Food and Chemical Toxicology 107 (2017) 108–121

Contents lists available at ScienceDirect

Food and Chemical Toxicology

journal homepage: www.elsevier.com/locate/foodchemtox

Review

Impact on environment, ecosystem, diversity and health from culturing and using GMOs as feed and food

Aristidis M. Tsatsakis [a,1], Muhammad Amjad Nawaz [b,1], Victor A. Tutelyan [c], Kirill S. Golokhvast [d], Olga-Ioanna Kalantzi [e], Duck Hwa Chung [f], Sung Jo Kang [g], Michael D. Coleman [h], Nadia Tyshko [c], Seung Hwan Yang [b], Gyuhwa Chung [b,*]

[a] Laboratory of Toxicology, School of Medicine, University of Crete, Heraklion, Crete, Greece
[b] Department of Biotechnology, Chonnam National University, Yeosu, Chonnam, 59626, Republic of Korea
[c] Federal Research Centre of Nutrition, Biotechnology and Food Safety, Moscow, Russian Federation
[d] Educational Scientific Center of Nanotechnology, Engineering School, Far Eastern Federal Univeristy, 37 Pushkinskaya Street, 690950, Vladivostok, Russian Federation
[e] Department of Environment, University of the Aegean, Mytilene, 81100, Greece
[f] Department of Agricultural Chemistry and Food Science and Technology, Gyeongsang National University, Jinju, Gyeongnam 52828, Republic of Korea
[g] Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, Geyongnam 52828, Republic of Korea
[h] School of Life and Health Sciences, Aston University, Birmingham, United Kingdom

ARTICLE INFO

Article history:
Received 5 June 2017
Received in revised form
17 June 2017
Accepted 19 June 2017
Available online 20 June 2017

Keywords:
Environmental risk
GMO
Precision agriculture
Toxicity
GMO law

ABSTRACT

Modern agriculture provides the potential for sustainable feeding of the world's increasing population. Up to the present moment, genetically modified (GM) products have enabled increased yields and reduced pesticide usage. Nevertheless, GM products are controversial amongst policy makers, scientists and the consumers, regarding their possible environmental, ecological, and health risks. Scientific-and-political debates can even influence legislation and prospective risk assessment procedure. Currently, the scientifically-assessed direct hazardous impacts of GM food and feed on fauna and flora are conflicting; indeed, a review of literature available data provides some evidence of GM environmental and health risks. Although the consequences of gene flow and risks to biodiversity are debatable. Risks to the environment and ecosystems can exist, such as the evolution of weed herbicide resistance during GM cultivation. A matter of high importance is to provide precise knowledge and adequate current information to regulatory agencies, governments, policy makers, researchers, and commercial GMO-releasing companies to enable them to thoroughly investigate the possible risks.

Contents

Abbreviations: Bt, Bacillus thuringiensis; Cas, CRISPER-associated; CRISPER, clustered regularly interspaced short palindromic repeats; DNA, deoxyribose nucleic acid; EFSA, European Food Safety Authority; EPSPS, enolpyruvulshikimate-3-phosphate synthase; EU, European Union; GF, gene flow; GM, genetically modified; GMO, genetically modified organism; HGT, horizontal gene flow; HR, herbicide resistance; ISAAA, International Service for the Acquisition of Agri-Biotech Applications; NAS, National Academy of Science; NOS, nopaline synthase; nptII, neomycin phosphotransferase II; US, United States; WHO, World Health Organization.

* Corresponding author.
E-mail address: chung@chonnam.ac.kr (G. Chung).
[1] Authors contributed equally to this work.

