Focus

Biotechnology for Second Green Revolution in Indian Agriculture

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The tools of biotechnology present an opportunity to infuse a new round of technology into Indian agriculture, which has been going through "technology fatigue" in recent period. These technologies follow from the conventional plant breeding techniques and complement them in improving crops to resist biotic and abiotic stresses, break yield barriers, and sustain yields in the face of resource degradation and climatic change. Though India has been making rapid strides in the field of biotechnology, the progress in harnessing agricultural biotechnology is rather slow largely due to the uncertainties created by campaigns by civil society groups based on ideological grounds. However, the commercialization of biotech cotton with a gene from soil bacterium Bacillus thuriengensis is a small step taken in the right direction in 2002. That has brought about a revolution in cotton production and productivity; catapulted India to the second leading position in cotton production in the world and earned foreign exchange worth more than Rs. 60000 crores in the last decade. Most importantly, it has improved the conditions of cotton farmers and accrued additional gains worth more than Rs. 75000 crores. Now is the time to move beyond cotton and replicate the success in other crops by providing the required enabling framework for the private sector, apart from enhanced investments in the public sector and public private partnerships and industry-academia linkages.

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Rationale for second green revolution and need for biotechnology

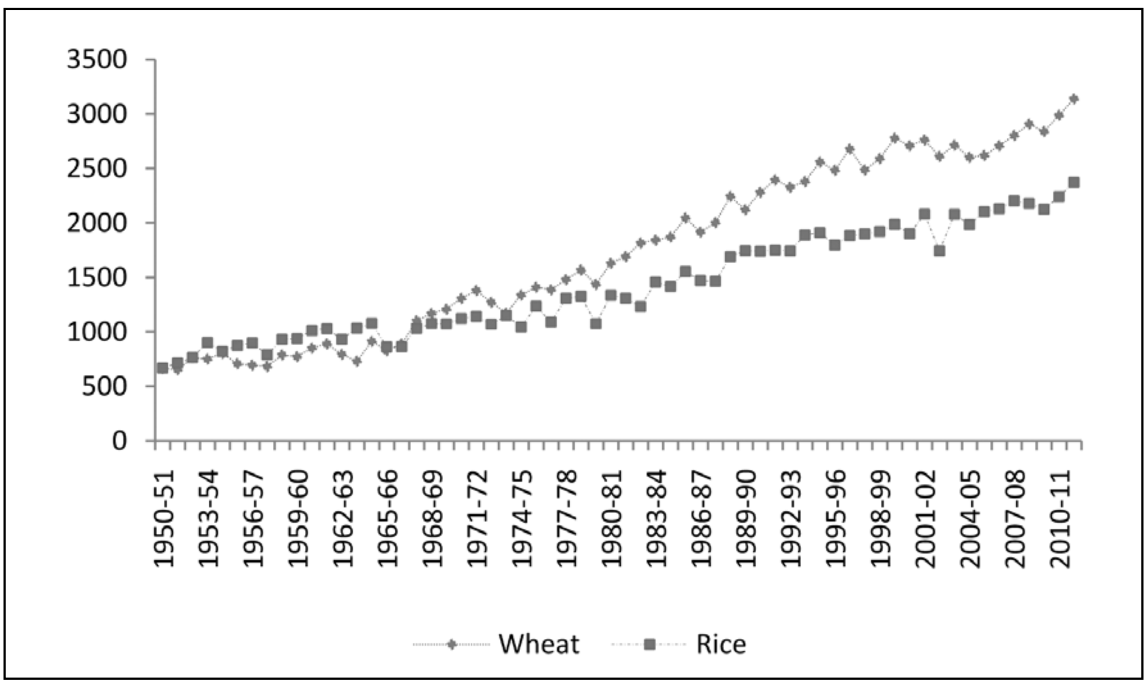
The tools of biotechnology present an opportunity to infuse a new round of technology into Indian agriculture, which has of late been going through a worst ever crisis since independence and need revival from the current morass. While discoveries in physics in the Newtonian era led to industrial revolution, developments in chemistry formed the background in which Green Revolution happened with the help of *Mendelian* genetics. The yields of several crops stagnated or increased at a very slow rate leading to starvation and hunger deaths across the world for a long time until the application of science and technology in the form of *Mendelian* genetics changed the scenario drastically and improved human welfare. For example, wheat yields in U.K took 600 years to enhance by one tone from 400-700 kgs/ha to 1.7 tonnes in 1850 AD before accelerating with modern varieties to go up by five tones in just 90 years from 1900 AD (Plucknet, 1993).

The recent advances in biology increase our understanding of life so much that experts say these discoveries are likely to define changes in the way we live in the 21st century. In fact, 21st century is predicted to be the century of biology. The biotech sector got a big boost from deciphering of human genome in the new century, which is being widely regarded as the 'biological equivalent of landing on Moon'. Several new disciplines like functional genomics, bioinformatics, proteomics etc., emerged as a result of these developments.

