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Review Article

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Transgenic Plants: A Curtain Raiser Implying Risks vis-a-vis Benefits on Present Environment and Society.

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Abstract

Transgenic crops are the revolutionary outcomes of genetic engineering. These crops are currently being cultivated on a commercial scale in many countries. But they have remained a matter of debate since they were first introduced. The debate over their environmental impact is growing increasingly complex and intense. The benefits and risks of any particular transgenic crop depend on the interactions of its ecological functions and natural history with the agro-ecosystem and ecosystems within which it is embedded. Several concerns related to consequences of gene escape, adverse impact on biodiversity, natural enemies, pollinators, soil organisms, decomposers and various non- target organisms have been raised. In addition, corporatization of agriculture raised several concerns. On the other hand, many positive impacts of transgenic crops are also praised like reduced environmental impact from pesticides and insecticide, increased yield, soil conservation, phytoremediation etc. These evolutionary and ecological factors must be considered when assessing transgenic crops. A critical analysis of this controversy is the main concern of the following discussion. Along with that, attempt has also been made to highlight the possible impact of corporatization of agriculture through transgenic crops, especially in developing countries.

Keywords: Transgenic crops, Genetically Modified Organisms, Impacts, Risks, Benefits, Environment and Society, Corporate Control , GURT and CRISPR

1. Introduction

Transgenic organisms, also called as Genetically Modified Organisms (GMO), are generally produced by applying the technique of genetic engineering to modify the genetic material of an organism for the benefit of mankind (Skeritt, 2000). In case of genetically modified crops the modification can most simply be defined as the transfer of genetic material from a different species (plant, bacteria or animal) or from a chemically synthesized gene into the target plant to get the required genetic traits. The first genetically modified plant (GMP) was antibiotic resistant tobacco in (Bevan et al, 1983).

By 2019, 190.4 million hectares of biotech plants were planted by up to 17 million farmers in 29 different countries (ISAAA, 2019). GM plants may bring huge benefits to the society and the environment, by increasing yield and protecting the environment, by reducing usage of toxic chemicals, efficient use of renewable sources, efficient use of arid land and improving environment, also by monitoring, detecting and detoxifying environmental pollution, respectively.

However, like all other technologies transgenic plants are not 100% safe (Kuiper et al, 2001). Potential environmental risks may occur in case of cultivation of transgenic crops. Risks associated to gene flow, risks associated with the allergy or toxicity to human being, beneficial insects and other non-target organisms, risks associated with directly switching transgenic plants to super weeds, risks associated with increasing use of herbicides and pest resistance to Bt plants are the major concerns of the day. Both the benefits and the risks of transgenic plants may vary spatially and temporally in different cases. We need to consider transgenic plants on case-by-case basis, and to compare transgenic plants with traditional plants, and other agricultural practices for elucidating the relative risks and benefits of transgenic plants. In this paper, the overall impact of transgenic plants to the environment and society is discussed.

2. Objective:

This work is to highlight the potential benefits and risks of transgenic crops and their long-lasting impacts to our society and environment and making people aware of them. The objective is to make a constructive criticism of transgenic crops to overcome the potential risk factors to ensure continuation of researches related to transgenic crops for the benefit of human and nature.

3. Plan of Work:

A. Collection of data regarding the current situation of GM crops worldwide.

B. Going through several research works for the assortment of different opinions about GMOs

C. Making a constructive criticism over different opinions.

D. Highlighting the impacts of corporatization of agriculture through GMOs

E. Finding a proper solution to overcome the risk factors.

4. Review of Literature:

4.1. Current Status of Field-grown Transgenic Crops Worldwide and in India:

In 1994, the first genetically modified Flavr-Savr tomato was produced to consume mainly in industrialized countries. The very next year, first transgenic crop to be commercially planted in global scale was *Bacillus thuringiensis (Bt)* Potato in 1995. By 2000, a total of 44.2 million hectors of transgenic plants were grown in 13 countries. It majorly increased in developing countries. Till date, more than 525 different transgenic events in 32 crops have been approved for cultivation in different parts of the world (Krishan Kumar *et al*., 2020). Cultivation of transgenic crops has increased significantly from 1.7 million hectare in 1996 to 191.7 million hectares in 2018 (ISAAA 2018) globally. The top GM crops grown in 2015 were soybean (92.1Mha), maize (53.6Mha), cotton (24Mha) and oilseed canola (8.5Mha). Top countries growing GM crops are the USA (70.9Mha), Brazil (44.2Mha), Argentina (24.5Mha), India (11.6Mha) and Canada (11Mha) (James 2001, 2013)

However, in India *Bt* cotton is the only genetically modified (GM) crop that has been approved for commercial cultivation since 2002 by the Government of India. Long term studies were conducted by ICAR on the impact of *Bt* cotton which did not show any adverse effect on soil, microflora and animal health. However, the Parliamentary Standing Committee on Science and Technology, Environment and Forests, in its report on ‘Genetically modified crops and its impact on environment’, submitted to parliament, August 25, 2017, recommended that GM crops should be introduced in the country only after critical scientific evaluation of its benefit and safety, and also recommended restructuring of regulatory framework for unbiased assessment of GM crops (Manjunath and Mohan, 2015).

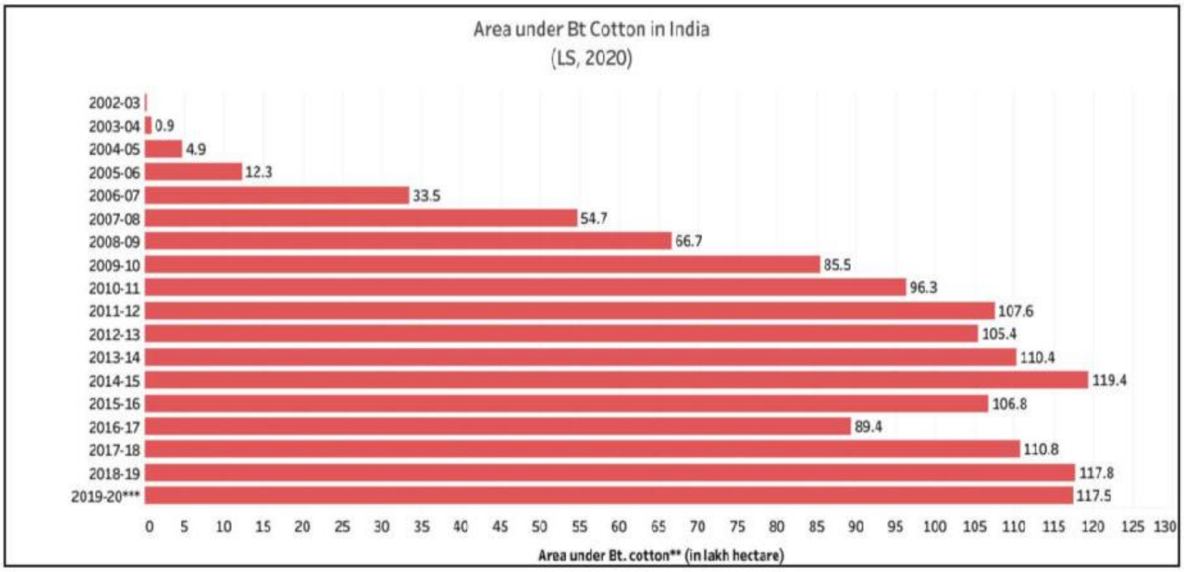

Fig.1 Area under BT cotton. [Adapted from Pavithra K M via https://factly.in/explainer-what-is-the-status-of-gm-crops-in-india/2020]

Besides that, Bt Brinjal resistant to brinjal shoot fly was developed by M/S Mahyco in collaboration with University of Agricultural Sciences, Dharwad, Tamil Nadu Agricultural University, Coimbatore and ICAR-Indian Institute of Vegetable Research, Varanasi. Bt brinjal was approved by GEAC in 2009 but due to 10 years moratorium imposed on GM crops by the Technical Expert Committee (TEC) appointed by the Hon'ble Supreme Court of India, no further action on commercialization has been taken so far. Recently the Genetic Engineering Appraisal Committee (GEAC), MoEF & CC, Govt. of India has again allowed biosafety research field trials of two new transgenic varieties of indigenously developed Bt Brinjal in eight states during 2020-23 only after taking no-objection certificate (NOC) from states concerned and confirmation of availability of isolated stretch of land for this purpose. These indigenous transgenic varieties of brinjal hybrids – namely Janak and BSS-793, containing Bt Cry1Fa1 gene (Event 142) – have been developed by the National Institute for Plant Biotechnology (NIPB, erstwhile National Research Centre on Plant Biotechnology, New Delhi) and Indian Council of Agricultural Research (ICAR) (PIB Delhi, 2020).

GM mustard Dhara Mustard Hybrid 11 (DMH 11) developed by Delhi University is pending for commercial release as GEAC has advised to generate complete safety assessment data on environmental bio-safety, especially effects on beneficial insect species (MAFW, India, 2020).

