

Genetically Modified Organisms and Biodiversity: Assessing the Threats

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ABSTRACT

Genetically Modified Organisms (GMOs) are those into whose genome a foreign well-characterized DNA from a different source (plant, animal or microorganism) has been stably inserted. Transgenic plants are a recognized example. Scientists genetically modify plants to: increase post-harvest life, resist biotic and abiotic stresses, improve plant nutrient qualities and use them as biofactories in pharmaceutical and vaccine production. For that reason, both transgenic plant cultivation and its public acceptance are growing faster than we had ever imagined. To date, there are around 52 million hectares with GM crops covering the world and the figures are expected to increase. Nevertheless, possible side effects surrounding the current massive planting of transgenic plants has created great public anxiety. The main alarm is related to their effects on the environment and on the preservation of biodiversity. In addition, the sanitary risks and others that could be classified as beyond technology (i.e., the monopoly of seeds by transnational companies, religious issues, etc.) have created great concern. However, in this paper the author has focused on how GMOs' widespread use can affect biodiversity (e.g., to local varieties, wild relatives and non-target organisms) and the type of research needed to adequately respond to this issue. Consequently, updated information of major findings and outcomes has been included. To complement this, the author's considerations on who should be responsible and on ethical scientific behavior, either among the opponents or proponent scientists with respect to GMOs, is presented.

Key words: GMOs, transgenic plants, environmental risks

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RESUMEN

Los organismos genéticamente modificados y la biodiversidad: evaluando las amenazas. Los organismos genéticamente modificados (OGMs) son aquellos a los que se les ha insertado de manera estable en su genoma ADN foráneo de diversas fuentes (plantas, animales o microorganismos). Las plantas transgénicas son un ejemplo bien conocido de estos. Los científicos modifican genéticamente las plantas para: incrementar la vida post-cosecha, lograr resistencia a estrés biótico y abiótico, mejorar las cualidades nutritivas de las plantas y, usarlas como bio-fábricas en la producción de fármacos y vacunas. Por tal motivo, tanto el cultivo de las plantas transgénicas, así como, su aceptación pública crece mucho más rápido de lo que jamás habíamos imaginado. Hasta la fecha, alrededor de 52 millones de hectáreas de cultivos transgénicos cubren el mundo con posibilidad de incrementarse aún más en los próximos años. Sin embargo, los posibles efectos secundarios alrededor de la siembra masiva de plantas transgénicas han creado una gran ola de preocupación dentro de la sociedad. La alarma fundamental está relacionada con los efectos sobre el ambiente y la preservación de la biodiversidad. También, existe expectativa por los riesgos sanitarios que pudieran ocasionar y por otros que pudiéramos clasificar como más allá de la tecnología (específicamente, el monopolio de las semillas por parte de las transnacionales, asuntos religiosos, etc.). No obstante, en este trabajo el autor ha centrado solamente la atención sobre cómo el uso extensivo de los OGMs influye en la biodiversidad (ej., hacia las razas locales, parientes salvajes y organismos "no blanco") y el tipo de investigación necesaria para adecuadamente responder a los problemas surgidos. En tal sentido, se ha incluido una actualizada información de los principales hallazgos y resultados. Como complemento, en el trabajo se presenta la opinión del autor acerca de la posición que debe afrontar el científico, ya sea pro- o anti-OGMs, para enfrentar desde un punto de vista responsable y ético dicha problemática.

Palabras claves: OGMs, plantas transgénicas, riesgos ambientales

"...Science is beautiful, and the interests that led scientist to defend its fundamental traditions coincide with the interests of society, more than is apparent from the present wave of public ambivalence."

Bernard D. Davis, Microbial physiologist
Harvard Medical School, Boston, Massachusetts 1994

Introduction

Since the re-discovery of Mendel's Laws at the beginning of the last century, crop improvement stopped being a merely empiric act and it was transformed into a true scientific procedure. In this procedure elite varieties were obtained through cross-pollination cycles (hybridization), and trait selection was started in a time-consuming process limited to the same species.

