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Environmental impacts of genetically modified plants: A review

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ABSTRACT

Powerful scientific techniques have caused dramatic expansion of genetically modified crops leading to altered agricultural practices posing direct and indirect environmental implications. Despite the enhanced yield potential, risks and biosafety concerns associated with such GM crops are the fundamental issues to be addressed. An increasing interest can be noted among the researchers and policy makers in exploring unintended effects of transgenes associated with gene flow, flow of naked DNA, weediness and chemical toxicity. The current state of knowledge reveals that GM crops impart damaging impacts on the environment such as modification in crop pervasiveness or invasiveness, the emergence of herbicide and insecticide tolerance, transgene stacking and disturbed biodiversity, but these impacts require a more in-depth view and critical research so as to unveil further facts. Most of the reviewed scientific resources provide similar conclusions and currently there is an insufficient amount of data available and up until today, the consumption of GM plant products are safe for consumption to a greater extent with few exceptions. This paper updates the undesirable impacts of GM crops and their products on target and non-target species and attempts to shed light on the emerging challenges and threats associated with it. Underpinning research also realizes the influence of GM crops on a disturbance in biodiversity, development of resistance and evolution slightly resembles with the effects of non-GM cultivation. Future prospects are also discussed.

1. Introduction

Recent claims of consensus over the safety of genetically modified organisms (GMOs) seems to be an artificial and misguided perpetuated construct (Hilbeck et al., 2015; Domingo, 2016) regardless of contradictory evidences published during last three decades which lead scientific community to reconsider that the debate on this topic isn't 'over' yet. Debates about the commercial introduction of genetically modified (GM) crops started soon after the development of the first transgenic organism (1970s) which led to the development of guidelines for use of recombinant DNA by the US (United States) National Institute of Health (NIH, 2013). Such debates gave birth to some interesting questions needed to be addressed before the release of each and every transgenic organism. Could GM crops outcross to produce weediness? Could they harm wildlife and non-target insects? Could they help to benefit the environment by providing raw materials? Is

Abbreviations: ALS, Acetolactate Synthase; bp, Base pairs; Bt, *Bacillus thuringiensis*; CaMV, Cauliflower Mosaic virus; DNA, Deoxyribonucleic Acid; EFSA, European Food Safety Authority; EPA, Environmental Protection Agency; ERA, Environmental Risk Assessment; FSA, Farm Scale Evaluations; GD, Genetic Diversity; GM, Genetically Modified; GMO, Genetically Modified Organism; HGT, Horizontal Gene Transfer; HR, Herbicide Resistant; ICSU, International Council for Science; IMI, Imidazolinone; Mn, Manganese; nDNA, Naked DNA; NIH, National Institute of Health; NOS, Nopaline Synthase; PAT, Phosphinothricin Acetyltransferase; RNA, Ribonucleic Acid; UK, United Kingdom; US, United States; WYMV, Wheat Yellow Mosaic Virus.

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their environmental impact acceptable or unacceptable? Such arising questions encouraged evolutionary biologists, ecologists, epidemiologists and environmental biologists to broaden the debate for a wider prospective. After the publication of the first report on environmental risks of GMOs (Sharples, 1982), the scientific community started to focus on the impacts which are unacceptable and the tools for assessing such impacts. By reviewing various models of GMO risk assessment, Regal (1986) flawed all concerns which purported that there were no environmental aftermaths produced by GM crops. He claimed that nature has not tried yet all possible genetic variants and that possible risks exist which should be assessed and accounted for. Consequently, for the past three decades, environmental safety has been the subject of research and the assessment of the impact of GM crops on the environment has emerged as an essential component of GMO development and also in the international regulatory process. So, a timely consideration of a present state of knowledge is required as in many parts of the world GM crops have been commercialized and many are in the regulatory pipeline. Generally, risks to the environment could be summarized as (1) risks associated with biodiversity including ecosystem functions effects on soil, and non-target species; (2) risks associated with gene flow and genetic recombination; and (3) risks associated with their evolution i.e. development of resistance either in insect pests or in weeds and *Bacillus thuringiensis* (Bt) crops. The objective of this review is to highlight and discuss the environmental impacts of GM plants. Globally, the scientific community is in intense discussions on the topic and extensive literature of the topic compelled us to illustrate the nature of impacts in detail. We focused to explain primary questions related to direct and indirect effects of GMOs on the environment.