The tools of biotechnology especially genetic engineering have become controversial. It is worth mentioning here that all the major scientific breakthroughs were viewed with suspicion and resistance before they could prove the benefits to the society, with the unfolding information and communication technologies being the recent experience in India. In the same way, agricultural biotechnology is the centre of thriving controversies and the critics argue that there is no need for this technology. The critics argue that poverty reduction does not require production of more food and the problem is with the access to food for the destitute. This argument is flawed because poverty is concentrated in rural areas of the country[1] and livelihoods of majority of people in the rural areas depend on agriculture. Several economists concluded that raising agricultural productivity of small-scale farms reduces poverty significantly (Herdt et al, 2007; Johnston, 1970; Lewis, 1954; Mellor, 1966; Pinstrup-Andersen, 2002; Ravallion and Datt, 1998; Thirtle et al, 2003). It increases and stabilizes income and employment from agriculture. In India, the rural poverty in 2009-10 was 38.8 and higher compared to urban poverty, which was 29.8. Also, 78 per cent of the poor are from rural areas. The unique feature of the Indian agriculture is that the small and marginal farmers dominate the farming community forming 82% of all those engaged in agriculture. It was also found that the poverty among the farmers is 30% higher compared to the rural population in general in India, as calculated from the data of National Sample Survey Organsation's data in the Situation Assessment Survey of Farmers. Therefore, raising agricultural productivity through new technologies like biotechnology would be crucial for poverty reduction at this juncture of development. Several studies also showed that raising agricultural productivity can enhance growth in rural non-farm sector and thereby contribute to poverty reduction. There is a consensus in the literature that agricultural growth, which can be promoted with the same level of input use by new technology like biotechnology, is crucial for poverty reduction (Ahluwalia, 1978; Mellor, 2006).

Green revolution technologies losing steam

The improvement in the land productivity given by the growth in per hectare yield is the most crucial aspect in raising the productivity of farming and farmers especially in developing country context as mentioned above. The seed-fertiliser technologies of the green revolution brought about this desired change in India by spiking wheat and rice yields by 150% and 100% in less than three decades since mid-sixties (Figure 1), apart from improvement in several other crops. The yields of wheat went ahead of rice with the green revolution technologies and grown at relatively higher rates because of those technologies. However, the growth in yields of these crops flattened since late nineties, as could be seen from the figure.



Source: Directorate of Economics and Statistics, Government of India.

Figure 1: Per hectare yields in rice and wheat since 1950 in India

[1]Out of the total poor people of 355 million in 2009-10, 78 per cent live in rural areas in India .

The robust growth rates in yields also means that the operation of the Ricardian theory of law of diminishing returns is postponed in the country's agriculture and the same output is produced at lower costs leading to the decline in the food prices. However, this has changed with the seed-fertiliser technologies losing their steam and yields tapering off by late eighties or mid-nineties for most crops (Table 1). The yields of the two most important staple crops crucial for food security viz., rice and wheat have grown at less than 1.50% per annum, showing a decline of 50% in the growth rate in the earlier period of eighties. The same can be observed in several other crops during the latest period.

Table 1: Growth Rates in Yields of Major Crops

	1981-90	1990-99	2000-10
Rice	3	1.36	1.47
Wheat	3.6	2.87	0.73
Maize	4.1	1.37	4.13
Coarse cereals	3.1	2.03	4.64
Total cereals	—	2.38	1.69
Gram	0.92	2.97	1.19
Tur	-0.50	2.03	-0.65
Total pulses	2.3	1.82	1.21
Total foodgrains	3.1	2.43	1.37
Groundnut	1.11	-0.3	12.76
R & M	4.89	2.96	2.72
Soyabean	2.6	4.67	4.17
Oilseeds	4.8	1.76	5.18
Sugarcane	1.3	0.91	0.03
Cotton	5.3	-0.54	9.15

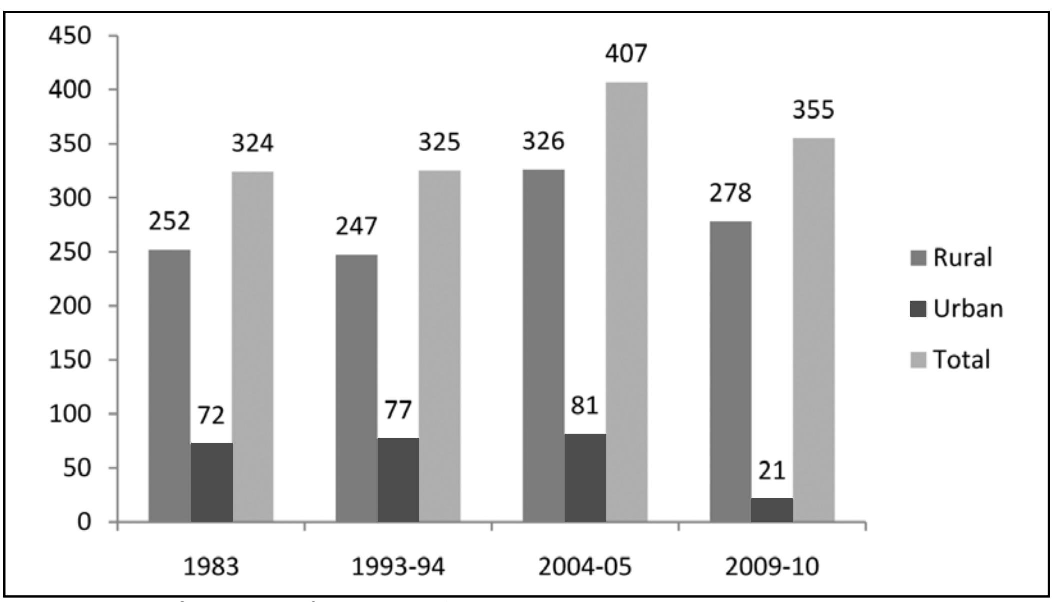
Source: Rao and Dev (2010) and GoI (2013b)

