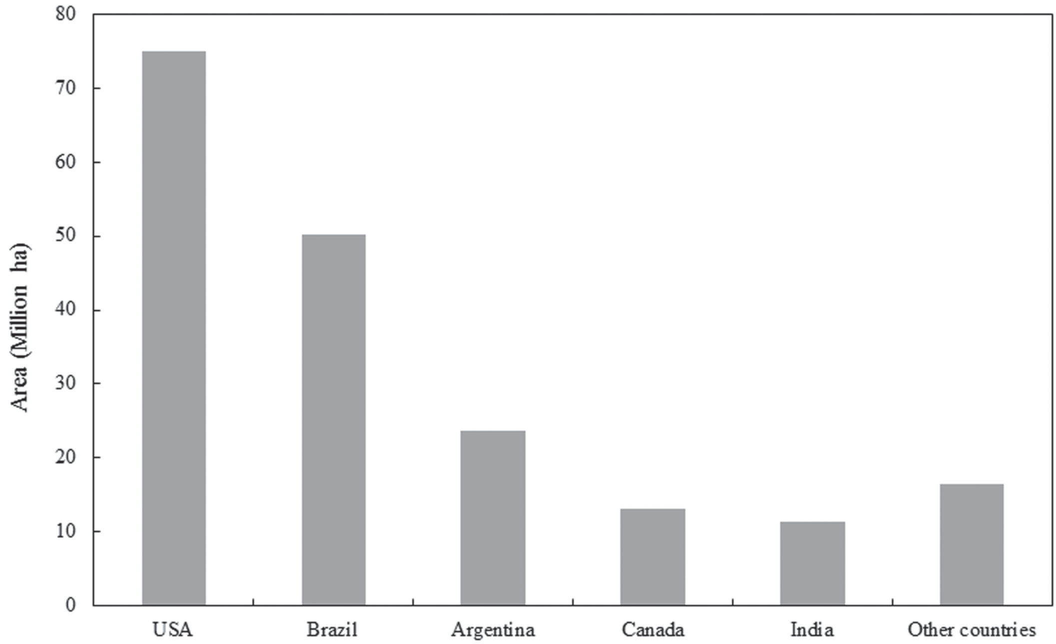


Fig. 2. Area under GM crops in major countries growing them (**Source**: ISAAA briefs 2017)

marked expansion in area in the US. GM crops are now cultivated in a total area of 189.8 million hectares in 26 different countries. Out of the 26 countries growing GM crops, 19 are developing and 7 are advanced industrialised countries. The top five countries grow more than 90 per cent of GM crops. Out of them, three are developing countries (Brazil, Argentina, and India) and two are highly developed industrialised countries (US and Canada) (ISAAA briefs 2017). Though there was a steady increase in area of GM crops cultivation since 1996 the trend decreased during 2014-15. The main cause for the decline, which measured one per cent from 2014 levels, was low commodity prices, which led farmers to plant less corn, soybeans and canola of all types, both genetically engineered and non-engineered (Giddings, 2016). US has the largest area under GM crops as of 2017 (75 million hectares), followed by Brazil (50.2 million hectares), Argentina (23.6 million hectares), Canada (13.1 million hectares) and India (11.4 million hectares) (Fig. 2). Nineteen developing countries in total including India, Pakistan, Brazil, Bolivia, Sudan, Mexico, Colombia, Vietnam, Honduras and Bangladesh have increased their GM crop area.

North America, particularly the US is in the forefront of cultivation of GM crops followed by South America (Table 3). Asia trails far behind at a distant third position. Among Asian countries, India has the largest area under GM crops which is occupied by one single species, namely Bt cotton (Benedict and Altman, 2001). US has adopted the technology and at the same time benefitted from it while in other continents adoption rate is far behind. In the 21 years of commercialization of biotech crops (1996-2016), the US has benefited the

