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Risks and Benefits of Genetically Modified Crops and the Application of Remote Sensing Techniques for Assessing the Impact on the Native Species and Multidisciplinary Challenges

Olivia Dhandhayuthapani*
IBDP Student, DRS International School, Hyderabad, India

***Abstract*: Increasing food production without expanding agricultural lands is on the top of the agenda of all the countries and related International Organizations. This means high yielding crops with resistance to plant diseases and many countries have adapted Genetically Modified Crops (GM or GMO Crops).This paper critically looks at the impact of the expansion of GMO croplands on the native species and the ecosystem , the attendant multidisciplinary challenges and risks and explores the possibility of using remote sensing data captures to deduce that the native species, natural as well as cultivated, are being replaced because of large scale cultivation of GMO crops, giving rise to loss of biodiversity.**

***Keywords*: Biodiversity, Climate change, Ecological imbalance, Ecosystem, Fertility, Food cycle, Gene flow, GMO crops, Hybridization, Indigenous crops, Immune system, Invasive species, Monoculture, Native species, Phenotype, Productivity, Remote sensing satellite data, Resilient organisms, Speciation, Transgenes.**

1. Introduction

The reduction in cropland and greenery over time, gradually at first and at accelerated rate now, means that the food production will not be able to keep pace with the exploding population, maybe as early as a decade or two from now, in spite of technological advancements, as was voiced in the High-Level Expert Forums of the Food and Agriculture Organization (FAO). There are new techniques like ‘Hydroponics’ coming up, but crop land is the primary source. There is a need for increasing production in the available lands and that means high yielding crops, with resistance to plant diseases to improve the yield, while at the same time ensuring their sustainability. Genetically Modified Crop (GM or GMO Crops) suits this bill.

Although GMO cultivation is increasing globally (USDA ERS report, 2014) and there has been a 112-fold increase from 1996 to 2019 (ISAAA, 2019), there is resistance in some countries, specifically towards food crops, because of the impact on the environment, native species and biodiversity.

2. Aim of the Research and Methodology

A critical question is whether GMO crops destroy the native species and thereby the ecosystem? GMO crops give rise to genetically modified organisms and flora and fauna and by virtue of being resilient, these invade and destroy the native species and together with large scale human adaptation of GMO crops, results in loss of biodiversity and the disruption of the ecosystem. The International Union for Conservation of Nature in its information paper has quoted cases of hybridization of GMO crops with indigenous species and invasion by uncontrolled gene flow (IUCN report, 2007) and in recent studies on the invasive species control by J. Mitchell and Bartsch (2020).This research aims to examine the impact of GMO crops on native species using visual and contextual interpretation of satellite remote sensing data and relevant statistics and addresses the attendant multidisciplinary challenges.

Ethics and Environmental concerns in transgenic research: The Nuffield Council on Bioethics (NCOB) in its 1999 and 2004 reports on the social and ethical issues involved in the use of GM crops like potential harm to human health; potential damage to the environment; negative impact on traditional farming practice; and the 'unnaturalness' of the technology, recommended a precautionary approach to the risks inherent in the technology including preferences for traits selected by plant breeders and rights of native plant species (Weale,2017). This is the premise of this research.

3. Data Collection and Inclusion Criteria

Landsat remote sensing satellite data from the United States Geological Survey (USGS) /Google Earth portals are the main online satellite imagery sources. The sources of statistics and related information are the global statistical offices of NNSS, AAFT, USDA, Eurostat, Gene Watch, FAO and the UN. The subject was well understood by structured literature search,

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*Corresponding author: oliviamars2003@gmail.com chief among them being scientific and research papers, journals and books online, in view of the Pandemic. As many as about 50 publications in English were initially reviewed based on abstract/full text, by search strategy.

Test site: The test sites are sample GMO croplands from countries with the most area (above 85%) under GMO crops.

Genetically Modified Crops, how are they done?

All living things have identical DNA structure. In Recombinant DNA technology (Watson et al. 1992), specific genes from any organism can be introduced into the genome of another. In agricultural biotechnology, changes are made to the plant's genome and this is the basis of GM crops.