'Network Project on Transgenic in Crops' (presently Network Project on Functional Genomics and Genetic Modification in Crops) was launched by ICAR in 2005 for development of GM crops in case of pigeon pea, chickpea, sorghum, potato, brinjal, tomato and banana for different traits and currently the material is in different stages of development (PIB Delhi, 2020).

The Government of India has very strict guidelines to test and evaluate the agronomic value of the GM crops so as to protect the interests of the farmers. There are several guidelines to address all concerns regarding the safety of GM seeds. The regulatory system for GM crops as operative in the Department of Biotechnology, Ministry of Science and Technology (Review Committee on Genetic Manipulation; RCGM) and Ministry of Environment and Forests (Genetic Engineering Appraisal Committee; GEAC) has guidelines to consider the GM crops on case-by-case basis towards their testing (MAFW, India, 2020). Being a matter of debate, tension arose several times in recent times in different parts of India regarding the cultivation of GM crops. Cultivation of Bt brinjal has remained a matter of debate for a long time in India.

4.2. Assessment of environmental risk in ecological framework:

It is realized these days that agricultural fields are also a part of the "ecological theatre" in which the "evolutionary play" is continuously being played

(Hutchinson). When transgenic plants are planted in the field, they interact with many other species growing around in the environment and perform several ecological processes in agricultural fields. Quite natural, these plants are natural ‘actors’ playing important roles in this ecological ‘theatre’ (Shrivastava et al., 2019). Their roles which are being played together with the transgenic plants, raise a number of questions, as mentioned below.

The transgenic plant will come in contact with-

1. Other plants, whether conspecifics or individuals of other species. This creates the questions of invasiveness and gene spread.
2. Herbivores that feed on plants above or below ground. The effects on non-target herbivores (and biodiversity) must be considered.
3. Natural enemies of these organisms. What are the consequences for natural pest control?
4. Pollinators that visit their flowers. What are the potential consequences for pollinating insects?
5. Symbionts that live in the root zone, such as mycorrhizae or nitrogen fixing bacteria.
6. Detritivores and decomposers that feed on dead plant parts. How does this affect the soil ecological processes maintaining soil fertility, nutrient cycling and growth? (Ferrante et al., 2017)

4.3. Effects on Biodiversity:

In the regions of intensive agriculture, especially in the Northern Hemisphere, agriculture is a significant environmental management factor, and much of biological diversity of those countries exists in a cultivated landscape (Krebs et al., 1999). Alteration of current management regime has potentially significant consequences for biological diversity in such countries. Herbicide-resistant crops are expected to allow more efficient weed control. Objections have been initiated, especially in the United Kingdom, which emphasis the negative consequences for biological diversity in the countryside. Explanations are put forward for fewer surviving flowering plants to provide resources for organisms ranging from invertebrates to birds. The possible effects of such a scenario were cited by modelling (Watkinson et al. 2000). They presented their view by model of weed (*Chenopodium album)* and a songbird (skylark, *Alauda arvensis*) in a landscape to predict the effects of herbicide resistant sugarbeet on biological diversity in general. Their work points out potentially significant negative effects on seed-eating birds. Similar concerns prompted the UK government to ban commercial growing of transgenic plants to avoid damage on biodiversity (Firebank et al., 1999; Firebank and Forcella, 2000). Studies published so far on the effects of transgenic plants on agricultural biodiversity rather may be imperfect (Gábor et al. 2010).

The conclusion is that in tropical environment with a natural high biodiversity, the interactions between potentially invasive hybrids of transgenic crops and their wild relatives should be buffered through the complexity of the surrounding ecosystem (Ammann, 2009).

4.4. Consequences of Gene Escapes:

The movement of genetic material from a genetically engineered organism to another population or another species is known as gene escape. The extent of escape depends on the properties of the GM plant itself, but it is highly affected by the strategies used to limit uncontrolled escape (Lu, 2008).

Tremendous debates have arose regarding transgene escape from a GM crop variety to its non-GM crop counterparts, particularly to the crop landraces and traditional varieties, or to the weedy/wild relatives of crop species (Xu et al., 2006). This is because transgene escapes can easily occur via gene flow and may result in potential ecological and biodiversity consequences if significant quantities of transgenes constantly outflow to non-GM crops and weedy/wild relative species. This is particularly true when specific transgenes can introduce evolutionary selective (dis) advantages to the crop varieties or wild populations. The full understanding of potential biosafety problems, including transgene escape and its environmental consequences, along with effective assessment and management of such problems, may facilitate the promotion of the further development of transgenic biotechnology, as well as guarantee the safe and sustainable utilization of biotechnology and its products in our generation and generations to come. The most relevant questions regarding transgene escape and its environmental consequences include those as listed here:

- Will transgene escape from a GM crop considerably influence the sustainable and safe use of crop biodiversity and impact agro-ecological systems?
- How does transgene escape to non-GM crop varieties and to weedy/wild relatives happen in reality?
- How can the genetic diversity of crop landraces and wild populations be affected by escaped transgenes?
- What are the potential biosafety consequences caused by gene flow from an environmental perspective?
- How can the potential environmental risks caused by transgene outflow using a biosafety framework be assessed?
- Can we mitigate environmental risks, if any, through the use of management measures?

Type of gene flow	Occurrence	Influenced by affinity between donors & recipients	Factors that constrain gene flow
Pollen-mediated	Common	Yes	Out crossing rate of recipients, pollen loads of donors, pollen competition between donors and recipients, the pollinating media (e.g. wind, animals), and climate conditions
Seed-mediated	Common	No	Seed dispersal media (e.g. wind, water, animals and humans) and sometimes climate conditions
Vegetative-propagule-mediated (usually for perennial)	Not common	No	Vegetative-organ dispersal media (wind, water, animals, and humans)

Table 1. Types of gene flow via different avenues & their characteristics [Adapted from Lu. Bao-Rong, 2008]

These questions are to be highlighted, not only for the benefit of scientists and researchers, but importantly also for the public and consumers of biotechnology products within the international community. (Lu. Bao-Rong, 2008)

The ecological consequences could be serious if the new trait causes the changes to fitness parameters or invasiveness of the modified plants. Data related to fitness or invasiveness of genetically modified plants is rare. The oilseed rape containing the Bt-toxin gene acquires a fitness advantage under insect herbivory (Stewart et al., 2003). In a long-term study of survival in the wild and invasiveness of herbicide-resistant crop plants in different area of the British Isles, no genetically modified plant line survived longer than 4 years when planted in natural habitats (Crawley et al., 2001).

However, invasion success is scale-related, and it is rather difficult to predict the consequences of wide-scale planting of transgenic crops from limited-scale studies (Gerhart, 2014).

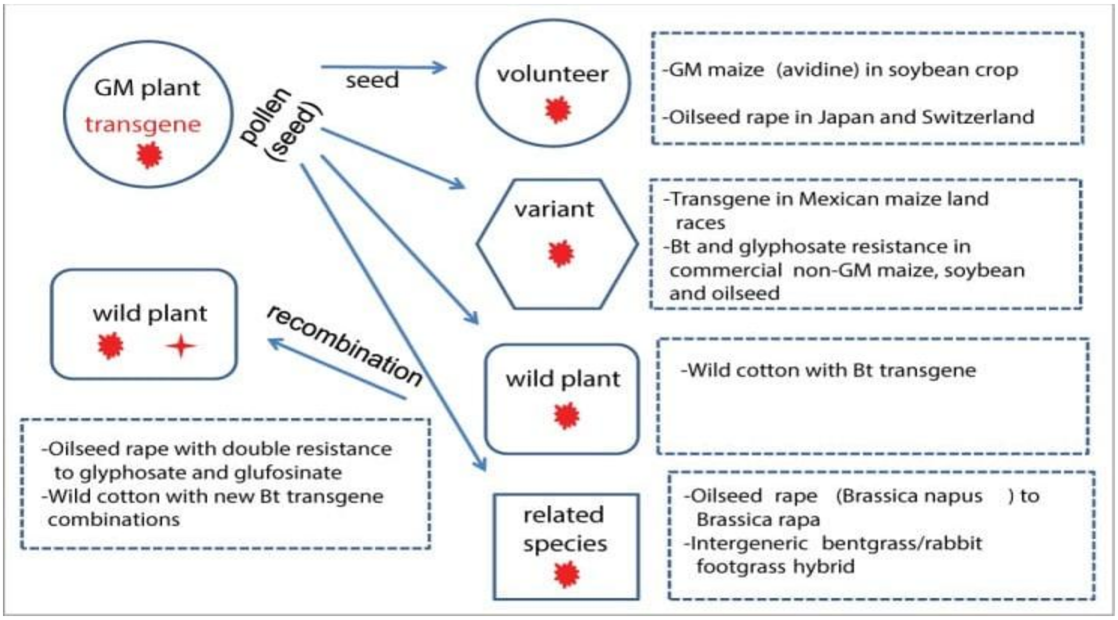

Fig: 2 Unintended transgene escape: Summary of the reports showing unintended escapes of transgenes from GM plants to volunteers, variants, wild type plant and related species. The GM maize in soybean crop exemplifies an inadequate handling in a test field. [Adapted from Gerhart, 2014]

4.5. Effects on Natural Enemies and Insects:

Though they are apparently simple, agricultural systems are consisted of several organisms that interact in our food webs (Price et al. 1980). In the last 20 years effects of host plants on several higher trophic level organisms like parasitoids and predators have been studied discretely (Groot & Dicke 2002). Various scientists have exclaimed their concerns that changes in traits in plant genetics may affect natural enemies directly. As plants are a direct source of water and nutrition for many parasitoids and predators that fed on floral or extrafloral nectar, pollen or plant sap, consequent changes in plant quality may affect them (Eliana M.G.F. et al., 2002).