In the early years of the second half of the 20th century, agriculture underwent sensitive transforma-

tions with the introduction of mechanization advances and the development of the chemical-product industry (fertilizers, pesticides and herbicides), starting what we have called "the Green Revolution". In this Era, the use of modern hybrid varieties and the adoption of intensive agricultural practices yielded higher food production, especially in countries characterized by a demographic explosion and concomitant malnutrition problems (China, India, Latin-America). How-

ever, the Green Revolution introduced unforeseen risks to the environment.

In recent years, several factors have started emerging and threatening the future of humankind. In the first place, a spectacular increase of the world population has been observed. At present, there are more than six billion human beings living on our planet (mainly in Third World areas) and the Food and Agricultural Organization (FAO) has estimated a discrete increase to nine billion by the year 2050 [1]. In parallel, the evident reduction of global potable-water reserves is already becoming a big problem for human survival. Secondly, several circumstances associated with climatic change have brought about a significant decrease in cultivated lands, which directly affects food yields. It is not possible to solve these problems using conventional agricultural practices. Also, due to the rapid appearance of pest resistance to chemicals, much more potent pesticides reach the market each day, which in turn pollute soils and water, thereby poisoning our foods.

Under these conditions, our world is entering into a new era of agriculture: the Era of Agricultural Biotechnology. Now, the central role is being played by Molecular Genetics, which has been strengthened by the basic knowledge on Plant Biology and the application of Genetic Engineering (GE) techniques. The most spectacular component of this new science is Plant Genetic Engineering: the creation of transgenic plants, into whose genome a foreign well-characterized DNA from a different source (plant, animal or organism) has been stably inserted. In this way, it is possible to genetically manipulate plants to:

- Increase post-harvest life
- Make them self-pesticides (insect, fungus and virus resistant)
- Make them herbicide-resistant
- Improve their nutrient qualities and resistance to abiotic stress (drought and salinity)
- Use them as bio-factories

Despite all the apparent advantages, possible side effects surrounding the current massive planting of transgenic plants has created a great anxiety wave within the society. GE-critics have identified several kinds of risks that we could classify as: those associated with the new technology (sanitary and ecological) and, those beyond technology. The unintended consequences of genetically modified agriculture for the preservation of biodiversity have long been the focus of international attention, perhaps raising even more controversy than their potential impact on human health. In this regard, scientists have looked into problems associated with the traditionally improved crops in order to anticipate possible environmental risks of transgenic crops. The potential hazards have been evaluated as follows:

- Escape of the foreign DNA insert to other non-transgenic varieties or wild relatives
- Uncontrolled dispersion of transgenic plant descendants transforming them into weeds
- Induction of resistance of plant pathogens and pests to the transgenic products controlling them
- Adverse effects to non-target beneficial organisms (i.e., butterflies, honeybees, earthworms)

It is hard to ignore the international public debates, which have often been stirring, related to the impact

and threats to the biodiversity of the genetically modified organisms (GMOs). Scientists have responded to this debate with a series of workshops, symposia and meetings where their results on how to assess the risks have been openly discussed and debated. In each case, scientific responsibility has been the main reason supporting the existing concerns. Consequently, decisions on the development and use of GMOs will require the contribution of all sectors of society and will necessarily involve global humanitarian issues i.e., food security.

The contribution expressed here reflects the critical vision of the author, and focuses on how the widespread use of GMOs affects biodiversity (e.g., to local varieties, wild relatives and non-target organisms). Furthermore, the types of research needed to adequately respond to the issues raised have been included with updated information on major findings and outcomes.

Concerning the Possibility of Horizontal Gene Transfer

Several scientists have already independently recognized the possibility of transgene flow from engineered crops to their local varieties and wild relatives with unknown consequences [2, 3]. However, this hazard is not exclusive to transgenic plants, since the sexual transfer of crop genes to weedy species is a normal process, which may and actually does occur. Goodman and Newell (1985) were among the first to warn about this possibility [4]. It is currently known that this gene transfer between cultivars represents a crop management problem that can occur in an "out-crossing" crop [5]. The problem is of less concern in self-pollinating crops like wheat, barley, cotton or peas, which do not transfer pollen between plants. Nevertheless, the problem is intensified when the impact of the gene flow of herbicide-tolerant GM crops to the nearby flora is analyzed.