The declining crop productivity has its implications for food security and manifested by increasing cost of production after 1990s. Our studies using the farm household data generated by the Department of Economics and Statistics of the Ministry of Agriculture of Government of India provide conclusive evidence on the reversal of declining cost of food in the recent past, subsequent to the stagnation of yields in rice and wheat (Table 2). The data indicate that for both rice and wheat, the increase in cost of cultivation was more than compensated by the spike in land productivity leading to

Table 2: Reversal of Declining Cost of Food

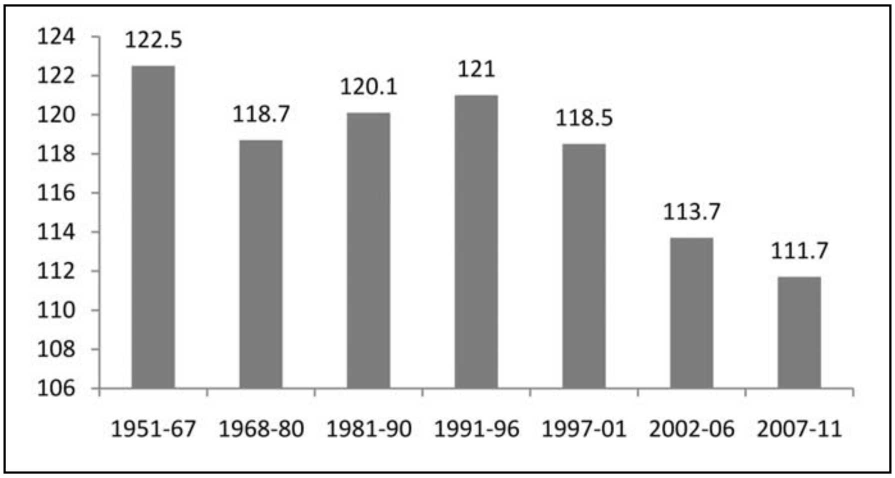
Period	Rice	Wheat
Cost of production per quintal		
1981-82 to 1992-93	-0.13	-1.96
1994-95 to 2006-07	1.46	1.41
Cost of cultivation per hectare		
1981-82 to 1992-93	2.32	1.36
1994-95 to 2006-07	1.92	1.96
Yield (Qtls/ha)		
1981-82 to 1992-93	2.67	2.54
1994-95 to 2006-07	0.86	0.52

Source: Dev and Rao (2010)



Source: Planning Commission, Government of India

Figure 2: Number of people below poverty line



Source: GoI (2013)

Figure 3: Mean annual rainfall in India since 1950 (in mm)

lower cost of production in the eighties and the same could not happen in the nineties because of lower per unit yields in both the crops. This resulted in the real cost of food to increase and form the basis for continuous rise in food prices in recent period (Figure 3).

Burden of poverty and malnutrition

The green revolution played crucial role in reducing the income poverty from around 60% in the mid-sixties to 35% by early nineties. However, the declining profitability of agriculture as a consequence of plummeting growth in yields of crops and the rising cost of food as another fall out of the same have led to unfavourable outcomes for the poor and marginalised in the country. The recent rise in food prices has to be understood in this background. As can be seen from Table 3, the prices of almost all the crops have been spiking up in India. At the same time, similar phenomenon is happening in many countries across the world and the shifting up in the level of prices is argued by several scholars as an irreversible phenomenon in the medium to long run (For e.g. Rosegrant et al, 2012).

Table 3: Upward shift in foodprices

Crop/s	2006	2009	2011
Rice	99	121	110
Wheat	112	127	108
C. cereals	110	123	136
Pulses	134	146	129
Vegetables	103	124	115
Fruits	99	104	119
Milk	98	112	124
Eggs,fish&meat	101	116	137
Oilseeds	85	103	102
Sugarcane	91	81	107
fibres	91	107	140
All agriculture	101	115	122

Source: GoI (2012)

Despite the massive developmental efforts and higher growth rates achieved in the economy, the extent of poverty and the absolute number of poor in India are staggering. There are more than 350 million poor in 2009-10 as the Planning Commission's estimates. What is more worrying is the fact that the poverty reduction has slowed down during the recent period and happened despite high growth rates of the economy. This underlines the need for accelerating agricultural growth, which can be broad based and dent poverty quickly and effectively.