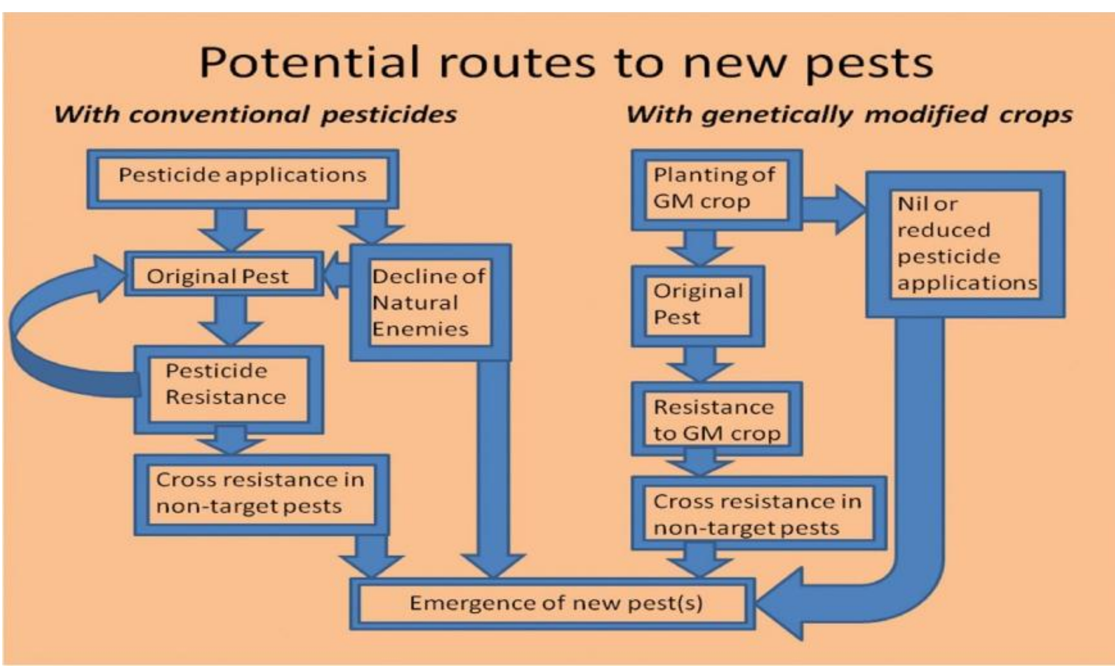

Fig. 3 New pests for old as GMOs bring on substitute pests. (Adapted from Robert A. Cheke, 2018)

Insect-resistant GM plants are responsible for reducing the density of certain communities of insects which fed on plant. These insects also serve as prey for a range of natural enemies. Therefore, an important potential effect of transgenic plants maybe the consequences of changing the occurrence and density of prey for natural enemies. As evidence, transgenic potato controlling the Colorado potato beetle is probably responsible for a noticeable decrease of its special predatory ground beetle (Riddick et al., 1998).

Predatory and parasitoid insects are also sensitive to quality of their prey at one side and on other side host plants determine the quality of prey; thus, tri-trophic interactions exist in the crop field (Price et al., 1980). A lot of such examples have been recognized in the environment of transgenic plants or their experimental equivalents. Such as, the parasitoid wasp *Eulophus pennicornis* had reduced parasitic ability on tomato fruit-worm (*Lacanobia oleracea*) hosts from plants with the cowpea trypsin inhibitor (Bell et al., 2001). Parasitoids can also react at a behavioral level to a host originating on transgenic plants (Schuler et al., 1999). Adults of the ladybug, when fed on aphids raised on transgenic potato (expressing the snowdrop lectin), were negatively affected. Adult female (but not male) longevity was reduced, egg laying and egg viability decreased (Birch et al., 1999). Interestingly, larvae of the same ladybug did not seem to suffer the same consequences (Down et al., 2000). In another case, adult ground beetles consumed less of their caterpillar prey when this prey was raised on proteinase inhibitor-containing diet despite their normal diet. This effect persisted longer than the actual exposure to the manipulated prey and was age-dependent (Jørgensen et al., 1999). Proteinase inhibitors seem to affect herbivore suitability as prey for this predator.

It is reasonable to point out that the potential impacts on natural enemies associated with the plants produced by conventional and transgenic methods fall into the same general categories (David and Anjelina, 2004) which encompassed extensively the genetic engineering and conventional breeding for host plant resistance and the possible non-target effects of both breeding methods. She emphasizes that the season-long and high-level expression of *Bt* toxins on crops may have more three-trophic effects than conventionally bred crops. It is important to remember that any human interference to protect crops from pests will have some negative impact on those arthropods that depend on those pests (Schular et al., 2001), and on the overall biological community (Shelton et al. 2002).

Plant characteristics that affect herbivores may also directly or indirectly affect their natural enemies. The tools of genetic engineering have provided a novel and powerful means of transferring insect-resistance genes to crops, and there is evidence that those resistant traits have similar effects on natural enemies than resistance achieved by conventional breeding. GE insect resistance crops have been grown on a large scale for more than 20 years, and there is considerable experience and knowledge on how they can affect natural enemies and how their risks can assessed prior to commercialization (Romies et al., 2019)

4.6. Effects on Pollinators:

More than 25% of the world's food crops are pollinated by animals. Pollinating organisms in the temperate regions are mostly insects, namely bees and wasps (Buchmann & Nabham, 1996). They can be agents for spreading pollens and are exposed to any transgenic product that is expressed in pollen or nectar. Bees and bumble bees can be affected by transgenic products (Suwannapong et al., 2012); thus, the systematic study for the environmental risk assessment of transgenic plants seems essential which can insure us that ecosystem service is not being damaged (Malone and Pham-Delegue, 2001).

Though, Extensive field experience with commercial GM crops which are bred for herbicide tolerance or insect resistance using *Bacillus thuringiensis* (Bt) crystal (Cry) toxin genes, has shown no deleterious effects on pollinators. Many other insecticidal GM plants, not yet commercialized, have been studied to see if they could be hazardous to bees. Of these, only some of the protease inhibitors and lectins caused dose-dependent hazards to bees if there were realistic routes for sufficiently high exposure. A good understanding of crop pollination biology is essential for adequately assessing risks of GM plants to pollinators.

The proteins present on commercial formulation of *B. thuringiensis* have been considered non-toxic against bees (Malone and Pham-Delegue, 2001). However, different proteinase inhibitors have shown different effects on performance and behavior of worker honeybees, *Apis mellifera* L. (Moisan-Deserres et al., 2014). The proteins inducing resistance to pest cowpea trypsin inhibitor and b-1,3 glucanase negatively affect the behavior of honeybees (Picard-Nizou et al., 1997) but three proteinase inhibitors, suitable for incorporation into oilseed rape, did not affect bee behavior and caused no short-term mortality (Girard et al). These results showed that a case-by-case analysis is needed when evaluating the effect of proteinase inhibitors on learning performance of bees (Moisan-Deserres et al., 2014). In addition, it is necessary to test the different protein inducing resistances to insects on other bee species because, in a diverse group such as bees, it is possible that different species present different susceptibilities to these insecticidal molecules of GM crops.

Intensive agricultural practices resulting in large scale habitat loss ranks as the top contributing factors in the global bee decline. Growing Genetically Modified Herbicide Tolerant (GMHT) crops as large monocultures has resulted extensive applications of herbicides leading to the degradation of natural habitats surrounding the farmlands (Colton O' Brien and Arathi, 2018).

