Modern technologies for sustainable food and nutrition security

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In the hierarchy of human needs, food is absolutely the most basic. As the human population was increasing at an accelerated rate with concomitant depletion of natural resources during the 18th century, Malthus was greatly concerned about the sustainability of food availability. Despite the fact that the human population has been burgeoning, a total collapse in food supply has not yet happened. This is because of new technologies emerging from time to time to boost agricultural productivity and preventing the onset of the Malthusian scourge. However, none of these technologies, including the Green Revolution of the 1960s, has been truly sustainable largely because of their adverse environmental and social impacts. It is expected that the Evergreen Revolution which eliminates the negative attributes of the Green Revolution would be more sustainable. Critical evaluation of the most modern technology, modern biotechnology, reveals that the *Bt*- and herbicide-tolerant-crops are highly unsustainable. In addition to causing environmental harm, these crops exhibit genotoxic effects. The original objective of reducing the need for application of chemical pesticides has also not been realized. There is need for basic research to understand the causes of 'unintended effects' associated with genetically engineered crops. It will be prudent to adhere to the recommendations of the Task Force on Agricultural Biotechnology, Government of India (2004) in the development and regulation of genetically engineered crops. These aspects are briefly discussed in this article.

Keywords: Green to evergreen revolution, modern technologies, nutrition security, sustainable food.

Technologies: long-term adverse effects

KNOWLEDGE is a continuum and new scientific discoveries are made all the time. For example in the field of genetics, discovery of induced mutagenesis, polyploidy, radiation genetics and genome union in Triticale are all based on earlier discovery. Quite often discoveries may lead to positive results in the beginning and later produce undesirable effects. DDT is a good example. It played a dominant role in the eradication of malaria, but had long residual toxicity. With reference to Green Revolution technologies, one of us (M.S.S.) warned as early as 1968 that unless we take care of the ecological consequences of the different components of Green Revolution technology, we may end up with negative impacts. The following kind of proactive analysis is necessary while introducing new technologies.

Technologies with a record of breakthroughs

In the middle of the 19th century Justus von Liebig (Germany) noted that nitrogen-containing chemical compounds enhanced growth and yield of crop plants. The next question was regarding how to manufacture large quantities of nitrates that could be applied to the soil so that the crop species could uptake them for growth and increased yield. The Haber–Bosch chemical process of combining nitrogen and hydrogen at high temperatures and pressures to produce ammonium nitrate solved the problem. Liberal supply of nitrogen fertilizers became available. This positive side of the Haber–Bosch technology, however, had at least two harmful environmental effects which were realized only after several decades. One is that energy for the fusion of hydrogen and nitrogen comes from burning fossil fuels, which results in greenhouse gas emissions. The other is that the nitrogen cycle is vitiated in the sense that much of the atmospheric nitrogen is converted into nitrates, which accumulate on land and in aquifers largely because there is no equally efficient chemical process to denitrify and release nitrogen. Rockström *et al.*[1] have discussed the anthropogenic vitiation of the nitrogen cycle. This is a change at the planetary level in epoch Anthropocene. In nature, the nitrogen-fixing bacteria on the one hand, and the denitrifying bacteria on the other, keep a balance between nitrates and nitrogen. What is obvious is the yield increase by the application of nitrogen fertilizers, and what is unnoticed is the progressive harm to soil, water and atmosphere. Then in the middle of the 20th century, Paul Muller demonstrated the insecticidal properties of a compound, dichlorodiphenyltrichloroethane (DDT) that had been synthesized several decades earlier. DDT was considered a saviour of humankind from all sorts of pests, and Paul Muller from Switzerland was awarded the Nobel Prize in 1940. Two decades later in 1962, Rachael Carson[2] who in the 1960s was dying of cancer, wrote, *The Silent Spring*[2], which revealed the significant damage