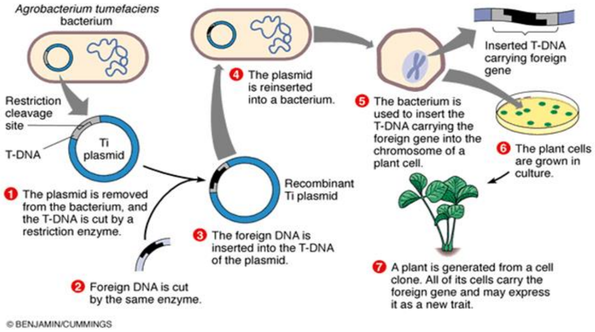


Fig. 1. The process of genetic engineering
Source: Pearson Education, Inc., publishing as Benjamin Cummings

Genes are inserted or extracted from genetically modified crops using traditional genetic engineering methods such as electroporation, microinjection, and Agrobacterium (natural plant parasites), as well as CRISPR, based on the bacterial CRISPR-Cas9 antiviral defense system; and TALEN, (Boyle R, 2011), the Transcription Activator-Like Effector Nuclease, used to cut specific parts of DNA; which offers a more precise and efficient technique. An example is shown in Figure 1 above. The plant species is given a set of new traits that does not occur naturally. Non-food crops are modified to include the production of pharmaceutical catalysts, biofuels, other useful products and also bioremediation, which stimulates the growth of substances in contaminated media to degrade pollutants. (International Service for the Acquisition of Agri-biotech Applications, 2013, Executive Summary Global Status of Commercialized Biotech/GM Crops). Along with all this, has come increased scrutiny of the risks posed by these crops.

4. Desired Agronomic Traits

Table 2
Herbicide resistant GMO crops

Crop	Resistance trait	First Commercialization Approved by USDA
Alfalfa	Glyphosate	2005
Canola	Glyphosate Glufosinate Bromoxynil	1996 1995 2000
Cotton	Bromoxynil Glyphosate Glufosinate	1995 1996 2004
Corn/Maize	Glyphosate Glufosinate	1998 1997
Soybean	Glyphosate Glufosinate	1996 2009
Sugarbeet	Glyphosate	2007

Main Source: K.N. Reddy and V. K. Nandula (2012)

Table 1
Insect-resistant GMO crops. The cry genes are from Bacillus thuringiensis

Plant/Crop	Gene introduced	Target Insect
Cotton	*CryIA(a,b,c)*, Potato inhibitor *GNA*	Lepidoptera Homoptera
Potato/sweet potato		
	Cry3Aa, *cryIAc*, Cowpea trypsin inhibitor, *GNA*	Coleoptera Lepidoptera
Soybean	*cryIA(b,c)*	Lepidoptera
Rice	*cryIA(b,c)*,PinII,*cry1C*	Lepidoptera
Maize	*cry3Bb1*, *cry1Ab*, *cry19c*	Lepidoptera
Chickpea	cry1A(b), cry1A(c), cry2Aa	Lepidoptera

Source: Allahbakhsh, Baloch, Demirel, Khabbazi, 2016

Table 3
Disease resistant GMO crops

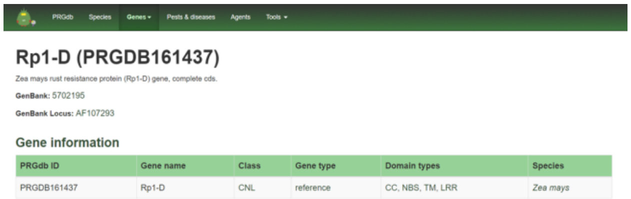
Crop Species	Developer	Initial Approval	Target Pathogen	Gene(s) Expressed
Squash	Semis and Monsanto	1994 USDA	Watermelon mosaic virus 2, zucchini yellow mosaic virus and Cucumber mosaic virus	Coat proteins
Papaya	Cornell University and the University of Hawaii	1996 USDA	Papaya ringspot virus	Coat proteins
Potato	Monsanto	1998 USDA	Potato leaf roll virus	Replicase and helicase
Sweet pepper Tomato	Beijing University	1998 MOA 1999 MOA	Cucumber mosaic virus	Coat protein
Papaya	South China Agriculture University University of Florida	2006 MOA 2009 USDA	Papaya ringspot virus	Replicase and coat protein
Plum	USDA/ARS	2007 USDA	Plum pox virus	Coat protein
Bean	EMBRAPA	2011 CTNBio	Bean golden mosaic virus	+,- RNA of viral replication protein
Potato	J. R. Simplot	2015 USDA	Phytophthora Infestans (light blight)	Resistance protein

Main Source: Oliver Xiaoou Donga and Pamela C. Ronald (2019)

Pest resistance: This trait improves a crop's pest resistance, allowing for a higher yield. Bacillus Thuringiensis is a bacterium that makes insect repellent proteins that are generally non-toxic to humans. Examples are Bt corn and cotton. Cowpeas, sunflowers, soybeans, tomatoes, tobacco, walnut, sugar cane, and rice are all being studied in relation to Bt, to reproduce this trait.