4.7. Effects on Non-Target Organisms:

Many species of Lepidoptera or Coleoptera (depending on the type of Bt toxin expressed), both target and non-target, are likely to be susceptible to the Bt toxins produced by transgenic crops. Losey et al. showed that the larvae of the monarch butterfly, *Danaus plexippus* (L.), living in weeds near corn fields, could be affected adversely by Bt corn pollen drifting onto the foliage of plant species explored by the butterfly. These results have been questioned on the basis that they came from small-scale laboratory assays with high levels of toxin expressed in no-choice tests. Indeed, recent studies suggest that risks posed by current corn crops incorporating the Bt toxin genes to monarch butterflies are not likely to be significant (Sears et al. 2001). These studies show that, while Bt pollen does have some toxic effects when fed to butterfly larvae, the pollen densities likely to be encountered in the field are too low to pose a risk to monarch larvae. However, another study showed that low concentrations of pollen from event 176Bt corn, dramatically reduced growth rates among black swallowtail caterpillars, *Papilio polyxenes* F., in field tests (Zangerl et al. 2001). An earlier study (Wraight et al. 2000) has noted that a widely used Bt corn-containing event 810, had no adverse effect on black swallowtails living on weeds near cornfields. From these results, it is reasonable to infer that a careful event selection is advisable in the development of pest-protected crops, and that more research is needed on the impact of Bt varieties on several non-target species.

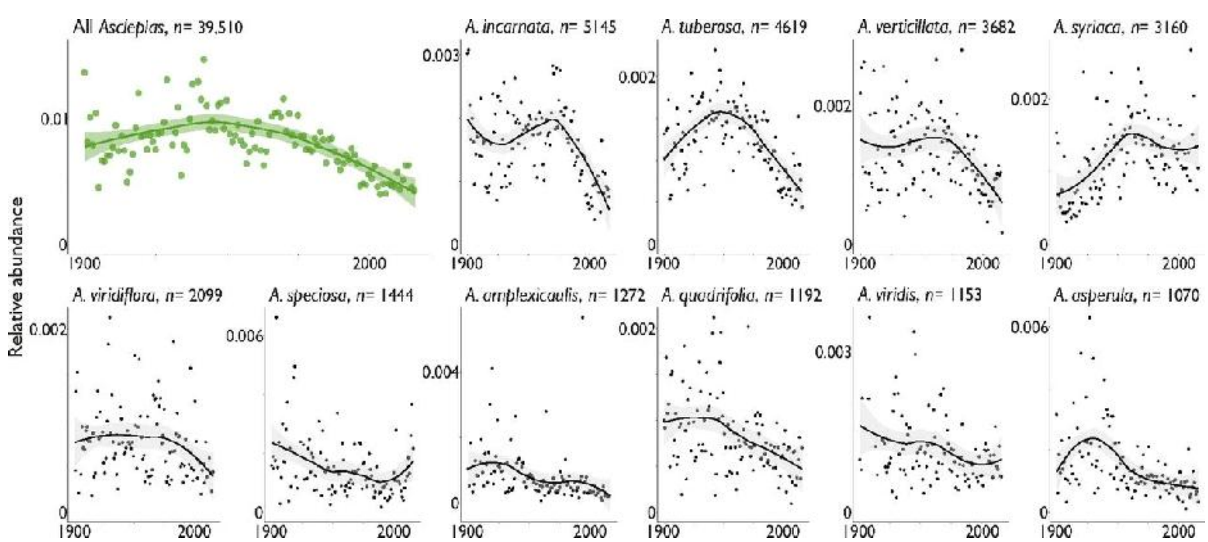

Fig. 4 Genus level Milkweed declined over the 20th century is recapitulated in the 10 most common Asclepias species. The total number of specimens collected is shown next to each species. Points indicate abundance for each year and lines and indicate smoothed mean and 95% confidence intervals. Smoothing was done using the Loess. (Adopted from Boylea et al., 2019).

4.8. Insecticidal Toxins and Effects on Soil Organisms:

A healthy agricultural production system cannot exist without healthy soil and soil organisms. Soil health is evaluated based on how soil performs its capacity to promote plant growth and productivity. The effect of genetically modified (GM) crops with herbicide tolerance and insect resistance traits can be explained to elucidate the impact of GM crops on soil health (ISAAA, 2017). The Bt-toxin has been reported in root exudates of transgenic Bt-maize in such a high concentration that is sufficient to kill insects (Saxena et al., 1999). Their long-term consequences are still unknown. Transient effects and significant changes have been reported in soil protozoan populations in soil under genetically engineered potato lines (Griffiths et al., 2000). The maintenance of soil fertility depends on biological process, so the tests of the effects of transgenic plants on soil processes are very important. Many of these protozoans participate in ecological processes that are useful and necessary for agricultural production. These processes are termed 'ecosystem services' (Lövei, 2001).

Bacillus thuringiensis (Bt) insecticides have been used for more than 30 years and they are generally considered safe for the environment. This is probably because Bt does not survive or grow well in natural habitats such as soil and its spores are rapidly inactivated by ultraviolet radiation (Saxena and Stotzky, 2003). However, when the genes that code for the production of insect toxins are genetically engineered into plants, the toxins continue to be synthesized during the growth of the plant and are present throughout the whole life cyclethat may possess long lasting impacts (Saxena and Stotzky 2000). There are other differences between Bt-insecticides and transgenic Bt plants, including the Bt toxin mode of action (Hilbeck et al., 2002), that make it necessary to verify the possible impact of Bt crops on the soil environment, particularly on the soil microbiota. Deviations in the numbers and kinds of soil organisms may influence the fertility considerably, for example by decreasing the ability to retain water and nutrients.

Genetically modified plants that produce Bt toxins may release these proteins into the environment when the plants are incorporated into the soil. It has also been shown that some toxins will be released to the soil from root exudates during the entire growth of a Bt crop (Saxena and Stotzky 2000). In this case, a question is raised whether an increasing amount of Bt toxins in soils could result in novel exposure of soil organisms to these toxins, with potential negative non-target effects. A series of studies has investigated the fate of the Bt toxins in the soil environment and their effect on soil organisms (Saxena and Stotzky 2000). The toxins released in root exudates and upon disintegration of transgenic crop residues are adsorbed rapidly, bound to elements of the soil (clay particles, humic acids) and stabilized. In this case, only for a short time of period they will be in a free state, susceptible to rapid degradation (Saxena and Stotzky 2000, Saxena and Stotzky, 2003).

However, several comprehensive review showed that there were few or no toxic effects of Cry proteins on non-target soil organisms including woodlice, collembolans, mites, earthworms, nematodes, protozoa, as well as the activity of different enzymes in soil. The minor effects reported were mostly results of differences in geography, temperature, plant variety, and soil type, and were not linked to Cry protein presence. Some of those studies are summarized in the following table.

Organism	Crop Event	Comparison	Effect
Enchytraeids	Corn: Bt11 (Cry1Ab), MON88017 (Cry3Bb1)	Bt & non-Bt	No significant differences for Cry3Bb1; significantly higher survival and significantly lower reproduction for Cry1Ab, likely to be caused by differences in plant components.
Soil microbes	Corn: MON863 (Cry3Bb1)	Bt & non-Bt	No adverse effects on saprophytic microbial communities of soil and decaying roots or on decomposition.
Soil microbes	Corn: Event 176 (Cry1Ab), MON810 (Cry1Ab)	Bt & non-Bt	The presence of Bt maize did not cause changes in the microbial population of the soil or in the activity of the microbial community.
Earthworms	Corn: Bt11 (Cry1Ab), MON819 (Cry1Ab), MON863	Bt & non-Bt	No significant differences in biomass of juveniles and adults.
Earthworms	Cotton: GK19 (Cry1Ac)	Bt & non-Bt	No significant acute to toxicity, average weight, numbers of cocoons and new offspring not significantly different.
Snails	Cry1Ab	Purified protein alone in soil	No negative effect during the observed stages.

Adopted from ISAAA 2016, publication, pocket K No. 57: Impact of GM Crops on Soil Health

On the other hand, the cry1Ab toxin from transgenic corn released in root exudates persists in the rhizosphere and can be active for hundreds of days (Saxena and Stotzky, 2003). The effects of cry1Ab toxin released in the root and from biomass of Bt corn in the total number of earthworms, nematodes, protozoa, bacteria and fungi were investigated. Results suggested that degradation of biomass of Bt-corn is nontoxic to a variety of species used as models.

The above studies determining rates of degradation of cry proteins in soil have been of sufficient duration, and were performed under adequate conditions. However, they were essentially developed in soil microcosms. Tabashnik et al. (2002) investigated what happens to Bt toxins released into the soil from Bt crops under field conditions, in the state of Arizona (USA). They collected soil samples from within and outside fields where insect-resistant transgenic cotton encoding the cry1Ac gene had been grown and subsequently incorporated into the soil by post-harvest tillage for 3-6 consecutive years. These samples were analyzed by enzymatic and bioassay tests for the levels of cry1Ac protein. They found no detectable cry1Ac protein in any of the soil samples collected from within or outside the Bt-cotton fields. Other studies including analyses of different types of soils under Bt-crops cultivation are necessary to clarify the contrasting differences observed in the persistence of Bt cry1Ac protein between laboratory assays and field observations. Moreover, more information on the effect on soil microbiota is needed, including possible interference with nutrient cycles and effects on ecosystem functions, although these kinds of data are still very difficult to obtain (Tabashnik et al., 2013).