Increasing demands on agricultural technologies

The demand for technologies have also been undergoing dramatic change in the past few decades in India, as has happened worldwide with climatic change and consumer preferences and perceptions on food safety. The degradation of lands, declining water tables, deterioration in water quality, changing rainfall and temperature patterns with climatic change require the new generation agricultural technologies to address far more issues than during the days of green revolution. The pattern of rainfall and temperatures given in Figure 1 and 2 clearly indicate that climate change in real. While the mean annual rainfall of 122.5 mm during 1951-52 to 1967-68 was never received in subsequent periods, the trend in Figure 1 points to decline in the overall precipitation levels, not to speak of the distortions in the pattern of rainfall distribution. The rise in temperatures was far more evident that the changes

Table 4: Transgenic Crops in Advanced Stage of Trials with Traits

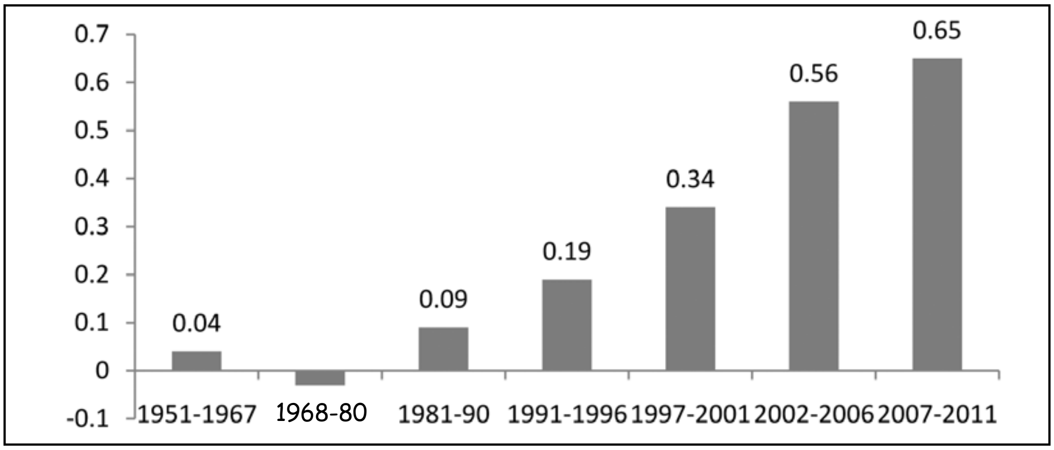
Crop	Company	Trait	Gene/Event	Stage
Corn	Pioner Ovrseas corporation	Insect resistance and herbicide tolerance NK603 (DAS-01507-1X MON-00603-60]	*cry1F&cp4epsps* genes [Stacked events TC1507x	BRL-I 2nd year conducted in 2012
	Syngenta Biosciences Pvt.ltd	Insect resistance and herbicide tolerance	GA21 event (*cry1Ab& mepsps* genes)	BRL-I 2nd year conducted in 2011
	Pioneer Overseas Corporation	Insect resistance and herbicide tolerance	*cry1F&cp4epsps & PAT* genes [Stacked events TC1507xNK603 (DAS-01507-1XMON-00603-60]	BRL-I 2nd year conducted in 2011
	Pioneer Overseas Corporation	Insect resistance and herbicide tolerance	*cry1F* & *PAT* and *CP4EPSPS* genes [TC1507xNK603 (DAS-01507-1xMON-00603-6)]	BRL-I 2nd year conducted in 2010
	Dow AgroScience India Pvt.Ltd.	Insect resistance	*cry1F* (event TC 1507) gene	BRL-I 2nd year conducted in 2010
	Monsanto India Ltd.	Insect resistance and Herbicide Tolerance	Stacked *cry2Ab2* and *cry1A.105* genes (Event MON 89034) *CP4EPSPS*genes (Event NK603)	BRL-I 2nd year conducted in 2010
	Monsanto India Ltd.	Insect resistance and Herbicide Tolerance	Stacked *cry2AB2*and *cryA.105* (MON89034) &*CP4EPSPS*	BRL-I 2nd year conducted in 2009
Mustard	University of Delhi (South Campus)	Male sterile female inbred rice lines	*barnase, barsar* and *barg*enes [Events bn 3.6 (barnase line) and modbs 2.99 (barstar line)]	BRL-I 2nd year conducted in 2011
Cotton	Dow AgroSciences India Pvt.Ltd.	Insect resistance	*cry1Ac & cry1F* (WideStrike= Event 3006-210-23 and Event 281-24-236)	BRL-I 2nd year conducted in 2010
	JK Agri Genetics Ltd.	Insect resistance	*cr1Ac* (Event-1) and *cry1Ec* (Event-24)	BRL-I 2nd year conducted in 2010
	Maharashtra Hybrid Seds Co.Ltd.	Insect resistance and Herbicide tolerance	Stacked *cry1Ac* & *cry2Ab* (MON 15985) and*CP4EPSPS* (MON88913)	BRL-I 2nd year conducted in 2009
Brinjal	University ofAgricultural Sciences	Insect resistance	*cry1Ac*	Seed multiplication Conducted in 2009
	University ofAgricultural Sciences	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
	Sungro Seeds Research Ltd.	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
	Tamil NaduAgricultural University	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
Rice	MAHYCO	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
Okra	MAHYCO	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007