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caused by DDT to non-target organisms, including beneficial pollinators, honeybees, etc. And the birds began to disappear. Today, several countries have banned or restricted the use of DDT and several other chemical pesticides. While these two technologies are chemical, the Green Revolution of the 1960s is biological and gene-based. The height of the wheat and rice crops was genetically reduced without altering the length of the grain-bearing panicle. The rationale was that these dwarf and semi-dwarf plants could uptake high levels of chemical fertilizers and water, and produce a greater number of heavy grains. Never before, not in 4000 years of wheat cultivation, had a new technology brought about such a quantum jump in yield gain and within 3–4 years. Its impact was such that India's then image of a 'begging bowl' suddenly changed into a 'bread basket'. This was a high-input technology of inorganic chemical fertilizers, chemical pesticides and fungicides also requiring copious irrigation with groundwater drawn with thousands of pumps (electricity was given free). A few of these high-level fertilizer-responsive, high-yielding varieties were grown continuously over large areas displacing several locally adapted varieties and landraces (loss of biodiversity). These genetically homogeneous varieties were more susceptible to pests and diseases, with the potential for widespread failure. It was already known that chemical inputs exert deleterious effects on soil and water (the major components of the ecological foundations of sustainable agriculture). The Green Revolution (christened by the late William Gaud of the US Agency for International Development), was a farming technology. This revolution requiring high-level chemical intensification (i.e. high cost), therefore, largely excluded resource-poor small and marginal farmers. Scientific integrity demands that society is kept informed of the deficiencies and negative impacts of products of technology and innovation. Swaminathan[3] did just this. As early as January 1968, months before the 'Wheat Yield Revolution' stamp was released by the Government of India (GoI), he elaborated as follows:

> 'Intensive cultivation of land without conservation of soil fertility and soil structure would lead ultimately to the springing up of deserts. Irrigation without arrangements for drainage would result in soils getting alkaline or saline. Indiscriminate use of pesticides, fungicides and herbicides could cause adverse changes in biological balance as well as lead to an increase in the incidence of cancer and other diseases, through the toxic residues present in the grains or other edible parts. Unscientific tapping of underground water would lead to the rapid exhaustion of this wonderful capital resource left to us through ages of natural farming. The rapid replacement of numerous locally adapted varieties with one or two high yielding strains in large contiguous areas would result in the spread of serious diseases capable of wiping out entire crops, as happened during the Irish Potato Famine of 1845. Therefore, the initiation of exploitative agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture and without first building up a proper scientific and training base to sustain it, may only lead us into an era of agricultural disaster in the long run, rather than to an era of agricultural prosperity.'

Since we are at a stage of rapid advances in science and technology, it may be worthwhile discussing their impact on food and nutrition security. Only a few examples are taken up for discussion.

The research programmes adopted at the M.S. Swaminathan Research Foundation (MSSRF), Chennai fall under the categories of anticipatory, participatory and translational research. This is essential for ensuring that the technologies are ecologically, socially and economically sustainable.

As had been foreseen and forewarned by Swaminathan, the Green Revolution started showing '*yield fatigue*' by the late 1980s, and reached a peak decline by the mid-1990s (refs 4, 5). By then, Swaminathan[6,7] had developed strategies to transform the unsustainable Green Revolution into an Evergreen Revolution. Unlike the former, which focused mainly on the genetic modification of the plant type, the latter was designed on 'systems approach' to ensure concurrent attention to environmental and social dimensions as well. It is emphasized that the Green Revolution, which was not designed to fight the famine of rural livelihoods, could establish food security only at the national level, but not at the individual household level of millions of the rural poor. On the other hand, the Evergreen Revolution combined 'ecoagriculture' to produce food (i.e. ensuring availability of food) with 'ecotechnologies-led ecoenterprises' consisting of on-farm and non-farm rural livelihoods in order to enhance 'access' (i.e. purchasing power) of rural communities to food. Hunger in India is largely due to lack of purchasing power especially in rural areas, than a lack of availability of food. The paradigm 'mountains of grains on one hand, and millions of hungry people on the other' well described the national hunger paradox following the Green Revolution. The lessons learnt are that any technology, modern or traditional, ought to be eco-friendly and relevant to the weakest among the poor. Jeffrey Sachs[8] (Earth Institute, Columbia University, USA) wrote, 'The great agronomic successes since Malthus' time, including the Green Revolution itself have come at a huge and sometime irreversible environmental costs. Even with all our technological wizardry, we have not yet conquered the Malthusian challenge, since we have not adopted a truly sustainable method of feeding the planet.' Even centuries ago, humankind experienced that faulty technologies leading to environmental degradation and consequent hunger could wipe out flourishing civilizations, as happened with the Sumerians (4th millennium BCE) and Mayans (CE 900).