Herbicide Resistance/Tolerance: Herbicide resistance refers to a plant's inherited ability to withstand an herbicide application that would otherwise kill that species. Herbicide tolerance, on the other hand, is a species' inherent ability to survive and reproduce following herbicide treatment at a normal use rate.

Disease Resistance: Until recently, the only way to stop diseases transmitted by insects such as Aphids was to burn or raze the infected crop. Genetically engineered viral resistance is one approach offered by Agricultural Biotechnology. GM disease-resistant crops include cassava, maize, and sweet potato. For example, GM maize has a higher amount of Rp1-D protein, granting it resistance from the fungal rust of maize disease (Figure 2).



Rp1-D (PRGDB161437)

Zea mays rust resistance protein (Rp1-D) gene, complete cds.

GenBank: 5702195

GenBank Locus: AF107293

Gene information

PRGdb ID	Gene name	Class	Gene type	Domain types	Species
PRGDB161437	Rp1-D	CNL	reference	CC, NBS, TM, LRR	*Zea mays*

Fig. 2. PRGdb database showing proteins in maize

Drought-tolerance (climate change), saline-tolerance, nitrogen use efficiency and non-browning transgenic plants (e.g. apple): Selection of these characteristics of GMO crops are mostly based on the geo-climatic conditions of the region.

Distribution of GM crops: As people became aware of the resistance of genetically modified organisms to diseases, insects, inherent herbicide tolerance, increased yield, reduced wastage as well as the trials and tests involved in order to produce a new GM crop, the spread of GM crops increased. Many trials of GM crops globally showed that it boosted crop yields by 22% and reduced pesticide use by 37% (Raman, 2017, Mishra et al., USDA, 2020). The area planted under GM crops increased to 191.7 million hectares in 2018 from 1.7 million hectares in 1996, with developing countries growing a bigger share of the crop (USDA, refer Figure 3). The United States, Brazil, Argentina, Canada, and India are the top five countries growing GMOs in terms of crop area as of 2019 (USDA). The main crops are cotton, sugar beet, soybean, corn, canola, potato, papaya, squash, Bt cotton, maize and alfalfa.

Analyzing the effect of GM crops on native species, a new approach using Satellite Remote Sensing data:

According to NNSS (The Non-native Species Secretariat, UK, 2017), an invasive species "is a non-native species that has the ability to spread, causing damage to the environment, the economy, our health and the way we live". A lot of the public, politicians and scientists have framed GM crops as an invasive species. The movement of genes across species boundaries without regard for natural species boundaries is that the transgenes will cause the host species to become invasive or that they will escape from the original host species and infect other species (Prakash et al., 2011). Natural gene flow occurs between organisms, though the frequency varies within and across kingdoms. This type of gene flow is responsible for the formation of new gene combinations, which may lead to introgression or speciation. The immediate ecological impacts of GM crops are likely to be minor as compared to that of introduced organisms i.e., non-native. GM crops are more reliant on human assistance than introduced plants. Crops, for example, depend on pesticides and mechanical disruption to eliminate possible competitors. It cannot be overlooked that as the number and variety of GM species grows, so does the possibility of GM crops or genes escape (Gerhart U Ryffel2014, FAO Newsroom, March 2003). This in effect means that a newly introduced GM crop has traits that strengthen its ability to sustain outside of controlled systems and its ecological effect could be much greater than that of a non-GM crop.