Table 3. **Major GM crops and area under their cultivation in different continents (2017)**

| Continent | Countries | Area (mha) | Crops |
|---|---|---|---|
| North America | US, Canada, Mexico, Honduras, Costa Rica | 88.4 | Maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash, potato, pine apple |
| South America | Brazil, Argentina, Paraguay, Bolivia, Uruguay, Colombia, Chile | 79.4 | Soybean, maize, cotton |
| Asia | India Pakistan, Philippines, Myanmar, Vietnam, Bangladesh, China | 18.3 | Cotton, maize, egg plant, papaya, poplar |
| Europe | Spain, Portugal, Romania, Slovakia, Czech Republic | 0.2 | Soybean, maize, cotton |
| Africa | South Africa, Burkino Faso, Sudan | 2.9 | Maize, soybean, Cotton |
| Australia | Australia | 0.9 | Cotton, canola |

maximum of US $80.3 billion (Brookes and Barfoot, 2018). The US, one of the first six countries to commercialize biotech crops, is expected to retain its position with the most new biotech crops and traits being developed and commercialized.

Unlike in the US, GM crops are not particularly popular in Europe which used to have more flexible GM regulations than the US in the early 1990s. A moratorium on GM crops came into effect in Europe from 1999 to 2004 for political, commercial and partly scientific as well as ethical reasons. Several major European countries have a highly restrictive policy, if not a ban on cultivating GM crops (Lynch and Vogel, 2001; Dale and Davison, 2010). Germany, France, UK, Greece, Austria, Hungary, Luxemburg *etc*. do not permit commercial growing of GM crops whereas in other EU nations stringent conditions exist. With just 0.2 Mha, Europe remains far behind other regions of the world in adoption of GM crops (Table 3). European nations such as Spain, Portugal, Romania, Czech Republic and Slovania grow GM crop mostly GM corn largely for animal feed. EU also imports GM crops for animal consumption (Hogan, 2012). GM crops are grown in Africa to a small extent with South Africa leading the lot (2.3 Mha), followed by Burkino Faso (0.4 Mha) and Sudan (0.1Mha) and the main crop is GM cotton.

China grows a wide variety of GM crops including cotton, poplar trees, sweet peppers, tomatoes, papaya and petunia flowers which were given permission for commercial release during different years since 1997. GM cotton is the most widely cultivated GM crop in China. The most widely planted edible GM available at local Chinese market is the disease-resistant GM papaya (Huang, 2003). Though China's Ministry of Agriculture has not authorized the commercial growing and sale of GM rice, corn, and soybeans it is reported that these are illegally available in Chinese market (Li *et al*., 2016).

Recently the adoption of GM crops increased in developing countries. Today 53 per cent of GM cropped area is in 19 developing countries and only 47 per cent is present in five industrial countries. The trend is expected to continue in the coming years also.

**Social acceptance of GM crops**

Agricultural biotechnology is perhaps the most widely adopted crop technology in the world after the green revolution. A decade after the first transgenic plants were developed in the laboratory, genetically modified food plants were introduced into the market. Despite overwhelming evidence in support of the safe use of agricultural GM technology and the obvious advantages in terms of better yields, improved nutritive value of the produce, reduced pesticide consumption, better tolerance to abiotic and biotic stresses *etc*. (Carpenter, 2013) many countries are still sceptic and remain reluctant in adoption of the technology. Stringent regulations resulting from negative public perceptions and political considerations remain the principal constraint to adoption of GM crops in many countries. This has adversely affected the small and marginal farmers in poor and developing countries. Over the past two decades, crop biotechnology led to an additional production of 213 million tons of soybeans, 405 million tons of maize, 27.5 million tons of cotton lint and 11.6 million tons of canola. The rate of adoption of GM crops in US was 90 per cent for maize, cotton and soyabean. This has allowed farmers to grow more without needing to use additional land and other resources, reducing pressure on typically high bio-diverse land to be converted for agricultural production.

In 2017, sixty seven countries used biotech crops. This included 24 countries in total that grew biotech crops, including 19 developing and five industrial countries; and an additional 43 non-planting countries that formally regulate the importation and use of biotech crops for food, feed and processing. In terms of the global area for individual crops, 77 per cent of soybean, 80 per cent of cotton, 32 per cent of maize and 30 per cent of canola were planted with biotech varieties in 2017 (ISAAA, 2017). Biotech soybean varieties accounted for large share of the global biotech crop area. The same was the case for soybean in Brazil and Argentina, cotton in India and China and oil seed rape in Canada.