Green to evergreen revolution

It should be noted that it is not as if the Green Revolution failed in its immediate objectives; it had delivered more than its expectations, i.e. it freed India from imports and made us self-sufficient. Therefore, it provided the much needed 'breathing space' to develop holistic strategies for sustainable agriculture. The Evergreen Revolution in a way, defends the gains of the Green Revolution. The Evergreen Revolution is lauded as the best option available to humankind to feed the burgeoning billions of mouths over the next several decades and save the 'rest of life' at the same time, without being trapped in a Faustian bargain that threatens freedom and security, as stated by Edward Wilson[9], in his epoch-making book, *The Future of Life*[9].

There are also examples of simple modifications in agronomic practices leading to huge benefits. The 'system of rice intensification' (SRI) is a good example. SRI reduces fertilizer and water needs; yet the tillering is profuse and hence yields are dramatically increased. What is most notable about SRI is that it makes paddy cultivation climate-resilient through reduction in inputs. This technology is promoted by MSSRF.

Plant breeding technologies

In a recent editorial, Swaminathan and Kesavan[10] have briefly referred to the rise and decline of auto and allopolyploid breeding. The synthetic (human-made) *Triticale* ($2n = 6x = 42$) is an allohexaploid of rye, *Secale cereale* ($2n = 14$) and wheat *Triticum durum* ($2n = 4x = 28$). It has a history of about 140 years. It was largely sterile due to meiotic irregularities. Over the years, meiosis has become almost normal and is now cultivated in marginal soil, in drought-prone areas of North Africa. The point being made here is that deviations from Mendelian breeding often exhibit problems which could take a very long time to overcome or not be solved at all. Mutations and natural selection are the predominant evolutionary mechanisms to induce variations in angiosperms. This fact accounts for the noteworthy success of mutation breeding (http://www.fao.org/ag/portal/age/age-news/detail/em/c/269620).

Exploitation of heterosis in hybrids derived from inbred parents with good combining abilities provides high yields (kg/ha), but farmers have to buy hybrid seeds afresh every year. Hence, it restricts them from saving seeds for successive sowing. Such technologies provide handsome opportunities for the corporate sector to produce hybrid seeds for sale at considerable profits.