Source: IGMORIS website

in rainfall pattern as can be seen in Figure 2. The mean variations have been continuously increasing since 1980-81 and reached as far as to suggest an annual increase of 0.65 degree centigrade each year, which cannot be brushed aside as a routine variation and deleterious to crop growth.

The prospective agricultural technologies will have to address these demands for technologies and should be able to produce more using minimum of natural resources and in the back ground of the degrading natural resources. The tools of biotechnology offer solutions to these requirements and they can also be very quick and precise compared to the conventional plant breeding (CPB) techniques. Though they have discontinuities with the CPB techniques in that sense, they are also continuation of CPBS in the sense that the tools of biotechnology can complement them. For example, tools like marker assisted selection (MAS) can help in identifying the specific gene responsible for the desired trait and then can be followed by CPB methods.

The tools of biotechnology, especially genetic engineering, are useful in achieving these objectives by having wide ranging applications to make crops resistant to pests, diseases, abiotic stresses like salinity, alkalinity, drought, water logging etc[2]. It can also be useful in developing fortifying foods rich in micro nutrients like iron, zinc etc and others like proteins. The much talked about Golden rice that is rich in vitamin A will reach farmers' fields in a few years. Insect resistant cotton is the only crop commercialised so far in India. However, there is wide range of crops that are modified for several important and useful traits that are in trial stage. Table 4 gives some of the GM crops with their traits that are in advanced stage of trials.

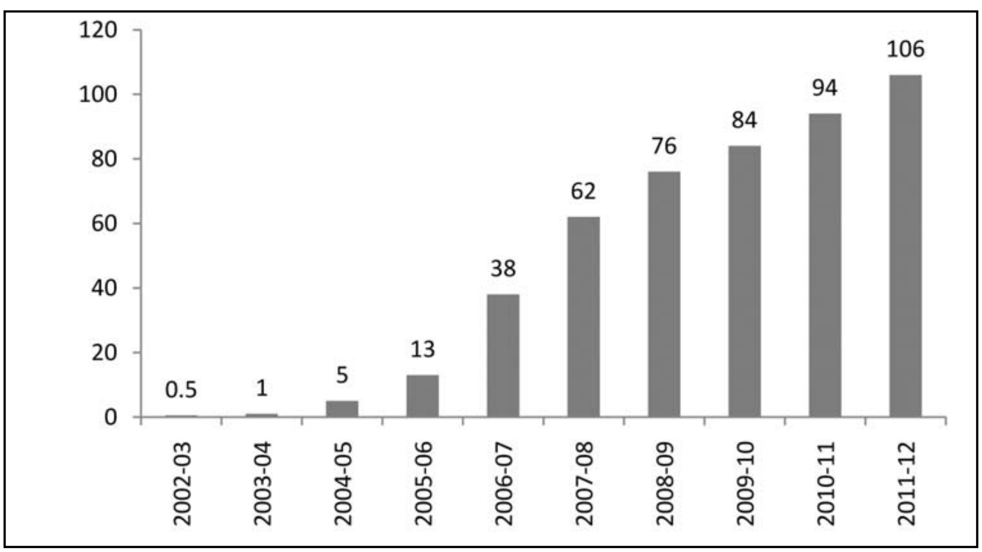


Source: GoI (2013)

Figure 4: Mean Variations in Temperature since 1951 in Centigrade

Adoption and Performance of Bt cotton

Several millions of farmers across 30 countries are cultivating 170 million hectares under the genetically modified crops in corn (maize), soybean, cotton and canola (mustard) in 2012 (ISAAA, 2012). In India, the



Source: James (2012)

Figure 5: Area under Transgenic cotton in India (In lakh hectares)

[2]C.H.Hanumantha Rao as far as back in 1994 brought out the potential of biotechnology and its relevance to Indian agriculture (See Rao, 1994).

adoption of the first biotech crop viz., Bt cotton[3] has progressed at a very high rate of growth and unprecedented for any agricultural technology since its commercialisation in 2002. The demand in the past few years for the Bt seeds exceeded the supplying capacity of more than 30 companies producing more than 1000 approved Bt hybrids. It is a common occurrence across the country to see the farmers jostling with each other for the seeds, standing in long queues, often guarded by heavily armed police force. Starting with less than 50000 hectares in 2002-03, when it was first commercialised, the area reached 106 lakh hectares or more than 90% of 12 million hectares of cotton area in the country (Figure 5). An estimated seven million farmers have adopted this technology, making India the country with largest number of small farmers adopting GM crops.