In Europe only a single GM crop species has been allowed so far for commercial cultivation *i.e.*, insect resistant Bt maize MON810, due to the strict regulatory mechanism. In several European countries the attitude of the farmers to GM crops is quite positive. About 70 to 90 per cent of the globally produced GM crops are used as animal feed. In USA 95 per cent of the animal feed is from GM crops. These animals were closely monitored and no detrimental effect was observed (Van Eenennaam and Young, 2014). Thus there is good acceptance and also a large market for GM as animal feed globally and even more sceptical Europe also imports and uses GM animal feed.

Spain and Portugal which grow Bt maize have the highest approval for GM food while those countries which are against GM (like Austria, Germany or France) have a lower approval rate. Mostly European customers are more sceptical about GM crops, especially GM food crops.

In US, authorities do not insist in labelling the GM products unlike in the EU. The consumers are also ready to buy food products from GM plants though the knowledge and public awareness are often superficial.

Chinese government have invested huge amount of money for the development of GM technologies to meet the food needs of its huge population. The adoption rate of Bt cotton was 90 per cent in China and in 2009 two Bt rice lines got approval for commercial cultivation, but there was a negative shift in the attitude of people. But the Chinese government strongly supports research on GM and major developments can be expected in coming years (Tao and Shudong, 2003).

Several new GM which have recently received approvals in some countries and are beginning to enter the market includes GM soybean variety that produces oil with a healthier fatty acid composition, a GM non-browning apple, and GM potatoes with lower acrylamide content after frying (Lucht, 2015).

**GM crops in India**

Commercial agricultural biotechnology started in India during 2002 when approval was granted for cultivation of Bt cotton by farmers. Even today, this is the only GM crop grown in the country. Area under Bt cotton saw marked increase until bout 2011 and since then the increase has been rather poor. India is the largest GM cotton producer in the world. India with 11.4 Mha has the world's fifth largest area cultivated under any GM crop. India's entire GM crop area is under Bt cotton developed by Mahyco-Monsanto Biotech containing the *cry1Ac* gene. With the adoption of Bt cotton, pesticide consumption drastically declined and cotton production in the country increased from 15.8 million bales to 34 million bales and transformed India from a net importer to a net exporter of cotton (ISAAA, 2017). India is ahead of China in area under GM. India has GM cotton planted in 11.6 m ha even as China has 3.9 Mha under GM cotton.

Bt Brinjal was developed in India by Mahyco. During 2009 Government cleared the approval for commercial release of Bt brinjal as the country's first GM food crop which subsequently courted controversies and cultivation did not take off. GM mustard developed in India also met with the fate of GM brinjal. Government of India has not yet approved its commercial release (Herring, 2015). During 2016, insect resistant Chick pea and Pigeon pea were developed in India, but yet to be grown commercially. Field trials of 21 GM food crops, including GM vegetables and cereals have been approved by Indian Government though commercial cultivation of GM food has not been permitted by any State Government in India till now (Vidya Venkat, 2016). Public perception and political compulsions seem to outweigh scientific reasoning.

Two universities and two state labs in India produced Bt brinjal in collaboration with Mahyco in the year 2000. Extensive safety tests and confined trials were done both at small scale and large scale levels and after nine years it was approved for commercial release. But the planting of the crop was made illegal rejecting the Genetic Engineering Approval Committee (GEAC) decision and an unlimited moratorium was issued for its commercial release.

Many public/private sector institutions are still actively engaged in developing new GM crops adapted to Indian agro-climatic conditions and huge amounts of funds flow into this area. Now other GM trials with crops in the pipeline including chickpea, sugarcane, sorghum, castor, rice, potato *etc.* are also not authorized and the future of these GM crops and agricultural biotechnology in general remain rather uncertain.

Many other GM crops including cash crops, fruits, vegetables, cereals and pulses are at different stages of development and field testing in India (Express News Service, 2015). Crops which have reached the regulatory pipeline include Bt brinjal, GM rice (both drought and submergence tolerant), GM mustard, Bt okra and Bt cabbage. The GM technology is regulated across the world and India also has a biosafety system to monitor the release of the crops. Commercial release of a GM variety requires the approval from the Genetic Engineering Approval Committee (GEAC) and in addition to environmental safety tests the GEAC ensures extensive food and safety tests for any new GM products. GM Mustard is the new GM crop in the block that is doing the rounds of constant speculation and has been cleared by the GEAC, the biotech regulator in India under the Ministry of Environment and Forests with no such biosafety or public health concerns. The demand for renewed field demonstrations comes year after GEAC had given final clearance for GM mustard in May 2017. There has been strong opposition from various organisations and also from within government to the approval given to GM mustard. The GEAC has demanded more tests for GM mustard for commercialization.