The most 'modern' technology is modern biotechnology, i.e. 'molecular breeding' using recombinant DNA (r-DNA) technology. The unique aspect of this technology is that genes from widely different taxa can be 'inserted' into a chosen recipient genome; sexual reproductive barriers to gene transfer from one species to another are broken. The basic problem with the r-DNA technology (i.e. genetic engineering) is that all the molecular and cellular events which are triggered with the insertion of 'exogenous DNA' (whether cis or trans), are as yet not precisely understood. Since the cost of GE (genetically engineered) seed and inputs required, particularly if hybrids are used as in India in *Bt*-cotton, are exorbitant compared to non-GE seeds, resource-poor small and marginal farmers are not able to withstand financial losses, especially if the crops fail for whatever reason. The site of insertion of exogenous DNA into the recipient genome is at random, and not controllable. 'Position effect' leading to alterations in gene expression is known to occur. In many GE organisms, 'unintended' effects raising health safety concerns have been and are being encountered. For instance, Calgene Company's 'Flavr Savr' tomato, the first GE food crop in the US was marketed for about just 2 years in the late 1990s and then withdrawn. Calgene's short term (28-day) studies with feeding Flavr Savr revealed occurrence of stomach lesions in experimental rats. In another case, pigs were genetically engineered with human growth hormone gene to produce 'lean' (i.e. flesh with less fat) pork. These pigs called 'Beltsville pigs' had defects in several organs, including heart. Moreover, the bone formation was extremely defective with the result that these pigs were not even able to stand up; they hardly walked. So, this project was also withdrawn. There are no 'Flavr Savr' tomatoes or pork from Beltsville pigs today. Yet another case of failure of genetic engineering was that of L-tryptophan. Normally L-tryptophan is produced by fermentation process (i.e. classical biotechnology) and has been consistently safe for humans. In the 1990s, Showa Denko (a Japanese pharmaceutical company in USA) started manufacturing L-tryptophan using GE *Escherichia coli*. In one batch of GE L-tryptophan, dimerization (an 'unintended effect') had occurred and this caused the deaths of 37 people and paralysis (esonophilia myalgia syndrome) of about 1500 people. The abovesaid failures suggest: (a) more research is needed to elucidate the causes of 'unintended' effects; (b) the assumption of 'substantial equivalence' to give market approval to genetically modified (GM) crops is wholly unscientific and extremely dangerous. These examples reveal that several uncertainties and unscientific assumptions render genetic engineering an imprecise technology. And multinational corporations are running ahead of the science to drive this technology of genetically modified organisms (GMOs), and colluding with regulators. Aware of these serious issues, the Task Force on Agricultural Biotechnology with Swaminathan as its Chairman, laid down the guiding principle in 2004 as follows:

> 'The bottom line of our national agricultural biotechnology policy should be the economic well-being of farm families, food security of the nation, health security of the consumer, biosecurity of agriculture and health, protection of the environment and the security of national and international trade in farm commodities.'

As of now, the ground reality is that the guiding principle has been set aside. The precautionary principle (PP) has been done away with[11] and no science-based and rigorous biosafety protocols and evaluation of GM crops are in place. The adoption of 'substantial equivalence' has been recommended[11], which is unscientific. Furthermore, in order to generate support for such recommendation[11], the statement on PP made in a Canadian paper[12] has been misrepresented.

It is claimed by some that hybrid *Bt*-cotton has led to an unprecedented increase in India's cotton production. These claims, however, are not based on analyses by experts or authorities on cotton in India. To set the record straight, we cite two of the world's most recognized authorities on the science and production of cotton.

Keshav Kranthi (former Director of Central Institute for Cotton Research (CICR), Nagpur, and currently with the International Cotton Advisory Committee, Washington DC, USA) notes that from 2008 onwards, *Bt*-cotton yield stagnated at around 500 kg/ha and currently remains at this level or perhaps even lower, despite the substantial increase in area under *Bt*-cotton cultivation. Pest resistance to Bollgard II was already evident as early as 2008 and the onset of secondary pests became a serious concern. Kranthi[13] concludes: 'Bt cotton was supposed to have conferred two major benefits to cotton production: (a) high yields due to effective protection of bolls from bollworm damage and (b) reduction in insecticides recommended on bollworm control. Official data show that none of these promises was kept in the past ten years in India'.