Herbicide-tolerant GM plants, in general, are mainly modified to resist the commonly used glyphosate and glufosinate herbicides, which can then be sprayed on crops without damaging them. The main idea is to reduce the use of herbicides in a single season. Regarding the creation and proliferation of "superweeds", plant ecologists and population geneticists working for environmentalist groups have claimed that this gene transfer encourages the possibility that GM crops could transfer a gene for resistance to herbicides to the surrounding weeds, creating a "weedkiller-resistant" weed. This could then turn out to be highly invasive. Thus, if a weed is closely related to the out-crossing crop—and some of the more invasive weeds are very similar to crops—then cross-pollination with a herbicide-tolerant crop could carry the gene into the weed population.

The issue of how readily a crop gene will be transferred to a weed species is being actively studied. King reported the frequencies of marker genes in wild sunflowers that averaged about 28-38%; and in wild strawberries growing within 50 m of a strawberry field it was found that more than 50% of the wild plants contained marker genes from cultivated strawberries [6]. Similarly, a herbicide-resistant

transgenic oilseed rape that was out-crossed with a weedy relative, *Brassica campestris* (field mustard) conferred herbicide resistance to it even in the first backcross generation under field conditions [7]. In 1996, Keller *et al.* summarized valuable data on the weedy wild relatives of sixty important crops and the potential hybridization between crops and wild relatives [8].

The primary question then should not be whether gene flow would occur, since this is already apparent, but whether the movement of a gene from GM crops to a weedy relative would provide the weeds with a selective advantage. Another issue is related to the possibility that transgene “pollution” could eliminate the preexisting crop biodiversity *i.e.* local varieties. Following the last scientific meeting concerning the ecological impacts of GM crops [9], the consensus was that there is little risk of enhanced weediness from the handful of transgenic plants already on the market. In addition, it is argued that there is no reason to believe that transgenic hybrids would affect biodiversity more than any other hybrid. Scientists such as Prakash, from the Center for Plant Biotechnology Research, Tuskegee, have pointed out that “If anything, gene flow would aid diversity by increasing variation” [10]. It has also been indicated that the genetically enhanced trait — which confers resistance to pests, herbicides or drought— would not necessarily confer any competitive advantage over other plants *i.e.* more vigorous growth, and would eventually die out. For example, in the case of herbicide resistance, unless the weed is sprayed with herbicide, there should be no selection pressure favoring the survival of resistant plants, and the trait should die out in time. Thus far, no threats from “superweeds” have arisen from genetic engineered plants. Moreover, regulators and scientists have insisted on further limiting transgene flow risk to wild relatives and local varieties by including a number of interventions. Below are some of the various steps that are being studied and developed for possible future use [11].

Biological gene flow barriers

Apomixis: the production of seeds without fertilization, a process that occurs naturally in many plant species. The transfer of the transgene to neighboring crops via pollen would be minimal because plants can be made sterile without compromising seed or fruit production.

Cleistogamy: the process whereby self-pollination and fertilization occurs with the flower remaining unopened. In this case, pollen is unlikely to escape from the flower. The adoption of this process to minimize transgene dispersal would require a modification of flower design.

Hybridization barriers: Interspecific hybridization only occurs between closely related plant species. Hybridization between more widely diverged species is prevented by two main barriers; interspecific incompatibility at the stigma surface or within the style which prevents fertilization, and post-fertilization barriers, which cause seed abortion. Strengthening either barrier would potentially prevent hybridization.

Genetically engineered male sterility so that a plant produces infertile anthers: It can be initiated by destroying the “tapetum” cells of a developing anther using non-specific nucleases. Driven by cell-specific promoters this can prevent pollen development.

Seed sterility: A genetically modified crop that produces seed that is unable to germinate, offers a promising technique for genetic isolation. This means, however, that the seed cannot be saved and planted the next season. At present, seed sterility has not been adopted because several aspects of the technology are unreliable and require further development.

Plastid transformation technology: a promising approach in which there is much hope to delay, not preclude, the movement of the transgene via pollen dispersal [12, 13]. Although transgenes can also spread by means of seed dispersal, this finding could have significant implications for risk assessment of crop biotechnology regarding gene flow. In addition, the integration of foreign DNA into chloroplast DNA can be more precise.