The agronomic and economic impact of the introduction of Bt cotton in cotton cultivation has been one of the most thoroughly researched topic in recent times. There are broadly three types of studies on the impact of Bt cotton using different kinds of data sets viz., trial data (prior to commercialisation), industry data, and data collected from field surveys. Some of the earlier studies like Qaim (2003), Qaim and Zilberman (2003) brought out significant yield and income benefits. However, they have been questioned as the data is from the field trials and supplied by the companies involved. On the other hand, using the field trial data Shiva et al (1999) showed that the benefits are not sizeable and in fact counterproductive.

Subsequently, several studies done by scholars in different agro-ecological conditions in different socio-economic settings have found significant positive increase in yields, net returns and decrease in expenditure on plant protection chemicals as the Bt cotton gives protection against boll worm damage. Some of the studies are summarised in Table 5. As could be seen from the table, the yield increase varied from 18%-80%. The extent of yield effect varied in direct proportion to the pest pressure as shown by Qaim (2003). If the pest pressure is high and it is not properly controlled using chemical pesticides, the yield advantage with the Bt cotton can be very and high and vice versa. Another important aspect of Bt cotton cultivation in India is that the yield effect is significantly higher compared to countries like USA, China, where cotton in cultivated in temperate climate. That is because of the lack of proper control of bollworms in tropic conditions, where cotton is grown in India. Further, the employment effect can also be positive in India as the labour requirements for increased cotton yields can be high as shown by Rao and Dev (2010). However, the subsequent survey by them has shown that the higher labour requirement for harvesting is neutralised by the decline in labour use for pesticidal sprays. Therefore, it needs some more studies for conclusive evidence. However, the most important thing is that the labour productivity has increased as a result of this technology and employment has become more secure as the crop damage due to bollworm is controlled effectively. Herring and Rao (2012) in a synthesis of all the studies on the subject have brought out these effects more vividly. A meta analysis done at the International Food Policy Research Institute, Washington, D.C with all the studies done on Bt cotton impacts in India has concluded that the positive yield effect was 41% leading to a higher net returns of 50% with decline in pesticidal expenditure by 52% (Gruere and Sengupta, 2011). The studies on other impacts like employment, farmer welfare and village-wide effects found significant positive role for the technology (Rao and Dev, 2010; Subramanian and Qaim, 2009, 2010).

There was a turnaround in cotton production and productivity in the country as a fall out of the introduction of the modern biotech cotton as more than 90% of the cotton area is covered with it (Table 5). The production has increased by 250% in the last decade and per acre yields have gone up from 203 kgs/ha of lint in the five year period before 2002-03 to more than double viz., 512 kgs/ha by 2011-12. The importance of this achievement can be understood from that the previous doubling of lint yield took 34 years from 1950. As noted above, the area under cotton has also gone up substantially to more than 12 million hectares compared to the past peak of nine m.ha, as the farming community found it more rewarding to grow cotton with the availability of biotech seeds. Though there are several factors like cotton technology mission, some improvement in the irrigated area in states like Gujarat, development of new pesticide molecules for sucking pests, widespread adoption of hybrids, the major impact of this is the adoption of biotech cotton. The adoption of the technology has also resulted in India becoming second leading producer of cotton in the world and a leading exporter of cotton, which would not have happened without

[3]A gene from soil bacterium *Bacillus thuriengensis* is inserted into the cotton crop to develop resistance against the dreaded bollworm *Helicoverpa armigera*, which damages crop output by more than 50% in several cotton growing regions in India.

Table 5: Percentage Changes w.r.t Yield, Pesticides and Profit in Bt Cotton vis-à-vis Conventional Hybrids in India

Authors	Survey year	Geographic coverage	Sample size	Percentage change in			
				Yield	Pesticides	Profit	Cost
Qaim, 2003	2001-02	Maharashtra	157	80	-60	500	NA
Naik et al, 2005	2002-03	Maharashtra	341	34	-41	69	17
Nelson-ORG Marg, 2004	2003-04	Maharashtra	3063	29	-60	78	NA
Narayanamoorty and Kalamkar, 2006	2003-04	Maharashtra	150	52	-5	79	34
Gandhi and Namboodiri, 2006	2004-05	A.P, Gujarat, Maharashtra &TN	694	31	-24	88	7
Rao and Dev, 2010							
i. With and without	2004-05	A.P	623	32	-18	83	17
ii. Before and after	2006-07	A.P	814	42	-56	251	-1
Sadashivaipa and Qaim, 2009	2002-03	Maharashtra, Karnataka, AP, TN	434	34	-50	69	17
	2004-05	-Do-	465	35	-51	129	11
	2006-07	-Do-	373	43	-21	70	24
	Average	-Do-		37	-41	89	17
Kathage and Qaim, 2012	2002-04	Maharashtra, Karnataka, AP, TN	533 (1655 plots)	35	31	71	NA
	2006-08	-Do-	533h, (1655 plots)	41	0	94	NA
Crost et al, 2007	2002-03	Maharashtra	352	47	-13	NA	NA
	2003-04	Maharashtra	366	47	-14	NA	NA
Morse et al, 2012	2002-03	Maharashtra	7744 plots	40	NA	43	15
	2003-04	Maharashtra	1577plots	63	NA	73	5
Stone, 2011 (Before and after adoption)	2003/2007	Warangal district in A.P	238181	18	-55	NA	NA
Guere and Sengupta, 2011 (Meta analysis)	Peer reviewed studies upto 2008	All over India	10931-12755 plots	41	-52	50	16