The pertinent records are available in the public domain. It is interesting that the Union of India in its counter affidavit in the Delhi High Court (in WPCC) No. 12069 of 2015, has correlated farmer suicides with the failure of *Bt*-cotton. At the same time, leading American cotton scientists, Gutierrez and coworkers[14] have shown that farmers' annual suicide rates in rainfed areas are directly related to increases in *Bt*-cotton adoption (i.e. costs). The lack of irrigation, onset of pest resistance and emergence of secondary pests necessitating application of chemical pesticides and the cost thereof, have significantly added to farmers' woes. Growing a refuge crop delays onset of resistance. But in India 'refuges' are not viable given our small-holder farming. The data points conclusively to the failure of *Bt*-cotton due to rising resistance, the hybrid policy and secondary pests. Many cotton scientists have acknowledged the huge socio-economic cost borne by cotton farmers as a result of deploying hybrids in *Bt*-cotton; that it was a clever ploy for a 'value-capture mechanism' by Monsanto. Its role in the failure of *Bt*-cotton in India and the resulting indebtedness of our farmers is significant.

There is no doubt that GE *Bt*-cotton has failed in India: it has failed as a sustainable agriculture technology and has therefore also failed to provide livelihood security of cotton farmers who are mainly resource-poor, small and marginal farmers. That a plea has recently been made to *Bt*-cotton farmers to adopt the time-honoured traditional integrated pest management (IPM) system to sustain Bollgard II cotton points to the relative effectiveness of a traditional vis-à-vis modern technology[15]. It is unethical to ask farmers to first adopt the highly expensive technology of *Bt*-cotton and when it subsequently failed, to then introduce an inexpensive traditional technology to protect Bollgard II cotton. Both *Bt*- and herbicide-tolerant (HT) crops are now proven to be unsustainable agricultural technologies. They have not decreased the need for toxic chemical pesticides, which was the reason for them in the first place. Benbrook[16] in his study of pesticide use in GM crops in USA (the first 16 years, 1996–2011) and using official data has shown that overall pesticide (insecticide + herbicide) use has increased by an estimated 183 million kilograms or about 7%.

The Technical Expert Committee (TEC) appointed by the Supreme Court of India recommended a total ban on HT-crops. Now, in view of the unsustainability and failure of *Bt*-cotton in the country, and the rising health concerns associated with *Bt*-crops, the recommended indefinite moratorium of the TEC in its final report on *Bt*-crops (2013), must now, like HT-crops, translate into a ban on *Bt*-crops as well (apart from *Bt*-cotton). In this context there have been strong criticisms that the GoI has imposed a moratorium on the commercialization of *Bt*-brinjal. What GoI has done is quite appropriate from several points of view. For example, the long-accepted version of Cry toxicity (its specificity to alkaline gut systems of insects) is not the actual mechanism. When feeding moths *Bacillus thuringiensis*, Broderick *et al.*[17] found that indigenous gut flora were required for killing. Studies have shown that the Cry proteins permeabilize the intestinal epithelium, providing an opportunity for commensal bacteria to act to cause septicaemia and death[17,18]. 'Elimination of the gut microbial community by oral administration of antibiotics abolished *Bt* activity, and reestablishment of microbial community restored *Bt*-mediated killing.' Virtually all animals, including humans, depend on the interplay of numerous species of bacteria that routinely colonize the stomach and intestines.

'In moths and butterflies, the complexity is much lower than in mammals, and even some other insects.' *Bt* toxins are toxic to all the organisms, including mammals. The exact role played by the microbes to promote the lethal effects of *Bt* toxin remains unknown. Paul *et al.*[19] showed that Cry 1 Ab protein in dietary feed is not completely broken in cow digestion. A year later, a Canadian study found *Bt* toxic proteins circulating in the blood of pregnant women and blood supply to their foetuses[20].