Physical gene flow barriers

Isolation zones: an area between a GM crop and a nearby non-GM crop that is either de-vegetated or planted with a non-insect pollinated crop. This would discourage insect pollinators from leaving the GM crop.

Barrier crops: a border of non-GM plants of the same crop surrounding the GM variety that can act as an “absorber” or pollen trap crops for the GM pollen. The barrier rows are then destroyed after flowering.

All these steps could help constrain or at least diminish the possibility of a rapid dissemination once the transgene has “escaped” from modified plants. Although many more studies are needed to define whether this transfer could really cause a disaster to the Planet’s biodiversity, the most sensible pathway at the present time is the analysis, assessment and management of all possible risks. At these early stages, I would venture the suggestion that it would be very important that both proponents and opponents of GE technology work together to achieve positive results on risk assessment rather than dissipating their time in a meaningless and uniform dialogue.

As an example, we could mention the recent dispute concerning the possible GM maize risk to Mexico. Some months ago, the prestigious scientific journal *Nature* published an original research article of the University of California at Berkeley by ecologists Ignacio Chapela and David Quist [14]. They identified the Cauliflower Mosaic Virus 35S (CaMV 35S) promoter sequences common in vectors for genetic transformation in Mexican maize landraces using both nested polymerase chain reaction (PCR) and inverse-PCR techniques. In addition, the researchers also claimed that the “introgressed” genes were unstable, having “become re-assorted and introduced into different genomic backgrounds.” This was then represented as a “contamination” of maize landrace varieties, a highly important genetic resource, by genetic material from the GM varieties, which presumably occurred via cross pollination. Many scientists have been highly critical of certain aspects of this paper, and present this criticism as “good, vigorous scientific debate”. However, a Joint

Statement by groups opposed to GM crops refer to “intimidating tactics” and a “highly unethical mudslinging campaign” [15]. Scientists have criticized the paper on two fronts. The major criticism concerns the methodology used to examine the results [16]. In addition, it has also been claimed that the general representation of the impact of the gene flow is misleading. More recently, “Nature” published a note, which retracted the Chapella Quist paper [17]. In this issue of the journal, the response of Chapella and Quist to biotech advocates’ criticisms appeared and new data were also included allowing the readers to “judge science for themselves”. The opponents counter-attacked this time arguing that Nature’s retraction was made under pressure from pro-biotech scientist.

Whether the dispute on transgene “escape” will continue or not, the most important point at this time is to concentrate all our efforts on determining its possible impact to Mexican maize landraces. Even if illegal GM corn planting is not currently occurring in Mexico, it will not take a long time to occur. Also, scientists should increase the risk studies with the CaMV 35S promoter and if a real hazard is demonstrated, they should phase it out as was done with the antibiotic selection markers.

Concerning the Possibility that Target Insects May Become Immune to *Bt*-plants

One benefit from the use of insect-tolerant crops is the need for smaller amounts of conventional pesticides, whose ability to harm the environment are well documented. The latest reports from the National Center for Food and Agriculture Policy (Washington D.C.) point out a considerable decrease in chemical pesticide applications in the southern part of the United States coinciding with the spread of *Bt*-crops [18].

Despite this benefit, there is much concern about the insects that may be rapidly becoming resistant to *Bacillus thuringiensis* (*Bt*) toxins as a consequence of the release of transgenic *Bt*-toxin expressing plants (*Bt*-plants). Insects are highly adaptable and have evolved resistance to many chemical insecticides. In this context, *Bt* toxins are not expected to be different from other insecticides. Laboratory studies have shown that resistance that is already present in the gene pool of a population can be selected for with purified toxins or *Bt* formulations in several insect species and for several different toxins [19, 20]. The occurrence of resistance in field populations in response to extensive applications of *Bt* sprays is rare, but it has been reported [21, 22].