4.9. Development of Resistance to BT-Toxins in Pests:

Historically, pests have rapidly adapted to the techniques used to control them. The experience with chemical pesticides has proven to be disappointing, as pests quickly evolved resistance to them (Raymond et al., Gould). More recently, several studies have shown that pests can also adapt to toxins produced by the bacteria *B. thuringiensis* under field and laboratory conditions, including resistance to Bt transgenic crops (Tabashnik et al., 2013); the exquisite capability of insects to adapt to Bt-toxin and different manage systems help the conclusion that the evolution of resistance by means of pests is the important hazard to the persevered success of Bt-crops (Kebedde, G.G., 2020).

One of the greatest concerns is that the widespread use of Bt crops could lead to the evolution of a number of important pest insects that are resistant to the Bt biopesticides. That is of particular concern to organic farmers because they use *B. thuringiensis* as a natural pesticide. Development of resistance to Bt crops among population of serious pests also brings concerns to the long-term use of the technology itself, as it may lose its effectiveness as a tool to control these pests.

Several strategies for resistance management have been proposed to delay the chances of pest population adaptations to Bt crops (Gould). The most widely used is the high-dose-refuge strategy, which has been implemented in North America (Alstad & Andow, 1995). In general, it is recommended that a 20-50% refuge area be planted with non-GM varieties. In the case of Bt corn, it is recommended that a minimum of 20% of the area be planted with conventional varieties; and in fields where Bt corn is planted where cotton has been previously cultivated, at least 50% of the area must be planted with conventional varieties of corn, to avoid the development of insect pest populations resistant to Bt (Mohamed, 2018).

The strategy was favoured by the industry of producing transgenic varieties expressing high doses of different toxins, associated with the tactics of refuges, seemed at first to be a good idea. This strategy, however, was not prove to be efficient, due to factors such as polyphagy among insect pests that also feed on other plants including weeds, or to the movement among different cultivated fields by some insect pests. When the pests move to non-transgenic fields they are exposed to low to moderate doses of the toxin, which prevents the desirable effects of high-dose exposure (Gould). Another approach to delay the evolution of resistance much more effectively is the use of additional pesticide gene, called transgene pyramiding. The new generation of GM pest resistance crops already contain two insecticidal genes. The cotton variety sGK, commercially available in China contains the cry1A gene and the CpT1, the cowpea trypsin inhibitor gene (Shelton et al. 2002).

Implementing resistance management practices when a pest protection substance or its functional equivalent are providing effective pest control, or when there is a threat to the utility of existing uses of the pest protection substance (e.g., Bt proteins) is crucial for obtaining the greatest benefits from pest resistance transgenic crops, and for allowing the continued use of *B. thuringiensis* biopesticides.

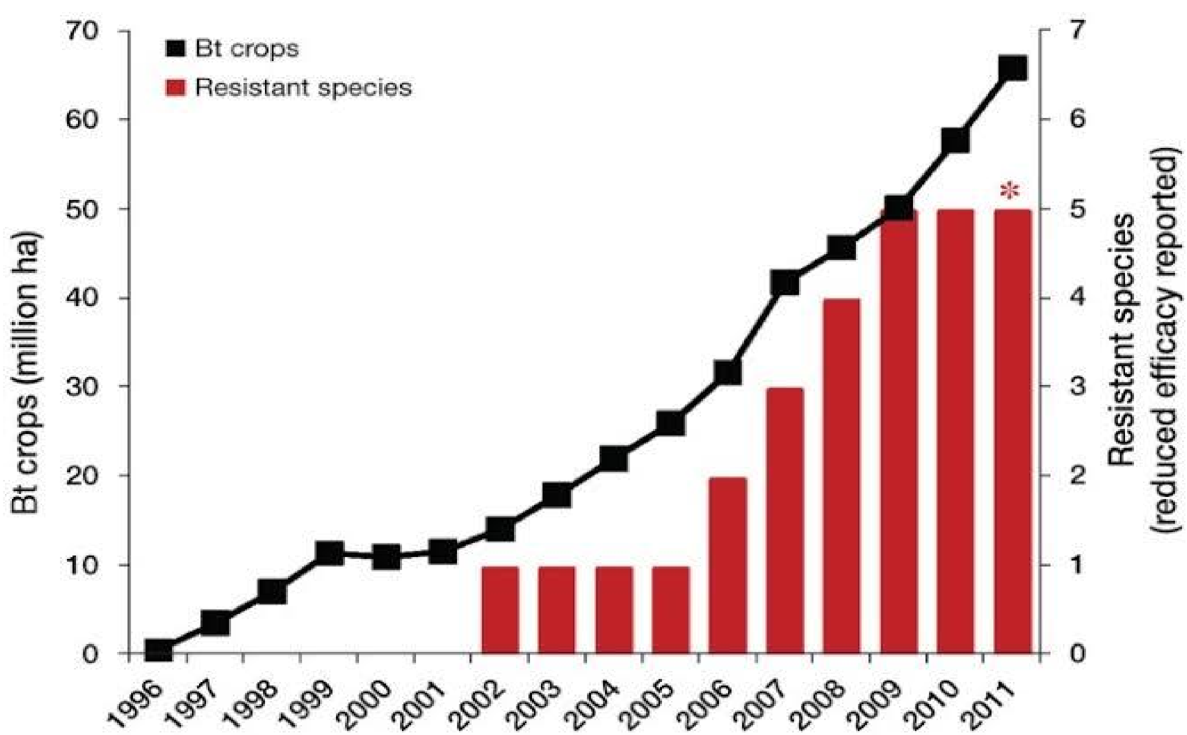

Fig. 5 Global adaption of Bt crops and evolution of insect resistance. (Adapted from Tabashnik, et al, 2013, via https://doi.org/10.1038/nbt.2597)

4.10. Potential Ecological Benefits:

The evaluation of the environmental impact of transgenic organisms often centers on the risks attached to them. This is justified, as any new, large-scale technology does have risks and unforeseen consequences. A number of arguments have suggested a positive environmental impact from large scale production of transgenic plants (Wolfenbarger and Phifer, 2000).

One of the significant environmental benefits of GM crops is the dramatic reduction in pesticide use, with the size of the reduction varying between crops and introduced trait.

- A study assessing the global economic and environmental impacts of biotech crops for the first 21 years (1996-2016) of adoption showed that the technology has reduced pesticide spraying by 671.2 million kg and has reduced environmental footprint associated with pesticide use by 18.4%. The technology has also significantly reduced the release of greenhouse gas emissions from agriculture equivalent to removing 16.75 million cars from the roads. (Graham & Peter 2020).

- According to a meta-analysis on the impacts of GM crops, GM technology has reduced chemical pesticide use by 37 percent. (Klu¨mper and Qaim, 2014)

- A study of U.S. maize and soybean farmers from 1998 to 2011 concluded that adopters of herbicide tolerant maize used 1.2% (0.03 kg/ha) less herbicide than non-adopters, and adopters of insect resistant maize used 11.2% (0.013 kg/ha) less insecticide than non-adopters. (Perry, et al., 2016).

- In China, use of Bt cotton resulted in pesticide use reduction of 78,000 tons of formulated pesticides in 2001. This corresponds to about a quarter of all the pesticides sprayed in China in the mid-1990s (Pray et al., 2002). Furthermore, another study, covering data collected from 1999 to 2012 showed that Bt cotton adoption has caused a significant reduction in pesticide use (Chen, et al, 2007).

- The use of Bt cotton can substantially reduce the risk and incidence of pesticide poisonings to farmers (Pray et al., 2002).

- Herbicide tolerant crops have facilitated the continued expansion of conservation tillage, especially no-till cultivation system, in the USA. The adoption of conservation and no-till cultivation practices saved nearly 1 billion tons of soil per year (Fawcett et al., 2005).

- Biotech cotton has been documented to have a positive effect on the number and diversity of beneficial insects in the US and Australian cotton fields (Carpenter et al., 2002).

4.11. Reduced environmental impact from pesticides:

Herbicides and pesticides have potential hazards for environmental pollutions, whereas, transgenic crops may decrease the use of environmentally harmful chemicals to control weeds and pests. (Wolfenbarger and Phifer, 2000). For example, reduced frequency of treatments can bring a net decrease in pesticide pollution if paralleled with a decrease in the total amount of pesticide and herbicide used. Conflicting claims have been made about the effect of herbicide-tolerant crops in the U.S.A. (Carpenter and Gianessi, 2000). In the absence of published documentation where the assumptions and the validity of the arguments can be checked, no conclusions can be drawn (Wolfenbarger and Phifer, 2000). Since, the wide spread commercial use of GM crops for 22 years it has been noticed that the adoption of GM insect resistant and herbicide tolerant technology has reduced pesticide spraying by 775.4 million kg (8.3%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops (as measured by the indicator, the Environmental Impact Quotient (EIQ)) by 18.5%. The technology has also facilitated important cuts in fuel use and tillage changes, resulting in a significant reduction in the release of greenhouse gas emissions from the GM cropping area. In 2018, this was equivalent to removing 15.27 million cars from the roads.