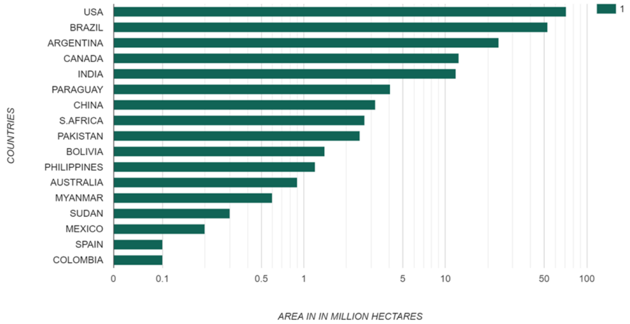


Fig. 3. Area of genetically modified (GM) crops worldwide in 2019, by country (in million hectares) constructed based on USDA Statistics using rapidtables.com

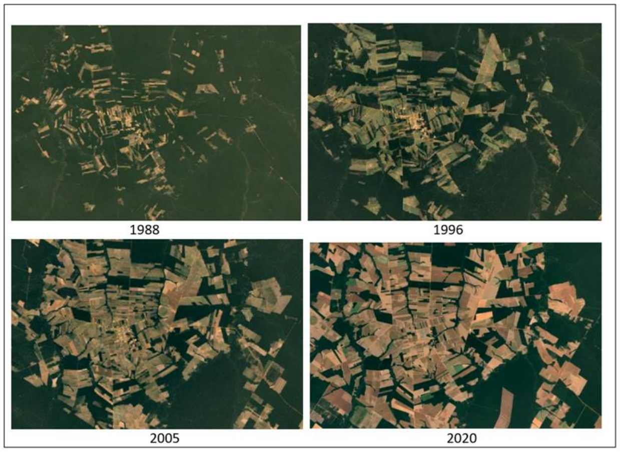


Fig. 4. Part of Claudia, State of Mato Grosso, Brazil (1615 sq.km approx.) Source: Google Earth Time lapse

The figure 4, 5, 6 are the remote sensing images of the USGS Landsat satellite (1984-2020) from Google Earth Time-lapse data (source) over Brazil, USA and Argentina, few of the top GMO cropping countries, showing time series images pertaining to pre-GMO introduction, initial phase of GMO inception (1995 and thereon) and current status. The images are compressed to adhere to document size and are clearer at full resolution (source quoted) and it is on this that the interpretations are based.

Fig. 5. Part of Beloit, Kansas, USA (87 sq.km approx.)
Source: Google Earth Time lapse

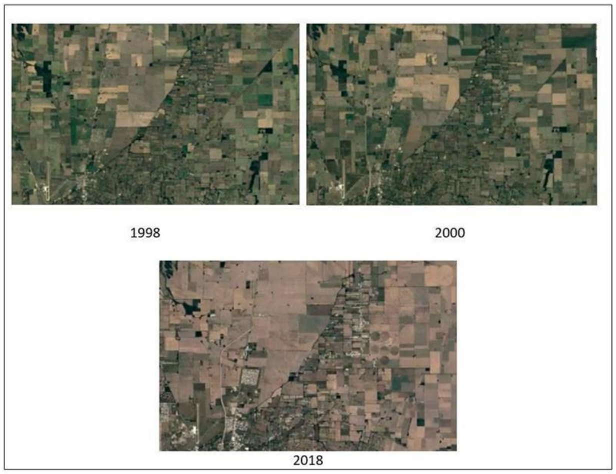


Fig. 6. Part of Cordoba, Argentina (257 sq.km approx.)
Source: Google Earth Time lapse

In this study, remote sensing satellite data has been used to analyze the effect of GMO crops on native species, based on visual interpretation, by training the eyes to notice spectral, contextual and associative changes. This method is the first analysis approach in remote sensing. Remote Sensing data is captured by the sensors/cameras with multiple optical bands, onboard the satellites orbiting the earth. The visual interpretation is done by assessing the tone, color, hue, intensity, shape, size, context and association and is the earliest and well-established technique in interpretation of remote sensing satellite data. This is based on the premise that the human eye is very efficient in recognizing geometry, dimensions, and spectral signatures of features. By virtue of the repetitive satellite coverage, synoptic view and imaging over inaccessible areas, remote sensing provides the only tool for monitoring the earth's resources, whether it is water, land based or weather. Its applications in the field of Agriculture, in terms of monitoring the crop growth, crop yield estimates, phonological study, crop diseases, precision farming, to name a few, are staggering.

The images shown above are called Natural Color Composites (NCC), formed using the red, green and blue bands of the electro-magnetic spectrum. The colors on the image are based on the response of vegetation to different spectral bands and their characteristic reflectance/absorption based mainly on the chlorophyll content, growth stage, canopy density and diseases, as these parameters have direct relation with chlorophyll content (P.S.Roy, 1989).