Resistance in response to *Bt*-plants has not been reported to date, but of course this may be attributed to the fact that *Bt*-plants have only recently been developed. There is little doubt, however, that the genetic potential for resistance is present. Many scientists, as well as members of environmental pressure groups, believe that continuous exposure to *Bt*-plants will lead to selection for resistance, and that the large scale introduction of *Bt*-crops endangers the durability of *Bt* as an insecticide, both in crops and in sprays [23]. This would have an impact on the growers of transgenic *Bt*-crops as well as on organic, conventional

and Integrated Pest Management (IPM) farmers who use *Bt*-sprays.

Research into the mechanism of insect resistance to *Bt* toxins indicates that a seemingly common factor is the loss or modification of the midgut binding sites for the toxin, which leads to resistance to only one or a few related toxins that detect the same receptor [19]. Increased protease activity may also render the toxin inactive. Other mechanisms could also exist, but have yet to be elucidated; some of these may lead to cross-resistance to other *cry* proteins. It is possible that, because of the specific form in which the toxin is expressed in the plant, the type of resistance mechanisms selected for with transgenic plants may differ from, or only partially overlap, those that occur in response to *Bt* sprays or purified toxins.

Several strategies, which should prevent or delay the rapid development of resistance to *Bt*-plants have been proposed and compared [24-27]. The efficacy of these strategies is difficult to prove without large-scale planting, but simulation modeling has been used extensively in an attempt to predict results. The most plausible strategies are:

- *the use of multiple toxin genes with different forms of action*, making cross-resistance unlikely to occur *i.e.* two *cry* genes for toxins with different receptors, or a *cry* gene in combination with an altogether different toxin gene.
- *the use of tissue-specific or inducible promoters to achieve spatial or temporal variation in the expression levels of the toxin*. The use of tissue-specific promoters would decrease selection pressure by allowing pests to feed unharmed on economically less important parts of the plant. The use of inducible promoters would decrease selection pressure over time, as the expression would only be induced when a certain economical threshold of damage was surpassed.
- *the use of temporal or spatial refuges*. Rotation of *Bt*-crops with non-transgenic plants would slow down the development of resistance, particularly if resistance is not stable in the insect population. With spatial refuges, part of a field is set aside for non-transgenic plants. This allows *Bt*-resistant insects that have survived on the transgenic plants to mate with non-selected, sensitive insects from the non-transgenic plants, preventing the growth of a population that is homozygous for a recessive or semi-dominant resistance allele.

In all three cases, the thorough understanding of the biology of the crop pest complex, the possible mechanisms of resistance, and the frequency of resistance alleles in the insect population would be necessary to devise an optimum resistance management strategy. A refinement of the spatial refuge strategy is the refuge/high dose-combination, which entomologists consider as the most promising. In this strategy, refuges of non-transgenic plants are combined with transgenic plants that express *Bt* at a high level: the level of *Bt* toxin expression should be high enough to kill insects that are heterozygous for a recessive or semi-dominant resistance allele. This strategy has been part of the resistance-management plans that are imposed by the United States’ Environmental Protection Agency (EPA) on the companies selling *Bt*-cotton and *Bt*-maize [28].

Finally, increasing levels of resistance in insects to the bioinsecticide *B. thuringiensis* can be also dramatically reduced through the GE of plant chloroplasts. Kota *et al.* have reported how feeding susceptible, Cry1A-resistant (20,000- to 40,000-fold) and Cry2Aa2-resistant (330- to 393-fold) tobacco budworm *Heliothis virescens*, cotton bollworm *Helicoverpa zea*, and the beet armyworm *Spodoptera exigua* with tobacco leaves expressing Cry2Aa2 protoxin in chloroplast caused 100% mortality in all cases [29]. Transformed tobacco leaves expressed Cry2Aa2 protoxin at levels between 2% and 3% of the total soluble protein, 20- to 30-fold higher than current commercial nuclear transgenic plants. This result suggested that plants expressing high levels of Cry proteins should be able to overcome or at least, significantly delay, *Bt* resistance development in the field.

Can *Bt*-crops Harm Non-target Insects in Practice?