The biosafety dossiers of *Bt*-brinjal were put in the public domain *only after* the Supreme Court forced compliance. The Supreme Court-appointed TEC found several deficiencies in design, collection of data and their interpretations, and also noted that the important studies were not done. When these data were analysed by several leading international scientists (Seralini of France, Heinemann of New Zealand, Schubert of the Salk Institute, Andow of the University of Minnesota, Carman of Australia, Gallagher of New Zealand among others), their reports confirmed our worst fears and proved to be a devastating commentary on our regulators. Ultimately, there was no meaningful response from the Genetic Engineering Appraisal Committee to the 'can of worms' exposed by the international appraisal of the raw data. Subsequently, two Parliamentary Standing Committees (of 2012 and 2017) both concluded that Regulators failed to uphold rigorous and independent test protocols for GMOs, that conflicts of interests militated against proper regulation, the Rules of which in the absence of an Act, were tinkered with at will. They concluded that 'field trials must be stopped until corrective measures were put in place, including a biotechnology Act that assigns priority to biosafety'. Thus both the TEC and PSCs are unanimous in their recommendation to stop field trials of transgenic seeds, which are a serious threat to biosafety.

Genotoxicity of glyphosate ('Roundup')

Nearly all HT-crops of corn, soy and cotton are resistant to Roundup, whose active ingredient is the herbicide glyphosate. The herbicide (and its adjutants) is known to be an endocrine disruptor[21], genotoxins[22,23], teratogens[24], etc. In 2015, the International Agency for Research on Cancer (IARC) of WHO classified glyphosate as a group 2A carcinogen, categorizing it as 'a probable human carcinogen'. Today, Argentina has significant birth defects and cancers in HT-soy regions[25]. Schubert[26] refers to a survey which shows that exposure to glyphosate has escalated over the past 20 years, and laments that as yet regulators are turning a blind eye. He says: 'we have reached the point where the evidence against probable carcinogen, glyphosate (the active ingredient in Monsanto's Roundup and in commercial HT-crops), is directly analogous with DDT, asbestos, lead and tobacco, where industries were able to block regulatory actions for many years by perpetually muddying the waters about their safety with false and misleading data'.

Close on the heels of this article[26], the Supreme Court of California's verdict in the Dewayne Johnson case of Roundup link to cancer found Monsanto guilty; it must pay US$ 289 million in damages (*The Guardian*, 11 August 2018, http://www.theguardian.com/business/2018/org/11/one-mans-suffering-exposedmonsantos-secrets-to-the-world). The jurors found not only that Monsanto's Roundup and related glyphosate-based brands presented a substantial danger to people using them, but there was 'clear and convincing evidence' that Monsanto officials acted with 'malice or oppression' in failing to adequately warn of risks. Evidence was also presented to jurors showing how closely the company worked with Environmental Protection Agency officials to promote the 'safety message' and suppress evidence of harm. In the light of this judgment alone and apart from other reasons (discussed later in the text), HT-mustard hybrid DMH-11, tolerant to glufosinate must be banned. Genotoxic glufosinate is at least as hazardous as glyphosate.

The major environmental harm by HT-crops is to exert 'selection pressure' on a wide spectrum of weed species, to induce formation of 'superweeds'. This in turn leads to their acquisition of a 'genetic shield' or resistance to the herbicide. Consequently, a new generation of herbicide-resistant superweeds invades HT-crop fields. Millions of hectares across several states in the US are now devastated by superweeds. According to Gilbert[27], superweeds have now spread to 18 countries worldwide and as of 2012, 24 different glyphosate-resistant weed species have been identified across USA. This is not a record that we may even contemplate for India, also given our very different approaches in farming systems.

Yield in non-GM crops in Western Europe and GM crops in the US compared

Another decisive pointer to the unsustainability of GM crops arises from the results of a comparison of yield in Western Europe's non-GMO maize with GM maize in the US. The data show that the former matches or exceeds those of the US, using less pesticide. (Western Europe does not grow GM crops, unlike USA and Canada.) Furthermore, yields in wheat and oilseed rape are increasing at an even faster rate in Western Europe than in both the US and Canada[28].