Note: NA- Not available

the new technology. The country has gained valuable foreign exchange through export of Rs.66000 crores of cotton in the last decade by means of adopting the Bt cotton (Table 6). Our own estimations based on the longitudinal studies indicate that the cotton farmers gained in excess of Rs.75000 crores in the last decade through the adoption of Bt cotton.

Controversies on Bt cotton performance

It is paradoxical to see so many controversies co-existing with the unprecedented adoption and reaching more than 90% of the cotton area in less than a decade. While the initial criticisms focused on showing that there is no improvement in yield or net income (Shiva et al, 199; Qayum and Sakhari, 2005; Sahai and Rahman, 2003), the recent diatribe directs its attention on proving that the yield increases are not as a result of the biotech cotton (For e.g. Kuruganti, 2009; Stone, 2012). Kuruganti (2009) attributed the rise in cotton yields to increasing irrigation in several cotton growing states and popularisation of hybrids. However, Herring and Rao (2012) have shown that there was no significant increase in cotton area under

Table 6: Changes in Cotton Production, Productivity and Exports in India

Year	Area in m.ha	Production in lakh bales of 170 kgs each	Lint yield in Kgs/ha	Exports*	
				Quantity in lakh tones	Value in Rs. crores
Five years ending 20002-03	8.7	104	203	0.11	50
2003-04	7.6	137	307	1.80	942
2004-05	8.8	164	318	0.87	423
2005-06	8.7	185	362	6.15	2904
2006-07	9.1	226	421	11.62	6108
2007-08	9.4	259	467	15.58	8865
2008-09	9.4	223	403	4.58	2866
2009-10	10.13	240	403	13.58	9537
2010-11	11.24	330	510	18.86	13160
2011-12	12.18	352	512	20.04	21624

Source: Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India
Note: * This data pertain to cotton year October-September

irrigation. The process of replacing the open pollinated varieties with hybrids in cotton started during the nineties and completed in the the first few years of the new millennium. While the same thing happened in maize, the yield increase in that crop never matched the speed with which it happened in cotton. Some argued that there is no correlation between the growth in cotton productivity and acreage under the Bt cotton (For e.g. Stone, 2012). However, the confusion arises because they follow the data set of the Cotton Advisory Board and not the official data provider in India viz., the Department of Economics and Statistics of the Ministry of Agriculture of Government of India. Another problem is the underestimation of area under Bt hybrids due to non-accounting of unofficial seeds that have been flowing in several states in India and specifically in Gujarat[4].

Stone (2012) raised the issue of efficient farmers adopting the technology and impact studies not accounting for this. However, several studies using sophisticated fixed effects model (For e.g. Crost et al, 2007; Kathage and Qaim, 2012) and before and after adoption scenarios (For e.g. Rao and Dev, 2009; Stone, 2011) separated the farmer effect and technology effect and shown that Bt has given significant yield increase. Gruere and Sun (2012) have also isolated the technology effect and found that that was the 'engine of productivity growth'. While these are the results of several scientific studies, there are some civil society groups attributing several adverse phenomenon like suicides of farmers to the introduction of Bt cotton. However, the suicides of farmers started happening in 1997 in Warangal of Andhra Pradesh and they have tapered off after 2004. On the other hand, the biotech cotton was introduced in 2002. Therefore, it is fallacious to link the two. If there is a link, it was by way of reducing the distress of cotton farmers by making them more profitable. Several of these NGOs oppose the technologies not because they are not performing, but because they are ideologically against biotechnology.