One of the most profound ecological risks of releasing transgenic *Bt*-plants would be the unforeseen effects of the toxin on organisms that are not pests of the crop itself *e.g.* pollinating insects or the natural enemies of pest insects that are of benefit to agriculture. In recent years, two relevant studies reported on this topic have attracted considerable media attention. On May 20, 1999, a short article in *Nature* called the attention to a potential ecological problem with GE insect-resistant crops [30]. John Losey and his colleagues at Cornell University reported that a variety of transgenic *Bt* corn could kill neonate monarch caterpillars (*Danaus plexippus* L.) after feeding milkweed "contaminated" with GM-pollen. A second one by Saxena and his colleagues at New York University reported that transgenic *Bt* corn releases an insecticidal compound through its roots into the soil where it binds with soil particles accumulating over time and retains its insecticidal properties for more than 230 days [31]. These authors argued that high levels of *B. thuringiensis* toxin persisting in the soils could harm a variety of earth-bound organisms, affecting the rate of decomposition and nutrient cycling.

Transgenic corn varieties expressing the insecticidal Cry1Ab protein from *B. thuringiensis* bacteria has been produced to protect this crop from the European corn borer (Ecb), *Ostrinia nubilalis*, one of the most damaging corn pests in North America [32]. The Cry1Ab toxin is specifically active on the lepidopteran species so the impact on non-target organisms (that do not feed on the corn) has been considered insignificant [33]. However, papers like those of Losey *et al.* [30] and Wraight *et al.* [34] have suggested that when high levels of Cry proteins are expressed in pollen, susceptible insects that feed on the *Bt* pollen may be harmed. Although most commercial *Bt* corn hybrids express the toxin throughout the plant, the expression in transgenic pollen varies for different approved *Bt* events. For example, pollen from event-176 *Bt* hybrids expresses the highest level of *Bt* toxin (up to 7.1 mg/g of pollen). On contrast, *Bt*11 and Mon810 hybrids express roughly 0.09mg/g, so the potential negative impacts of these

hybrids may be lower than that of event-176 hybrids [35, 36].

Bt proteins have been freely spread into the environment for decades, initially as *Bt* formulations and currently as those produced by GM crops. Consequently their effect on non-target organisms should continue to be evaluated. To date, there have been very few published studies, dealing with this concern. Too many times, results have been presented in a controversial way and often unavoidable controls have been missed. For that reason, scientists should take extra care in planning their basic research design. For example, GE proponents have made an issue of the fact that the Losey *et al.* [30] exposure study did not specify the pollen doses. Other authors have criticized the study by Jesse and Obrycki [37] raising the possibility of a pollen contamination from corn anthers or tassel fragments in their samples on the basis of the pollen collection and handling techniques reported [38]. For a study reporting that two species of caterpillars increased mortality in lacewing larvae after rearing on transgenic Cry1Ab-producing maize it was not clear whether this was a direct effect of the toxin, which accumulated in the prey larvae, or whether the increased mortality was an indirect effect caused by sub-optimal prey quality [39]. In another study, there was no detrimental effect of the Cry1Ab protein in the pollen of transgenic maize on the insect predators examined, indicating that the toxin has no direct effect [40]. *Bt*-plant field studies that are now available appear to confirm the original assumption that *Bt*-plants either have no effect on beneficial insect populations [41], or that they may even cause an increase in the number of non-target insects [42]. In consequence, this allows for an increase in the reliance on the biological control of secondary pests by eliminating the need for a nonselective spray [43]. Some authors have found that monarch larvae feed mainly on milkweed (*Asclepias syriaca*) commonly present in the agricultural habitat and the impact is likely to be minimal, based on the levels of *Bt* proteins collected on it [44]. The EPA has concluded that a significant impact on monarch populations is unlikely, in fact, with pesticide reductions the impact on monarch populations may be positive [45]. To date, no acute toxicity of insecticidal proteins towards beneficial insects has been observed either when expressed in plants or when incorporated into artificial diets at levels found in the leaves of transgenic plants. In consequence, the results suggest that regardless of the risks imposed by GM crops, changes in agricultural practices such as weed control or the use of foliar insecticides could have large impacts directly on monarch butterflies by affecting milkweed density and condition, or on monarch survival.