Herbicide-tolerant mustard hybrid DMH-11

The mustard hybrid DMH-11 is a herbicide-tolerant mustard hybrid deploying the sterility gene *barnase* and the restorer fertility gene, *Barstar*. There is no dispute that Varuna bn 3.6EH2 modbs 2.99 and DMH-11 are able to survive normally lethal exposures to the herbicide

Table 1. DMH-11: 2006–07: field trials in six valid locations (mean seed yield in kg/ha)

Location	Varuna	DMH-1	Kranti	DMH-11	Zoanl check
Zone II					
Sriganganagar	1527	1501	1606	1370	1344
Delhi	1395	1884	1503	1748	1313
Navgaon (Alwar)	1111	1434	1097	1264	1002
Mean yield (kg/ha)	1344	1606	1402	1461	1220
Zone III					
Kanpur	1168	1110	1380	1319	1577
Pantnagar	952	1666	1232	1311	1208
Kota	2566	2488	2433	2325	2368
Mean yield (kg/ha): Zone III	1529	1755	1682	1652	1718
Mean yield (kg/ha): Zones II and III	1437	1681	1542	1556	1469

Source: RTI.

glufosinate ammonium because of the gene called *bar*. Mustard DMH-11 remains a HT-crop irrespective of whether the herbicide is used or not, because intention (whether it is used in farmers' fields, which in any case cannot be stopped) is not a defining characteristic of the definition of HT-crops. As shown, HT-crops are also proven to be an unsustainable technology. Therefore, the fundamental question is whether a dangerous technology that has no benefit to Indian agriculture and is linked to cancer and other health hazards should be developed at all. Today, India has several mustard varieties and CMS mustard hybrids that out-yield HT-mustard hybrid DMH-11 as shown below.

In field trials with hybrid DMH-11, the mandated 'comparator' (non-GMO isogenic equivalent) was entirely excluded. No non-GMO hybrid, including the CMS hybrid DMH-1 was included for comparison in the later required BRL field testing (2010–2014), presumably because DMH-1 out-yielded DMH-11 in earlier trials. The fact is that DMH-11 was out-yielded comprehensively by both varieties and non-GMO hybrids (CMS) (Table 1). The DMH-11 field trials revealed atleast two unscientific and flawed decisions by the regulatory authorities.

1. The exclusion of non-GM hybrid DMH-1 from the subsequent field trials, which outperformed DMH-11 in 2006–2007. The mean yield of DMH-1 is 1681 kg/ha, whereas that of DMH-11 is 1556 kg/ha.

2. It also became evident from the RTI response that several non-GM varieties (Kranthi; RH 749, NRCHB506) and non-GM hybrid mustard (DMH-1 and DMH-4) have been subjected to rigorous field testing for at least 4–5 years in over 30–50 locations. GM hybrid DMH-11, on the other hand, was tested for just three years in six locations. It is clear that DMH-11 fails under the rules of statistical significance and performance. Since the mandated hybrid non-GMO comparator was entirely absent, DMH-11 under the rules should have been rejected outright. It is interesting to also note the data of heterosis in a study by Singh *et al.*[29] (co-authored with K. V. Prabhu, GEAC Member). Heterosis in non-GM hybrids is around 80% compared to 20–30% of hybrid GM mustard. Singh *et al.*[29] rightly conclude: 'The high quality oil genotypes involved in developing heterotic hybrids in this study, shall be converted into cytoplasmic male-sterile and/or restorer lines.' It is noted that the authors would use CMS and not GE mustard lines.

Claims of the biosafety and sustainable yield increases of *Bt*- and HT-transgenic hybrid cotton and mustard (respectively), do not have the backing of science nor field data. The statement by Padmanaban[30]: 'Large-scale analysis of data from authenticated reports covering a period of over 15 years has discounted engineered concerns on the health safety of millions of human and cattle consuming GM-corn or soybean across the globe', must, in the light of the evidence provided and the verdict of the US court case, be rejected. Furthermore, a pertinent question arises: how are these conclusions drawn when USA, under industry pressure, does not allow labelling of genetically-engineered foods? In the absence of labelling it is impossible to trace the cause of disease or allergenicity. Moreover, in the US people do not consume *Bt*- and HT-corn and soybean directly without processing; these are largely animal feeds. Milk and meat comprise 'secondary' GM foods derived from animals fed GM feed. Even so, *Bt*-proteins are found in the blood of pregnant mothers and foetal blood[20].