Concerns on safety and proprietary nature of biotechnology

There are two major concerns regarding biotechnology. The first one is the risks to the plant and animal health due to the genetic modification. Several studies have been undertaken and in fact, biotechnology is most thoroughly scrutinised technology. In India, the cotton oil is consumed in different preparations for human consumption, apart from the seed cake being used as animal feed. Several billions

[4]This problem was very serious in the early years initially because of lack of regulatory approval and later because of the high price of Bt hybrid seeds. Herring and Rao (2012) brings out this in some detail.

of people have consumed the GM soybean, corn, mustard, papaya, tomato, sweet potato etc in the world over the past 16 years and there were no verifiable incidents of any harm done to any of them. The GM products are not found to be any more harmful than the products from conventional plant breeding techniques in the studies done by International Council for Science (2003), Nuffield Council (1999, 2004), Royal Society, 2003; FAO, 2004; World Bank, 2007, European Commission, 2010, apart from the world Health Organisation, and scholars like Francis Crick, and Norman Borlaug. However, it is to be noted that it has not harmed so far does not mean that they will not be deleterious in future. Therefore, continuous monitoring of the technologies even after release is essential in case of biotechnologies. All the evidence so far suggests that the benefits far outweigh any perceived risks of the technology. In this scenario, precautionary principle should not deter us from using the technologies to the benefit of the food security needs of the ever growing population.

The second major concern is that the biotechnologies are developed largely in the domain of private sector and few multinational companies dominate the field[5]. Biotechnologies have been in the development for a long time without any commercialized applications. The first generation products developed using this technology are the ones that resist some of the insect pests like root weevil in corn, bollworm in cotton etc. As these applications in particular and biotechnology in particular alter the nature of agricultural technologies leading to the primacy of seeds, the companies involved in producing plant protection chemicals acquired seed companies and have also invested heavily in plant biotechnology. In the mean time, the conclusion of Uruguay round of trade talks leading to formation of World Trade Organisation in 1995 with intellectual property rights becoming a part of trade rules have changed the bio-property regime. India has also brought three amendments to the Indian Patents Act, 1970 to make it compliant to the rules of WTO. The developments in biotechnology on one side and change in trade rules on the other, made inventions and innovations in biotechnology strongly protected through patents. To add to this, the public sector in the world as a whole through the national agricultural research systems (NARSs) of different countries and the international public research on agriculture through the Consultative Group on International Agriculture (CGIAR) have been shrinking and their expenditure on biotechnology is miniscule of even this low investment[6]. All these developments make biotechnologies proprietary and dominated by few life science companies. Though it might seem to be a disadvantage, it also can be leveraged as an advantage to develop useful traits in crops in vast country like India. The major advantage is that the seed market is developed in our country and attracting many of these bigger players to develop useful traits. The changes in cropping patterns with the growing area under both maize and soybean reaching the ten million hectare level is another significant development in harnessing these technologies, since the available basket of technologies from these companies has solutions for improving these companies. The public sector research institutions under the Indian Council of Agricultural Research and some of the universities are making rapid strides in this area. The Indian Institute of Technology, Kharagpur played a crucial role in developing Bt gene (cry 1AC) construct for use by JK Agri Genetics Ltd. There are also opportunities to harness several technologies through public private partnerships, for which Golden Rice is the shining example.

Conclusions and way forward

Biotechnology has wide range of tools and can be applied in so diverse fields as agriculture, industry, forestry, animal husbandry, pharmaceuticals and any others that may emerge in future. This is a rapidly developing technology and can have far reaching implications in the way mankind live in the twenty first century. Some countries like USA have committed special funds and made specific plans to utilise applied research in bioeconomy, which is defined as an economic activity that is fuelled by research and innovation in the biological sciences by OECD[7]. While India has been making rapid strides in the field of biotechnology especially pharmaceutical biotechnology, the progress in agricultural biotechnology does not match the potential. There is a lot of uncertainty at the moment because of the resistance from the civil society groups opposing the technology on ideological grounds and fears created by their propaganda. The information asymmetries are also significant in this field of knowledge in view of the

[5]Rao and Dev (2009) bring out the asymmetry in the quantum of research expenditures on agricultural biotechnology among the developing and developed world and public sector and private sector.

[6]Spielman (2007)

[7]According to the OECD, the “bioeconomy,” is a large and rapidly growing segment of the world economy that provides substantial public benefit.

esoteric nature of biotechnologies. However, the small step taken in 2002 allowing commercialisation of genetically engineered cotton popularly known as Bt cotton, has played crucial role in mitigating the distress of cotton farmers, brought about a revolution in cotton production and productivity and helped India become second leading producer of cotton and earning huge foreign exchange worth more Rs.60000 crores in the last decade. The additional gains to farmers are estimated to be to the tune of Rs.75000 crores in the same period. Now is the time to move beyond Bt cotton and replicate the same success in other crops. The country should not be allowed to be hijacked by some individuals and groups with regressive ideas and agendas and it needs to be taken forward using the state of the art technologies. While encouraging the public sector through investments to do basic and applied research in the field, the huge capacities created in the private sector needs to be utilised by creating a good enabling framework for development and commercialisation of the biotech products that should include forging public private partnerships and industry-academia linkages. The long awaited policy measures like Biotechnology Regulatory Authority of India need to be expedited to assuage the fears of consumers and at the same time encourage producers of the technology. The embryonic second green revolution that has started with Bt cotton needs to be sustained through complementary policy framework, driving out the present uncertainty.

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Any sufficiently advanced technology is indistinguishable from magic.

—Arthur C. Clarke