http://dx.doi.org/10.1016/j.fct.2017.06.033
0278-6915/

1. Introduction

Genetically modified organisms (GMO) when consumed directly or after processing are rendered as genetically modified (GM) food or feed. These foods undergo artificial genetic modification during the phase of raw material production. The most common sources of raw material for GM foods are GM plants, which are genetically transformed to resist diseases, tolerate herbicides and/or insect pests. In addition, male sterility, fertility restoration, visual markers, and other metabolism related characteristics can also be influenced (Southgate et al., 1995). The estimated revenue generated by biotechnology in the United States (US) for 2012 was 323.8 billion US$, of which 128.3 billion US$ was generated from GM crops. US biotech revenue has had an observed growth of >10% over the past decade (Carlson, 2016). Similar revenue generation is expected for other countries that have adopted GM crops, as the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) has reported a forecasted increase in GM crop cultivation in Asian countries (www.isaaa.org; Carlson, 2016). Global commercial cultivation of GM crops has reached to an aggregate land mass of two billion hectares over the last two decades, with total generated benefits of 150.3 billion US$ (Brookes and Barfoot, 2016). The so-called 20th anniversary (1996–2016) of GM crops resulted in significant net economic benefits (through yield and production gains as well as from cost savings) ultimately reducing yield gaps, reduced pesticide application, and conservation of zero tillage (Brookes and Barfoot, 2016; Taheri et al., 2017). However, although cultivation of GM crops and their use in food and feed has not delivered what was expected in terms of accomplishment and GM technology has attracted an ever-increasing and an extremely emotional and complex scientific and political debate, involving a very wide community of different groups ranging from environmental conservationists and ecologists, to evolutionary biologists, politicians, biotechnologists, and epidemiologists. This broader debating platform has raised certain questions, such as whether GM food and feed are safe for human and animal consumption and whether they will have harmful impacts on environment health and biodiversity. Such questions clearly need to be addressed by scientific experimentation. In an attempt to minimize such uncertainties, many laws, restrictions, and legislations have emerged, and in most countries legislative procedures for the approval of any GM crop used for food or feed now exist (Waigmann et al., 2012; Yaqoob et al., 2016).

The consequences of cultivating and using GM plants as food/feed can be divided into two categories. First, cultivating GM plants could have unintended impacts on ecosystem health, such as unnatural gene flow (GF), diminished genetic diversity, effects on non-target species, weediness, reduced pesticide and herbicide efficiency, herbicide and insecticide toxicity, and modification of soil and water chemistry and quality (Mertens, 2008). Similarly, cultivation of GM plants could have damaging repercussions on ecosystem complexity by diminishing biodiversity (Lovei et al., 2010). Second, the use of GM plants as human food and animal feed could represent a hazard to health (Suzie et al., 2008). Globally, the debate on the environmental implications of GM food and feed is still ongoing. Recent reports, including a review by Domingo (2016), the National Academy of Sciences (NAS, 2016), and the letter signed by more than one hundred Nobel laureates (http://supportprecisionagriculture.org/) in opposition to Greenpeace and in support of modern “precision agriculture”, highlight the fact that in order to feed growing populations, there is no alternative to “precision agriculture” (GM food and feed). The objective of the current updated review is to reconsider the pros and cons of GM food and feed. With reference to recent scientific reports that consider the short- and long-term risks to human and animal health, the environment, and biodiversity, we consider the arguments in support of either the Greenpeace stance or modern “precision agriculture” and biotechnologically bred foods.

2. Gene flow and its implications

The movement of gametes, individuals, or group of individuals from one location to another causes changes in gene frequency, which is referred as gene flow (GF). Among the major evolutionary forces that modify gene frequencies, GF along with selection, genetic drift, and mutation, are considered the most prominent ones. This major evolutionary force has been proceeded for millennia between cross-compatible species (Ford et al., 2006). GF, being a natural force, is not a hazard as such; rather it is the genetic contamination of recipient species that have acquired transgenes that poses risks. The movement of gametes or genes is contingent upon many factors related to environment as well as species. Apart from sexual cross-compatibility, other important factors are relevant, particularly in the case of plants, such as floral morphology, synchrony of reproductive period, and the ecology of both donor and recipient species (Lu and Snow, 2005). Given the acknowledged outcomes of this natural evolutionary force, there would appear inevitable consequences of GM cultivation, such as evolution of pathogens, pests, and superweeds, displacement/extinction of genetic diversity and species, ecological disturbance, and diminished biodiversity. Transgenes controlling unique characteristics and having strong selective advantage can escape into related cross-compatible species and could lead to modify regional as well as international trade policies in agricultural markets (Dong et al., 2016).

The possible routes of GF from GM plants to non-GM plants are pollen-mediated GF, seed-mediated GF, and vegetative propagule-mediated GF. Pollen-mediated GF has been reported at various levels in most GM crops, such as maize, rapeseed, rice, barley, cotton, and beans (Ford et al., 2006; Han et al., 2015; Yan et al., 2015). Fig. 1 shows the factors affecting the frequency of GF. Transgenes in GM plants have certain features that favor successful introgression into cross-compatible species, including dominance, location on chromosomes, and non-association with lethal alleles (Yan et al., 2015).

Transfer of the *CP4-EPSPS* (enolpyruvulshikimate-3-phosphate