The implementation of a number of remedial steps could help overcome potential problems that have caused major concerns to date. Investigators should begin their research with a quantitative determination of transgenic products in plant tissues in contact with beneficial insects. That is the case for *Bt* protein expression in those parts of the plant that normally do not suffer lepidopteran-pest attack, such as pollen and roots in Ecb-resistant corn. In parallel,

the measurement of short- and long-term effects of *Bt* protein ingestion on the behavior, digestive physiology and development of beneficial insects must be studied. Finally, it is necessary to investigate the *Bt* protein accumulation in pest insects and how this could affect beneficial-insect population dynamics. In addition, a proposed procedure for *Bt*-plants ecotoxicological risk assessment should be required to include a list of organisms that should be tested for effects [46].

One of the possible future outcomes could be a corn strain selected for the expression only at very low levels of the *Bt* protein in pollen and roots. Other complementary strategies would be related to a consideration of the expression in plants of a new generation of Cry proteins, engineered to be less toxic to beneficial insects. The plant chloroplast-transformation procedure mentioned above [13] could also be a solution circumventing the production of toxic pollen. Most important of all would be the eco-toxicological studies carried out revealing these problems before approving the field release of any *Bt* crop.

Considering the enormous damage caused to human health and to biodiversity through the application of pesticides, it is clear that all efforts should continue to improve crop productivity while reducing the amount of pesticides applied. Additional research should be focused on the overall status of monarch butterflies and other species of concern. Remedial steps should be directed to other important factors as they are identified.

The Responsibility of Scientists

Throughout history, ignorance has been the major cause of irrational behavior, for the simple reason that most human beings feel uncomfortable when confronted with things and issues they do not understand. It is so much simpler to condemn something than to attempt to understand it. Usually, we hear comments like “*GMOs are unsafe and must never be released into the environment*” or “*Why doesn't someone do something to understand what the risks of GMOs are?*”. These comments come from people opposed to the release and commercialization of GMOs and to demand that the “precautionary principle” be used to halt their use in agriculture. Usually, those papers published by anti-biotech scientists demanding food security and more responsibility encourage these people. Their research could be considered reasonable, but their results require support on a rational base. GE proponents also have valid arguments to save the world. Then, who's right? Public perception on biotechnology is very ambivalent — interested in its progress, but also disturbed by finding that it creates problems, as well as benefits [47]. Anti-biotech scientists are hiding behind concerns about GMOs' environmental and health risks. At this point, we could point out that any technology derived from human activity involves a natural risk, in other words, zero risk does not exist. What we could do is an evaluation of these risks to decide whether we could manage them or not. In negative cases, the new technologies must be rejected.

Throughout this document, I have mentioned how controversial papers provide an emotional and con-

fused tone in that their conclusions appear to reflect more a passionate fight than a just cause. In some examples, the results either lack necessary controls to validate conclusions or had elementary incongruence in the basic experimental design. In such cases, it is astonishing to see how some scientific publishers accept such papers. On the other hand, it is also surprising to see how some biotechnicians consistently have underestimated risk factors and have dedicated themselves to their work in terms of research output schedules. At this point it is important to notice that the work of researchers does not end when the objectives have been achieved in terms of the introduction of new traits to crops. As part of their responsibility with the public, scientists must keep monitoring the actual impact of their GM plants once these are released into the environment. Many times, scientists study GMOs safety using findings from influential transnational companies who pay for superficial results that will continue ensuring their profits and therefore, the control of the market. This, however, does not mean that all the present studies supporting this technology and that have been expressed above are in the same situation. Most of them have a reasonably good scientific base, which lead to irrefutable conclusions.

I believe it is time to appeal to scientific responsibility. Anything that could endanger the preservation of the viable and sustainable conditions of our planet needs to be reasonably discussed. Research needs to be conducted with responsibility. It is controversial to see how, with the development of world communication and the existence of the Internet, scientists still fail to exchange information. We should not forget that scientists represent but a small part of the world population and yet this group could decide the world's future. While the discord between biotech proponents and opponents remains, nobody will seriously consider our arguments. We know that if we work together in the analysis, evaluation and management of the environmental risks of GMOs, our combined efforts will have more impacts on governmental policies. Our role as scientists is to obtain and interpret information so that governments and their advisors are in a better position to identify the best course of action. Since GM-plant cultivation already reaches almost 52 million hectares throughout the world —an area bigger than Germany— and this amount is expected to grow [48], GM regulatory systems and policies require our help in identifying important issues concerning the safe conditions for the release of GMOs. With this advice no GM regulatory system could be unwilling to modify its activities in order to take into consideration the implications of research on food safety.