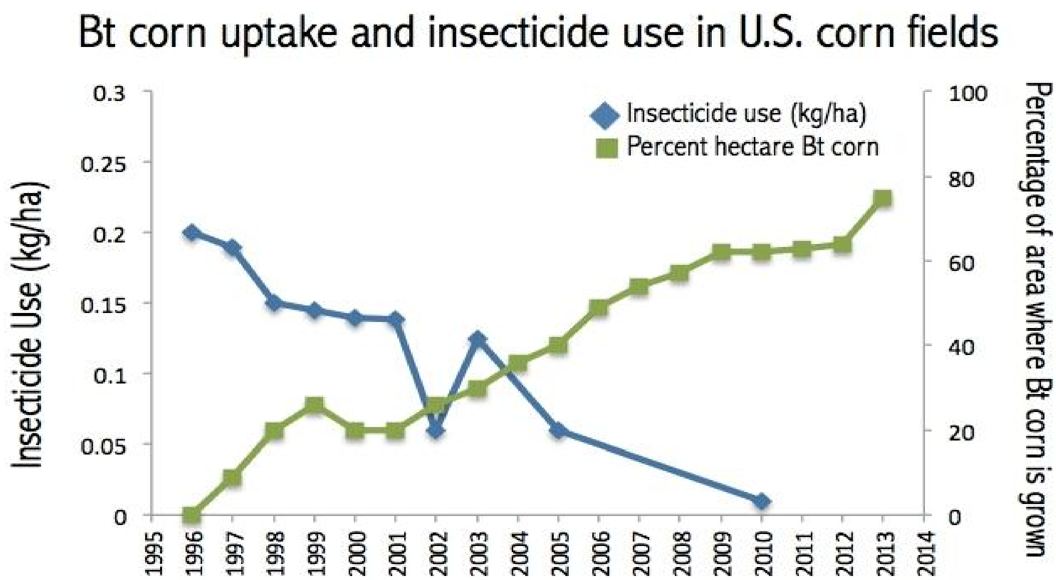

Fig. 6 Adapted from Malakof D. and Stokstad E. Pesticide Planet. Science Magazine. 16 August 2013.

4.12. Increased yield:

If crop yields increased, less cultivated area would be needed to produce the total amount of food required by people. This could result in a lower pressure on land not yet under cultivation and could allow more land to be left under protection. The potential environmental benefits of this type may be greatest in developing countries where most of the agricultural production increase was due to new areas taken into cultivation. Since their first commercialization in 1996, genetically engineered (GE) crops have been rapidly adopted in many countries becoming the fastest adopted crop technology in the world. GE crop cultivation has increased from 1.7 million hectares in 1996 to 185.1 million hectares in 2016, representing about 12% of the global cropland, 54% of which are found in developing countries (ISAAA, 2016).

Smallholder farmers in central and southern India who planted genetically modified (GM) cotton achieve larger yields, greater profits and a higher living standard than those who grow conventional cotton, finds a study published in the Proceedings of the National Academy of the Sciences (Kathage, Qaim, 2012).

The study includes data collected from 533 farm households between 2002 and 2008. The yield of plots planted with Bt cotton increased by 24% compared with conventional cotton plots. This translated to a 50% increase in profits, and during 2006–08, families that adopted Bt cotton spent 18% more money than conventional farming households, suggesting an increase in living standards. Bt cotton was officially approved for sale in India in 2002. Before that, a bollworm infestation could halve yields. Within a decade, Bt-cotton was adopted by nearly 7 million farmers, and they cover 97% of the area planted with the crop today. Yields have doubled, and insecticide use has halved. Similar benefits have been seen globally — a 2010 review of 168 farmer surveys from 12 nations found positive overall benefits from planting GM crops (Carpenter et al., 2002).

4.13. Soil conservation:

Herbicide-tolerant crops may allow farmers to abandon the use of soil-incorporated pre-emergent herbicides. This shift to post-emergent weed control may increase the no-till and conservation tillage practices, decreasing soil erosion, water loss, and increasing soil organic matter (Cannell and Hawes, 1994). The development of GMO crops have been instrumental in facilitating conservation tillage and resulting improvements in soil health (Kate Hall, 2016).

Mechanical weeding is one of the causes of top-soil erosion. Weeds rob nutrients from crops. In one year, weeds would rob enough nutrients to have fed one billion people globally (Cle´ment al. 2018). One of the common soil practices used in farming to get rid of weeds is tilling or plowing. However, this practice is very laborious, time consuming and not very effective in controlling weeds. It also causes erosion and runoff, affecting soil biodiversity and allows greenhouse gasses to escape from the soil. According to

World Wildlife Fund, half the world's soil has been lost in the recent 150 years (WWF). These concerns have led scientists to develop crops that would not need tilling, which are now known as herbicide tolerant crops (Bodnar, 2014).

Herbicide tolerant (HT) crops tolerate exposure to broad-spectrum herbicides like glyphosate and gluconate, which are also among the safest kinds used in farms. These herbicides target specific enzymes in the plant metabolic pathway, which affects plant food production and in extreme cases kill the plants. When the HT crops are exposed to these herbicides, they do not die, unlike the weeds surrounding them. Thus, HT crops promote no-till or conservation tillage. After herbicide application, the weeds die and work as a blanket that protects the soil from wash off. With less or no tilling, there would be less soil erosion. This would mean more water retention and fewer greenhouse gas emissions. This is a win-win solution for the farmers and the environment because there is less labor for farmers, and they don't need to purchase fossil fuel for tractors that plow the soil. The current types of herbicides used with herbicide tolerant crops are also far less toxic than those types used last century (Parrott, 2018). The herbicide tolerance technology has helped millions of farmers all over the world. In 2018, 88.7 million hectares were planted with HT crops, the largest area planted to a biotech trait (ISAAA. 2017).

4.14. Phytoremediation:

Emphasis has been given for in situ remediation of soil and water pollution by transgenic plants and micro-organisms. Transgenic plants can sequester heavy metals from soils (Gleba et al., 1999) or detoxify pollutants (Bizily et al., 2000). This has not yet been used widely, so its environmental impact has not been studied.

4.15. GM Crops and Corporate Control:

Along with all the risks and benefits, GM crop also has become a matter of concern regarding its all alone corporate ownership. They sell GMO seeds and associated products, including herbicides as well as non-GMO seed and products supporting agricultural production. They lobby and advise governments on GMO regulation, and they work with farmers on GMO cropping. But through the power of corporate lobbying they also have a worrying amount of control over food policy and regulation; and through aggressive marketing they can control the perception of what we eat and therefore the evolution – and, some would argue, breakdown – of food culture worldwide. Pat Thomas has highlighted some major concerns regarding this (Pat Thomas, 2021).

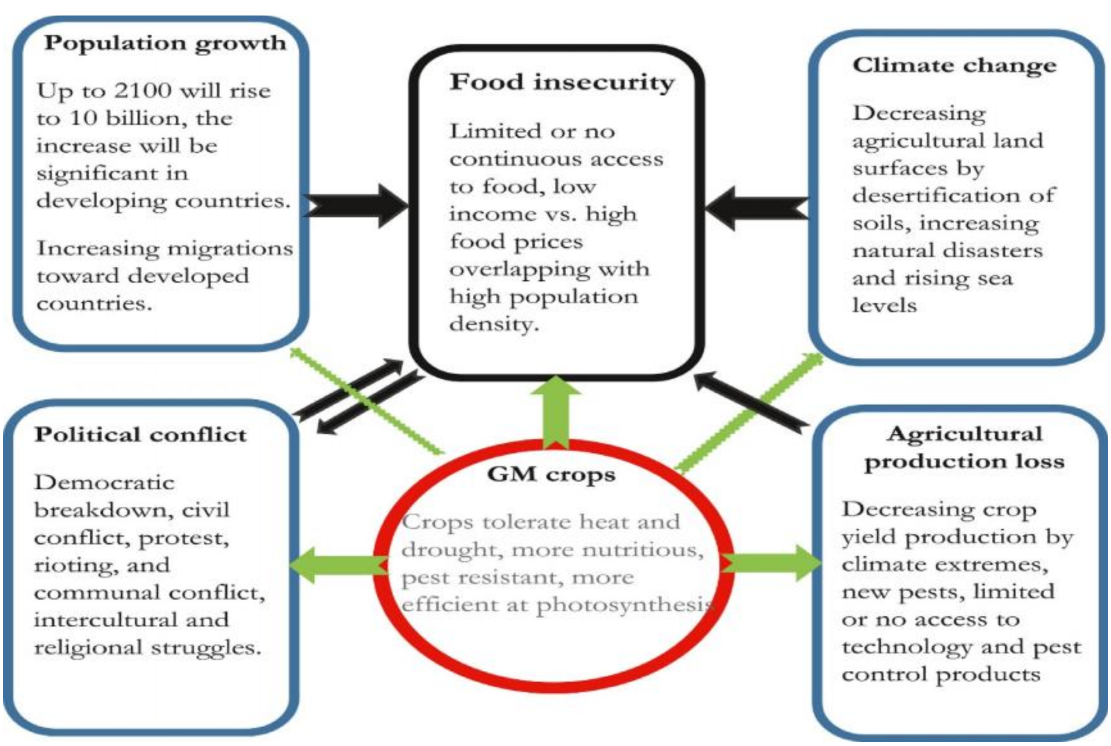

Fig.7 Several concerns directly associated to GM crops, by Pat Thomas, (2021).