Interpretation:

Based on the following premise;

- The contextual understanding of the GMO inception in the above countries (commercialization post 1995).
- Maximization of productivity lead to mechanization and monocultures (IUCN report 2007) of GMO crops.
- The visual interpretation of satellite images based on spectral changes, shape, size and association of factors; the following deductions are made.

The images prior to the inception of GMO crops (commercialization was post 1995) in these areas show variation in plant species as can be seen by the different tones of green (spectral signatures) in smaller land holdings and/natural vegetation outside the farmlands. This is very clear in Claudia and Cordoba sites. After the inception of GMO crops, the land holdings have become regular/larger to allow mechanization (clearly in Claudia and Beloit sites), smaller holdings with their native crops have disappeared (typical in the example of Cordoba site) and tonal/spectral variations have decreased within the individual farmlands, the latter an indicator of monoculture.

Although field studies and further research are required to prove the deductions and inferences, it can be safely presumed that the native species, natural as well as cultivated, are being replaced because of large scale cultivation of GMO crops. This will not only give rise to loss of biodiversity but also bring about dominance of genetically modified resilient organisms endangering native species, both flora and fauna, which in turn may create an ecological imbalance disrupting the natural food cycle. This may have a cascading effect, whether upwards or downwards, on the food chain. Automatic change detection technology, considering other factors mainly related to irrigation, socio-economic factors and food habits, changes in land ownerships, government programmes and policies as well as introduction of large-scale fodder crops, may conclude the inferences with certainty.

Analyzing Risks in different contexts with special reference to native species and multidisciplinary challenges:

The risks and benefits in different contexts will be looked at here in regard to the genetic modification, based on research.

- In regards to Herbicide resistance, it potentially reduces use of herbicides and increases opportunities for the use of a reduced tillage system by appropriate agitation of soil. On the other hand, it might reduce the in-field biodiversity that may in turn reduce the ecological services provided by the agricultural ecosystem.

- In regards to the Bacillus Thuringiensis Toxin, it might reduce the use of pesticides, which might promote the development of Bt resistance, thus eliminating it as a relatively safe pesticide. It might also lead to the killing of non-target organisms such as Monarch butterflies Danausplexippus, which are endangered.
- In regards to sterilizing traits, it prevents farmers from developing seed supplies that are specifically tailored to the conditions in their region. (Peterson 2000).

Questioning the social, ecological and agricultural needs, raises the following challenges.

- *Agriculturally:* Are there alternatives that provide more agronomic, technological, social and environmental benefits? Or does the GM crop avoid a particular type of harm to humans or habitats, such as pesticide use reduction? Is it clear that genes inserted into chloroplast DNA cannot be transmitted by pollen?
- *Ecologically:* Is the modified trait capable of improving the organism's health outside of the controlled environment, for example, by imparting herbivore resistance or increasing the reproductive rate? Can the trait spread to other species in the release region, and can they hybridize with other species nearby? What will be that impact on both species?
- *Socially:* Is there a system or method in place for surveying potential negative consequences after a large-scale release? Are there any institutions that could help reduce the potential negative effects of GM crops? Research on acceptance of GMO foods in countries such as the USA, UK and Canada finds that consumers are willing to pay a premium for non-GMO foods (USDA report, 2014) by 26-129 percent.
- *Medically/Health-wise:* Do consumption of GM crops have long term effects on human health and fertility? Do they strengthen the immune system or weaken it? Do the GM crops used as animal fodder have direct effect on animals and indirect effect on humans as well?
- *Economically:* Does the high productivity of GM crops empower the countries in the global forum?
- *Climate change:* Does the expanding GM cropland have an impact on local weather conditions? The last three areas are reflections based on the outcome of this research.

5. Conclusions: Technology & Progress vs. Opposition vs. Risk Assessment

Traditional agricultural approaches are reviving today, as in organic agriculture; which does not include the use of genetically engineered crops. GM organisms may also be bred to be sterile or to have characteristics including a decreased ability to disperse. This technology may also be used to help combat invasive species. There are no varieties currently in use that are risky to consumers, as evident from the increase in GM crops cultivation.