Genetic transformation experiments were initiated in the industrial tree crop, rubber, in several rubber growing countries during the early 1990's. Different laboratories were successful in developing transgenic plants for increased tolerance to abiotic stresses and TPD, enhanced rubber yield, recombinant protein production and altered phenotype (Venkatachalam *et al.*, 2006, 2007; Thulaseedharan *et al.*, 2017). Rubber Research Institute of India (RRII) developed the first ever GM rubber plants in the world integrated with a functional gene Mn-superoxide dismutase (MnSOD) during 2003 (Jayashree *et al.*, 2003). Though in 2010, GEAC had given clearance for controlled field trial (CFT) for GM rubber, this has not been realized so far as NOC from no state was received in time. The current status of GM crops in India seems to be based mainly on public perception than on scientific merit.

## GM crops-Global trade

A significant proportion of globally traded agricultural produce is from transgenic plants. Since 1994, sixty five countries have issued import and/or cultivation authorizations and the last two decades saw the adoption of GM crops by millions of farmers in countries where biotech varieties are available. United States and China are two large markets of GM foods, although the latter is not a major cultivator of GM crops as of now. Compared to other countries, regulation of GMOs in the US is relatively less stringent. For example, the US is the world's leading producer of genetically modified crops. Even Europe which is sceptical towards GM, imports and uses very large amounts of genetically modified animal feeds (ISAAA, 2016). The European Union imposes strict approval and labeling requirements for GM foods and countries like the UK, Sweden, Norway and Germany now insist that foods containing or produced from GMOs should be clearly labelled. China's Ministry of Agriculture recognizes that some GM crops are safe and has approved the import of such crops, typically for use in animal feed. During 2017, China approved 16 varieties - 14 renewals and two new permits - of genetically modified organisms, including corn, soybeans, cotton, canola and beets. China imports large quantities of GM soybeans and corn from the United States, Brazil, and Argentina although it does not cultivate them. Apart from these, it is reported that GM varieties that are not approved are also available in the Chinese market through illegal trades. During 2014, illegal large-scale planting of transgenic rice and corn in four provinces of China were reported (Wong and Chan, 2016).

### GM food - safety regulations in India

In countries like India where there are stringent restrictions in usage of GM crops, presence of GM food has been reported in the domestic commodity markets. The Food Safety and Standards Authority of India (FSSAI) has not allowed GM foods in India so far and the safety of GM foods has been a matter of societal concern. Centre for Science and Environment (CSE), a public interest research and advocacy organisation based in New Delhi, has reported penetration of genetically modified food in the Indian market (Bhushan, 2018). Chances of trans boundary movement of GM products from neighbouring countries like Bangladesh, Myanmar *etc*. which have already issued approvals for GM crops cannot be ruled out. However systematic and scientific investigations in this direction are required to confirm this.

### Future prospects of GM crops

There have been many tangible benefits of growing GM crops, both for man and environment. The Americas, particularly the US have made the most of GM crops, followed by Asia and Africa. Europe remains sceptical about adopting GM crops for commercial cultivation, particularly for human consumption for reasons such as unintended gene flow to related local varieties, bio-safety *etc*. But EU does import considerable amounts of GM produces for animal consumption. Area under GM crops continues to grow globaly although the rate of increase has come down. In many countries, including in EU and India stringent regulations exist making it almost impossible for new GM crops to enter the market, despite the governments and private laboratories continuing to spend huge amounts of money for GM research. The uncertainties, and this policy of ambiguity surrounding GM crops prevent the benefits of biotech crops reaching to farmers and consumers.

GM crops are here to stay and will continue benefiting the population with new crops and traits to cater to the needs of farmers and consumers alike. Delay in biotech crop approvals leads to immense economic loss and opportunity costs. In the long run more biotech crops are likely to emerge and countries that have taken a lead in this modern area of research are bound to benefit the most.

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