4.15.1. The Power of Patent:

The instrument of control, particularly when it comes to GM crops, is the patent. The definition of a GMO – which applies in both law and science – is an organism whose DNA has been altered in a way that cannot happen in nature. This definition is important because it is what allows biotechnology companies to patent the plants that they produce (and all GMO plants are patented) as well as the processes used to produce them. Patents provide an important income stream for large corporations. Today, living biological material like seeds and plants, which until now have been part of our natural and common heritage, are being appropriated and taken into corporate ownership through the use of patents and other forms of so-called intellectual property rights. The genetic modification, or "inventive step", which justifies the patent might be a small part of a GM plant's gene sequence, but it is used to claim ownership of the plant's entire genome and all of its uses. This gives the GM companies enormous power over plant breeding and farming; it takes away farmers' traditional rights to save and swap their own seeds; it squeezes traditional plant breeders out of existence; and it concentrates genetic resources in the hands of a few companies, giving them control over the future of food and farming. Patenting of any living organism is controversial and while it is true that non-GM seeds and food products can also be patented, biotech companies have pushed this issue almost as far as it can go and, in so doing, have caused a fundamental shift in the relationship between man and nature (Pat Thomas, 2021).

4.15.2. Seed control:

The practice of saving this year's seeds for replanting next year is as old as farming itself. It is an important part of the economy of many small farms and also helps ensure continuity in a farmer's crops, from season to season. GM seeds, which are patented products owned by the companies that engineer them, cannot be saved and farmers, risk prosecution and high fines if they try to do so. It can be hard to get to grips with just how concentrated this control is. Currently, a handful of large seed and chemical corporations (BASF, Bayer, Dow, DuPont and Syngenta) control 75% of the global agrochemical market, 63% of the commercial seed market and over 75% of private sector research and development (R&D) in seeds and pesticides. The influence of these companies extends well beyond just their market share, placing near unlimited power over our food system in a few, undemocratic hands.

4.15.3 Failing our farmers:

This concentration of power can be devastating for farmers, driving up farming costs while providing no benefit in terms of increased yields or higher value crops. Because GM seeds cannot legally be saved for replanting, farmers must buy new seeds each year. Biotech companies control the price of seeds, which cost farmers 3-6 times more than conventional seeds. This, combined with the huge chemical inputs they require, means GM crops are more costly to grow than conventional crops. The disproportionate emphasis on developing genetically engineered crops, has also led to lack of investment in conventional seed varieties leaving farmers with less choice and control over what they grow. Farmers who have chosen not to grow GM crops can find their fields contaminated with GMOs as a result of cross pollination between related species of plants and GM and non-GM seeds being mixed together during storage. Because of this, farmers are losing export markets. Many countries have restrictions or outright bans on growing or importing GM crops and as a result, these crops have become responsible for a rise in trade disputes when shipments of grain are found to be contaminated with GMOs (Farmaid.org, 2017).

4.15.4. Laws of Scientific Independence:

GM crops have accelerated the growth of a particularly toxic form of 'corporate science' – conducted in the name of profit and patents rather than honest enquiry. Although we are learning more each year, there are still gaps in our understanding of how GM crops behave in the environment and how they might affect health. Patent law maintains that gap by allowing patent holders to control and restrict Independent research into these and other areas. Typical restrictions include no-research clauses in license agreements with farmers and limiting access to GM seeds and plants for independent Researchers. This toxic science, which is solely for the benefit of biotech companies, distorts the true picture of potential risks – and in particular health risks – by suppressing results that show harm. Yet it is used regularly and aggressively to silence critics of agricultural GMOs and the harmful pesticides that are used on them. In contrast, studies conducted by independent scientists regularly find disturbing results. A recent open letter by more than 300 such scientists from around the world made it clear there was absolutely no scientific consensus on GMO safety and that the weight of the evidence suggests cause for real concern. (Ignatova, 2015). That's worrying enough. But there is also a compelling argument that when scientists are prevented from examining the raw ingredients in our food supply, or from testing the plant material that is intended to be planted in open fields over large tracts of land, these restrictions work against the public interest and, in fact, become a danger to the public.

4.15.5. Masquerading Control Altered as Choice:

Some might argue that the corporatization of food has been a boon for consumers, giving us greater access to a wide range of foods and food brands to choose from. But choice at the supermarket is largely an illusion. Although the average supermarket may stock upwards of 30,000 different food products, the truth is that most of those seemingly unrelated brands are owned by large multinationals companies. The picture shifts slightly as brands are bought and sold, but in general just 10 companies – Nestlé, PepsiCo, Coca-Cola, Unilever, Danone, General Mills, Kellogg's, Mars, Associated British Foods and Mondelez – control almost every large food and beverage brand in the world (Laughman, 2020). These companies have a vested interest in maintaining but also creating new markets. Since their food products depend on a predictable supply of a handful of monoculture crops – wheat, soya and maize – the 'best' way to innovate is at farm level, for instance by altering the genome of these crops to improve yield, or resist pests ensuring a steady and cheap supply of ingredients. With the advent of genetically modified animals – for instance the GM salmon that grows twice as fast as natural salmon – and new synthetic biology foods and ingredients, the same business model, with its distorted focus on cutting costs, persists. While we might marvel at the level of technical sophistication involved in genetically engineering crops, animals and foods the truth is that genetic engineering has simply entrenched the industry's tendency to look at food as a commodity and to think in terms of ingredients and processes rather than food and nutrition. Seed sovereignty, the right of farmers to save, exchange, use and sell their own seed, is violated by control over seed systems through patents and corporate domination of the supply of seeds (Ignatova, 2015).

4.16. Potential Impact in Developing Countries

China is the first country to grow transgenic crops on a commercial scale, virus resistant tobacco and tomatoes (Skerritt, 2000). China is now only a relatively modest producer of Bt cotton; the proportion of genetically modified crops in China as a proportion of those worldwide is decreasing. This is not due to Government influence in China, but rather because seed distribution and vertical integration of seed sales through to crop marketing are far better developed in the Western countries. From a technical standpoint, the use of transgenic plants could have substantial benefits for developing countries. These may include increased disease and pest resistance, increased yields, crops with higher nutrient content and delivery of vaccines. Higher lysine maize and bananas carry vaccines have already been engineered. There is potential, as yet unrealized, for genetic engineering to assist those in developing countries who did not benefit from the "Green Revolution", especially farmers in rain-fed marginal lands (Pat Thomas, 2015). Genetic engineering could enhance the ability of crops to be resistant to soils with high levels of salt, acidity or toxic elements such as aluminum or boron. Drought resistance is a difficult phenotype to manipulate, but advances are being made in conventional breeding and in some cases gene identification. For example, the international wheat and maize center, CIMMYT has made significant advances using conventional breeding in developing drought resistant maize genotypes [BM Prasanna, 2020]. Genetic engineering has the ability to enhance the ability for legumes to fix atmospheric nitrogen with the potential for crops such as cereals to also fix nitrogen. This would decrease the need for often expensive and imported fertilizers. Enhancement of storage qualities and transportability of perishable crops through genetic modification could be especially important for developing nations. However, the main benefits in the major crop, rice, could still dwell ahead, with rice blast resistance, stem borer resistance using Bt and herbicide tolerance being actively developed. Rising rice demand will not be met because of limited rice cultivation areas and rapid population expansion. Dr Ronald Cantrell, Director-General of the International Rice Research Institute, estimated that by year 2025, the population in Asia will increase by 1-1.5 billion and need 60% more rice. Bt rice, developed through the Asian Rice Biotechnology Network underwent major field trials in China in 1998.One of the greatest challenges will be in delivery of the technology to developing countries since there is often a poorly-developed seed industry. However, the fact that “Green Revolution” cereal varieties were relatively rapidly adopted in an era when infrastructure and transport were poorer is encouraging for future seed distribution. But are the crop genetic improvements that are currently available suitable for developing countries? A troubling situation for developing countries is that some of the products of genetic engineering have the potential risk of displacement which currently has lucrative export markets in developing countries. For example, coconut oil is naturally high in lauric acid, useful for soaps, detergents, margarine and cooking oil. It is especially central to Philippines agriculture, but is also important in Indonesia, Malaysia and India. Its major competitor, palm oil, is central to the Malaysian economy. However, both are now under challenge from high-lauric acid transgenic canola oil, and canola is suited for growth in temperate developed countries (Boateng et al., 2016). Transgenic crops that require capital investments such as aerial sprays and irrigation and/or may reduce labour needs could have poor adoption and fuel unemployment in developing countries. Other concerns include that the cost of accessing the technology may be too high, as transgenic crops are one of the greatest areas of commercial involvement in agriculture, and are dominated by US- and European-based multinationals. There are also broad patents (broad in both the terms of technology covered and geographical coverage) granted to these multinational companies. These not only cover specific crop products, but enabling technologies such as use of Agrobacterium vectors for transformation. Developing countries may not have access to technology at affordable prices. Several of the multinationals are reluctant to operate in developing countries as they perceive that their intellectual property may not be sufficiently secure. More importantly, biotechnologists in developing countries scientists in they may have their freedom to operate taken away. There is thus a rather spirited debate on whether transgenic crops will contribute to food security in developing countries or lead to food insecurity, and many of the same public acceptance concerns remain valid. In addition, is crop genetically modified appropriate technology for developing countries or should the focus be on standard breeding, agronomy and extension to improve yields, quality and reduce post harvest losses? The inability to re-sow seed in many of the commercial contracts established in the west is of particular concern. Terminator technology (more correctly known as Gene Use Restriction Technology (GURT) refers to a set of genetic switches that can be activated in transgenic crops to ensure that the grain is not useful as seed. While this is intended to ensure that the purchaser of the technology cannot avoid paying for its potential advantages through regular purchase of seed, it commits the farmer to regular outlays that may not be achievable. It is of interest that the Consultative Group for International Agricultural Research (CGIAR) and several other international groups have criticized GURT from an ethical standpoint, and banned its use in CGIAR breeding programs (Peschard and Randeria, 2020). While it can be argued that the technology has advantages in preventing escape of transgenes to wild relatives, a starving developing country farmer could not re-sow their seed in a famine year. It is fair to say that this debate is still active within many R&D organizations in developing countries and within donor agencies. The ICGEB (International Centre for Genetic Engineering and Biotechnology) have a focus on research and training in molecular biology and biotechnology, emphasizing developing country needs and safe use of biotechnology. IFPRI (International Food Policy Research Institute) carries out research on the implications of biotechnology and biotechnology policy for poverty alleviation in developing countries. There are various agencies to monitor and evaluate the availability of biotechnology, including genetically modified crop technology, for transfer to developing countries (Turnbull et al, 2021). They focus on horticultural crops (as there are economic structures that can absorb the higher-value commodities), non-commercial crops grown by poor farmers, and forestry; and also to make sure that scientists in particular countries have “freedom to operate” in manipulation of certain crops.