Any regulatory framework dealing with GM crops should aim to build the social adaptive capacity needed to deal with the risks that come with new technologies. Those who want to grow and sell genetically modified crops should contribute to the development and maintenance of biosafety infrastructure and risk management protocols, especially in developing countries. GM crop taxes, administrative fees, or other approaches, such as a global biosafety process, may be used to generate such funding.

To conclude, both the benefits and risks are almost equal to each other, once unknown factors are taken out. GM crops would undoubtedly pave the way for more serious discussion on genetically modified organisms. We cannot disregard that species on their own have survived and supplanting them incessantly with GM crops wouldn’t be the best decision.

This research will be revisited in the future with in-depth analysis of phenotypes in their natural habitat. It is proposed to use remote sensing satellite data for recognition of phenotypes in the test sites along with other collateral data and automatic tools to leverage the accuracy. With Remote Sensing and Artificial Intelligence (AI), it is possible to assess the phenotypic information and changes over time and integrate this into management tools.

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Acronyms

FAO: Food and Agriculture Organization
USDA ERS: United States Department of Agriculture, Economic Research Service
ISAAA: International Service for the Acquisition of Agri-biotech Applications
UCN: International Union for Conservation of Nature
STEM: Science, Technology, Engineering and Mathematics
AAFT: African Agricultural Technology Foundation
UN: United Nations
DNA: Deoxyribonucleic acid
CRISPR: Clustered Regularly Interspaced Short Palindromic Repeats
Rp1: D protein-Rust resistance protein

References

[1] Albert Weale, Ethical arguments relevant to the use of GM crops, 2017.
[2] Breckling, Broder; Laue, Hendrik; Pehlke, Hendrik, Remote sensing as a data source to analyse regional implications of genetically modified plants in agriculture-Oilseed rape (Brassica napus) in Northern Germany, 2011.
[3] Dhan Prakash, Sonika Verma, Ranjana Bhatia and B. N. Tiwary, Risks and Precautions of Genetically Modified Organisms, 2011.
[4] Jayaraman, K.S., J. L. Fox, H. Jia, C. Orellana. Indian Bt gene monoculture, potential time bomb, Nature Biotechnology, 2005.
[5] Jorge Fernandez-Cornejo, Seth Wechsler, Mike Livingston, and Lorraine Mitchell, Genetically Engineered Crops in the United States, USDA Economic Research Service Report Feb 2014.

[6] Mishra, Ranjana Roy, Adoption of Genetically Modified Crops Can Ensure Food Security in India, 2020.

[7] Nurhussen Ahmed, Clement Atzberger & Worku Zewdie, Integration of remote sensing and bioclimatic data for prediction of invasive species distribution in data-poor regions: a review on challenges and opportunities, 2020.

[8] Oliver Xiaoou Dong, Pamela C. Ronald. Genetic Engineering for Disease Resistance in Plants: Recent Progress and Future Perspectives. Plant Physiology, 2019.

[9] Peterson, Garry & Cunningham, Saul & Deutsch, Lisa & Erickson, Jon & Quinlan, Allyson & Ráez-Luna, Ernesto & Tinch, Rob & Troell, Max & Woodbury, Peter & Zens, Scot. The Risks and Benefits of Genetically Modified Crops: A Multidisciplinary Perspective. Ecology and Society, 2000.

[10] Ruchir Raman, The impact of Genetically Modified (GM) crops in modern agriculture: A review, 2017.

[11] Talbot D, Beijing Researchers Use Gene Editing to Create Disease-Resistant Wheat, MIT Technology Review, July 2014.

[12] Tuyet T. A. Truong, Giles E. St. J. Hardy and Margaret E. Andrew, Contemporary Remotely Sensed Data Products Refine Invasive Plants Risk Mapping in Data Poor Regions, 2015.

[13] Current knowledge of the impacts of genetically modified organisms on biodiversity and human health, an information paper, IUCN, 2007.

[14] Executive Summary, Global Status of Commercialized Biotech/GM Crops, ISAAA Brief, 2014.

[15] General Surveillance of genetically modified plants Possibilities for implementation in the Netherlands, National Institute for Public Health and the Environment, 2012.

[16] https://www.fda.gov/food/agricultural-biotechnology/how-gmos-are-regulated-food-and-plant-safety-united-states

[17] https://www.isaaa.org/

[18] http://prgdb.org/prgdb/