2. Environmental implications of GM plants

The debate for environmental implications of GM crops has been centered on questions such as: what are the potential environmental risks implicated by GM crops? And, if we commercialize GM crops how far it will impart undesirable effects on non-target species? Firstly, toxicity produced by chemicals used with GM crops, is a big challenge to the environment as well as to the inherited plants (De Schrijver et al., 2015). Secondly, such crops can be toxic to non-target species especially to the “friendly” species such as beetles, bees, and butterflies (Yu et al., 2011). Generally, the effect of subsistence, organic or intensive agriculture on the environment is obvious, which strongly demonstrates that GM crops must have implications on the environment. Among many environmental protection platforms, the International Council for Science (ICSU), the GM Science Review Panel and the Nuffield Council on Bioethics (www.nuffieldbioethics.org), approve that GM crops have either positive or negative effect on the environment depending on how and where they are used. The role of genetic engineering in more sustainable crop production as well as natural resource conservation, including biodiversity, is plausible. However, its role in accelerating the damaging effects of agriculture cannot be avoided. Issues of baseline environmental impacts are particularly relevant in relation to the release of transgenic commercial crops (Dale et al., 2002; Domingo and Giné Bordonaba, 2011a; Domingo, 2011b). Direct impacts include gene transfer, trait effects to non-target species as well as wild-life, invasiveness, weediness and genetic recombination of free DNA in the environment. On the contrary, indirect impacts include harmful and side effects of chemical control i.e. reduced efficiency of pest, disease and weed control, the effect on water and soil and global decline of biodiversity (Tutelyan, 2013). Addressed below are the most debatable environmental implications.

2.1. Direct impact of transgenes on environment

2.1.1. Gene flow

Gene flow is considered a major evolutionary force which brings changes in gene frequencies along with mutation, genetic drift and selection (Lu and Yang, 2009). Gene flow can affect the environment by creating a reduction of differentiation between populations as well as an increase in diversity between individuals within a population (Mertens, 2008). The structure of genetic diversity (GD) is also one of the consequences of gene flow (Gepts and Papa, 2003). The introduction of non-native GMOs in the ecosystems pose potential long-term risks to the environment and it is quite difficult to predict their consequences. Scientists from various streams around the globe are concerned with the possibility of transfer of the transgene sequences to related wild species or weeds via horizontal gene transfer (HGT) or hybridization. No doubt case-by-case environmental implications of gene flow are variable but some of the effects of gene flow could be generalized on the basis of general findings in relevance to many cases, such as development of superweeds, evolution of new viral pathogens, instability of transgenes in the environment, creation of GD, evolution of pests and pathogens having resistance to new compounds (Beckie et al., 2012; Yu et al., 2011; Egan et al., 2011). Concomitantly, secondary effects of gene flow also need to be addressed including effects on non-target species, biodiversity disturbance, species displacement and extinction, disturbance in soil micro-environment and species of ecological concern (Layton et al., 2015). The possibility of evolution of new species cannot be neglected and could also lead to an infinite number of biotic interactions (Beusmann and Stirn, 2001).

It is an implicit expectation to consider gene flow from GM crops as it has happened for a millennia between sexually compatible species (Keese, 2008). However, this expectation is based on some basic concepts such as distance between compatible plant species, synchronization of flowering time, ecology of the recipient species and off course sexual compatibility (Han et al., 2015; Gressel and Rotteveel, 1999). Certain features of transgenes make them more suitable to be introgressed into wild counterparts such as dominance, no association with deleterious crop alleles, and location on shared genomes and/or on homologous chromosomes (Hartman et al., 2013; Stewart et al., 2003). Mathematical models of pollen movement are being developed to forecast the possibility of gene transfer through this mechanism (Dale et al., 2002; Raybould and Gray, 1999). Examples of such investigations are reported in rapeseed, maize, cotton, wheat, barley, beans and rice (Yan et al., 2015; Han et al., 2015; Lu and Yang, 2009). Pollen-mediated gene transfer solely depends upon pollination biology of the plant, amount of pollen produced, mating system between donor and recipient species, outcrossing rate, relative densities of donor and recipient species, types of vectors, wind, air turbulence, water current, temperature, humidity and light intensity (Papa, 2005; Mercer et al., 2007; Hancock, 2003). From a recent investigation conducted by Dong et al., (2016) they reported that a pollen-mediated gene flow was significantly affected by wind direction. Furthermore, a drastic decrease in pollen-mediated gene flow was reported with increasing distance from the pollen source in WYMV- resistant transgenic wheat N12-1. In transgenic corn, canola and creeping bentgrass, pollen transfer rate decreased rapidly when the distance was increased just by 30 m, 20 m and 20 m respectively (Goggi et al., 2007; Knispel et al., 2008; Van de Water et al., 2007). Highest gene flow frequency has also been reported in creeping bentgrass and rigid ryegrass as a result of pollen flow with the pollen donor just 2000 and 3000 m away (Van de Water et al., 2007; Busi et al., 2008). Comparatively low frequency of gene flow has been witnessed in self-pollinated crops than cross-pollinated crops (Warwick et al., 2009) as in the case of pollen-mediated direct and indirect gene flow from rice to red rice weed and