4.17. CRISPR, a better and safer alternative:

As GM crops has raised several concerns regarding its impact to environment and society, an alternative of transgenic engineering is also necessary to cope up with increasing demand of food safety and also to provide a more sustainable food and agriculture system.

Where insertion of a foreign DNA to an existing organism has been a matter of concern, precise deletions or replacement of selective genetic codes can be a safer, cheaper and time saving alternative. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) gene technology has that tremendous potential for improving crops by changing their genetic code. Deleting or turning down a gene’ such as the one responsible for turning sliced apple brown, does not introduce foreign DNA and thus is a non-GMO method. Similarly altering the expression of a gene related to pest resistance in a variety of sweetpotato to make it more resistant, could be a non-GMO method (Mollie, 2020).

CRISPR-Cas9, an integral part of bacterial defense system against viruses, uses site-directed nucleases to target and modify DNA with great accuracy. CRISPR molecule is made up of short palindromic DNA sequences repeated along the molecule and regularly spaced. It also includes CRISPR Associated genes or 'Cas' genes. These encode helicases to unwind DNA and nucleases to cut specified DNA fragments. In case of improvement of crops, instead of viral DNA as spacers, scientists design their own sequences, based on their specific gene of interest. If a gene sequence is known, it can be easily used in CRISPR. It will then act just as a spacer for the system and guide the Cas9 protein to DNA matching sequences. Thus, gene knock-out, DNA-free gene editing, gene insertions or knock-ins and transient gene silencing can be done in the target crop variety (Kaoutar, 2020).

This natural technique has been used to delete fragment of *dense and erect panicle1 (DEP1)* gene in Indica rice IR58025B. In soybean, late flowering and increased vegetative size was inherited by inducing *GmFT2a*, an integrator in the photoperiod flowering pathway of soybean. In citrus, the promoter of *CsLOB1* gene, reason of canker development, was targeted through CRISPR-Cas9 to develop resistant variety. To manipulate photoperiod response in tomato, mutations were generated in flowering suppressor *SELF-PRUNING5G(SP5G)*that caused rapid flowering, early yield and compact growth. Thus, CRISPR-Cas9 is currently being used in larger scale all over the world to incorporate desirable traits in different crops like apples (non-browning when sliced), corn (non-transgenic improved crop yield), sugarbeet (increased tolerance to biotic and abiotic stresses), coffee (natural decaffeination) and many others (Kaoutar, 2020).

5. Conclusion

In conclusion, the evaluation of the environmental effects of transgenic plants should include the study of beneficial ecological interactions seems essential. The significance of conceptualization of the study on "ecosystem services" as it links this question to one of the most important intellectual concepts of current ecology. This was borne by the necessity to convey the realization that human impacts on ecosystems are global and profound (Vitousek et al), and we need to use a unified conceptual approach to interpret them. If transgenic technology causes significant harm to these ecological services, we are heading the wrong way. There is too little resilience left in the natural ecosystems to absorb continued abuse. However, assessing the impact of this technology does not have to be conducted with the mindset of "averting damage". The arguments regarding possible benefits of transgenic plants are plausible, but so far all of them are insufficiently documented (Wolfenbarger & Phifer 2000). They need to be incorporated into the environmental impact of this technology. It is important to stress that the total environmental impact should be measured against current practice, and not against an idealized but non-existing agricultural cultivation system. In the context of developing countries, we can conclude that the realization of beneficial aspects are more important than the risks covered by the use and maximum cultivation of transgenic crops. The practical use of transgenic crops may enhance the economy of developing country; therefore, in my opinion transgenic plants should be promoted in developing countries only after assuring their harmless impact to natural resources and society. The impact of transgenic crops on the ecosystems should be monitored regularly to avoid the potential risk factors.

Discussions of GM crops should be broadened to include alternative agricultural practices, ecosystem management, and agricultural policy. Such a discussion would be facilitated by a clearer understanding of the indirect costs of agriculture and the indirect subsidies it receives from nature. Furthermore, this discussion should test the proposition that GM crops are the best means of agricultural intensification compared with other agricultural technologies. A gradual and cautious approach to the use of GM crops that relies on a truly a comprehensive risk assessment could allow people to rip substantial benefits from GM crops while mitigating their serious risks.

6. Scope for Future Study

In 2016, 185 million hectares of land were planted with biotech crops, and the vast majority consisted of soybean, maize, cotton and canola. Almost all of this area, over 99 percent, contained crops resistant to herbicides, insects, or both. In the last few years we have seen a rapid expansion in crops with "stacked traits" that have genes for resistance to both herbicides and insects, and in the near future this is the direction that GM agriculture will no doubt be heading in. Another feature of the coming years will be an increase in the resistance challenge we are already facing from both weeds and insects. GM crops tolerant to glyphosate have caused over-reliance on this single herbicide, causing an ever-increasing number of weed species to evolve resistance to it. Likewise, the widespread planting of insect-resistant crops means the pests themselves are becoming resistant to the new technology, and the crops are once again vulnerable to attack. Scientists have entered into a technological battle with pests, developing new genes to create crops that insects aren't resistant to. But this resistance race won't simply be won with technology. Better management has the power to reduce the resistance problem—planting areas of non-GM crop next to the insect-resistant crop, for example (Rebeca Nesbit, 2017). Time will tell how wise we are in our management of insect-resistant crops, and how effective they continue to be. More exciting than these crop varieties, where new releases are variations on the same theme, are the many trials taking place in universities and research institutes around the world. Disease-resistant banana, wheat and potatoes are all in the pipeline, along with drought-tolerant sugarcane and maize. Rather than focusing on the high-yielding crops that dominate agriculture in the developed world, many publically funded research programs aim to reduce the crop loss faced by farmers who lack the resources to deal with disease and climate variation. Gaining regulatory approval and consumer acceptance will be a major hurdle for these crops, however, and how soon we see the benefits is more a social question than a technological one. Looking further into the future, even more ambitious projects are underway which may not bring benefits for decades, if at all. The Bill and Melinda Gates Foundation, for example, is taking a gamble funding projects that aim to create cereal crops that can fix their own nitrogen (Danny Watson, 2019). This could be a game changer for poorer farmers who can't access nitrogen fertilizers, and elsewhere could reduce the huge environmental cost of producing and using fertilizer. The challenge is complexity. Whereas other GM crops might have a single gene inserted, for nitrogen fixation you need entire biological pathways (Mollie, 2020).

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