As of now, the functioning of the GEAC and RCGM has rightly come under severe criticism due to endemic conflicts of interest, lack of expertise in GMO risk assessment protocols, including food safety assessment, the assessment of their environmental impacts, the lack of 'need' for expensive transgenic technology, and which must include a socio-economic assessment of their farming impacts on resource-poor small and marginal farmers, etc. which is also absent. The vacuum in these matters also means that the Swaminathan Agricultural Task Force

Report (2004) continues to be ignored. Furthermore, our regulators and institutions have been severely criticized in three official Government reports (below), of which two represent PSC Reports which may now be given as evidence in court proceedings (ref. recent order of a 5-member Constitutional Bench).

(i) PSC: The 37th Report of the Committee on Agriculture (submitted in August 2012) under the Chairmanship of Shri Basudeb Acharya on the 'Cultivation of Genetically Modified Crops – Prospects and Effects'.

(ii) The Unanimous 5-Member Report (June 2013) of the Technical Expert Committee appointed by the Supreme Court.

(iii) PSC: The 301st Report dated 25 August 2017 under the Chair of Renuka Choudhury (MP). The report of this Committee concludes: 'The Committee strongly believes that unless the bio-safety and socio-economic desirability, taking into consideration long-term effects, is evaluated by a participatory, independent and transparent process and a retrieval and accountability regime is put in place, no GM should be introduced in the country.'

This conclusion of the report incorporates the findings and principles enunciated in the Report of the Agricultural Task Force (2004, under the Chairmanship of M. S. Swaminathan) on the one hand, and the failure of *Bt*-cotton, and the unreliability of claims in respect of the yield of HT-hybrid mustard DMH-11 on the other.

In an interview to *The Hindu*, 16 August 2017; http://www.thehindu.com/opinion/interview/why-cant-the-government-provide-a-higher-income-for-farmers/article-19498056-ece, Swaminathan emphasized that genetic engineering technology is supplementary and must be need-based. Only in very rare circumstance (less than 1%) may there arise a need for the use of this technology. In more than 99% of the cases, the time-honoured, royalty-free, ecofriendly and socially equitable and also amenable for 'participatory breeding' Mendelian breeding will do.

Above all, we require independent, rigorous oversight of GE crops, without the least hint of any conflict of interest; persons of proven competence in genetic toxicology and safety analyses, able economists who are familiar with and will prioritize rural livelihoods, and the interests of resource-poor small and marginal farmers rather than serve corporate interests and their profits; ecologists of high competence and dedication to biodiversity conservation, with a scientifically credible understanding of the consequences of 'genetic contamination' in centres of rich diversity of crops for food, fibre and medicine.

In the end, we strongly believe that scientific integrity and social responsibility are not negotiable. No technology may be exempt from these values. Further, it is noted that the UN FAO's Food Security definition includes Food Safety as well, and therefore the technologies, whether traditional or modern, must establish this non-negotiable goal of food safety.

Finally, it is evident that we have not 'summarily dismissed genetic engineering technology as not sustainable based on a superficial analysis', as has been alleged by Padmanaban[30]. Fortunately, scientific truth prevails and finally succeeds.

Genetic engineering technology has opened up new avenues of molecular breeding. However, their potential undesirable impacts will have to be kept in view. What is important is not to condemn or praise any technology, but choose the one which can take us to the desired goal sustainably, safely and economically.

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ACKNOWLEDGEMENT. We thank Ms Sharmila Babu for secretarial assistance in the preparation for the manuscript.

Received 31 August 2018; accepted 25 October 2018

doi: 10.18520/cs/v115/i10/1876-1883