In summary, scientific responsibility involves the way in which we face these issues. We as scientists must respect our global responsibilities. Only our attitude will definitely determine GMOs acceptance or not by the general public.

Concluding Remarks

Climatic change and a disproportionate exploitation of natural resources are already affecting World Agriculture

through several crop yield factors. Such factors include the reduction of global potable-water reserves, as well as a continuous reduction of arable land. To survive and satisfy the needs of a growing population, World Agriculture desperately requires a technological jump. Transgenic plant techniques could play this role.

The cultivation of GM plants and their public acceptance are growing faster than we had ever imagined. To date, there are around 52 million hectares with GM crops covering the world and the figures are expected to increase. Herbicide resistance and soybean plants are the most firmly established trait and crop combination, with insect resistance and corn in second place. New generations of transgenic plants are already on the market and involve the improvement of food nutrient quality and the recombinant expression of pharmaceuticals and vaccines.

Environmentalist and anti-biotech groups have suggested the possibility that planting GM crops worldwide could harm the environment in many ways. Major concerns comprise the horizontal transfer of transgenes to wild relatives and local varieties, the possibility for the rapid appearance of insect-resistance to *BT* proteins and the effects of GM insect-resistant crops on non-target organisms. The opponents to GM crops predict that the uncontrolled spread of GM plants will cause uncountable ecological disasters by: a considerable increase in weeds, a loss of natural Biodiversity, the harm to beneficial insects, and the end of the almost 50-year use of *B. thuringiensis* in agriculture. Thus far, no threats from "superweeds", insect-pests resistance, or acute toxicity to non-target insects have arisen from the genetic engineering of plants. In contrast, a considerable decrease in chemical pesticide applications has occurred since the first insect-resistant and herbicide-resistant crops reached the market. This has represented a great economical and environmental benefit to farmers while providing consumers with crops with fewer pesticide residues. In addition, a huge benefit for the survival of pollinating insects and the natural enemies of pest insects has already been recognized.

However, reports such as that GM oilseed rape is able to cross with a common weed, the wild radish, and the possibility for transgene introgression into South Mexican traditional maize landraces threatens GMOs acceptance. Moreover, some significant effects have been observed on insect behavior and physiology following the incorporation of *BT* toxic protein into their diets at concentra-

tions higher than those expressed in GM plants. These results have produced a great concern within the general public, which has requested scientists to be more cautious in their research and to increase their studies on GMOs risk assessment. In order to demonstrate how the European Commission (EC) has tackled this need, a review of EC-sponsored research has been presented and includes a decade of results on the safety of GMOs carried out by multinational consortia of scientists [49]. In addition, EC has helped organize a series of international conferences on biosafety research, and set up a Task Force on Biotechnology Research with United States research agencies. As an example, EC supported, in Brussels, on September 1999 an international workshop "GMOs research in Perspective" to encompass a wide range of opinions on GMOs research in general, and to sharpen programme planning. The same year, a similar gathering of scientist, regulators and research managers took place in Bethesda, Maryland. Once again the role is being shared among the economic world powers. Since GE technology had long been misinterpreted as an opportunity to overcome the growing problems associated with food requirements, large areas of GM crops will soon be planted in Third World countries [48]. International technical and financial assistance to support risk assessment research in these countries are required. Most of these poor countries are located in tropical regions having an endemic and wealthy flora and fauna. They also represent the biodiversity center of many currently staple crops (e.g., rice in Asia, potato in the Andes, maize in Mesoamerica). Nevertheless, GM plants that are commercially available today have been engineered in developed countries and do not represent solutions for the agricultural problems of developing countries. As an example, Ecb is only a pest problem in maize plantations of Europe and North America. Under these circumstances, the dissuasive work of the scientific community as an authorized advisor to the governmental policies is extremely important and it should be done with responsibility.

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