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Genetically modified crops in world agriculture

Bachelor Thesis

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Declaration

I faithfully declare that the Bachelor Thesis Genetically modified crops in world agriculture is my own work and all the sources, which I have used are listed in the list of literature.

Prague, 10 April 2019 ______________________________

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Genetically modified crops in world agriculture

Summary:

Genetically modified organisms are known for the last few decades. Since early beginnings, this technology has been a very controversial topic among the wide public. On one side there are benefits, but on the other side, there are questions about safety. The benefits are not only for farmers but also for consumers such as reducing malnutrition and improving diet. Even though genetically modified crops have many benefits, the adoption process differs extensively across the world. For example, the United States as the main leader approach genetic modifications individually, and they are instantly approving new techniques while in the European Union crops must go through a centralized and protracted process.

The global trend of genetically modified crops is expanding, and the benefits may play a key role in solving universal problems such as overpopulation or decreasing arable land. This thesis explains the fundamentals of this complex subject such as legislation, labeling, safety and moreover it detachedly describes the current situation, trends and future possibilities.

Key worlds: genetically modified crops, biotechnology, transgenic crops, herbicide resistance, insect resistance

Contents

1 Objectives of work

The goal of this thesis is to describe the current situation of genetically modified crop in the world agriculture. This thesis especially focuses on the global biggest producer the United States of America and the contraposition of European Union. Moreover, there are described benefits, risks and future trends of this technology.

2 Introduction

Since the beginning of human existence people have depended on the richness of nature. During the process of domestication, people began to select better plant materials for propagation and animals for breeding, initially unwittingly, but ultimately with the intention of developing improved food crops and livestock (Wieczorek & Wright 2012). Over the centuries, thanks to traditional breeding that was based on the selective crossing of organisms with desirable characteristics, farmers came up with a number of new varieties. Usually, these processes were very time-consuming and labor intensive. Fortunately, modern science provided us with a very promising biotechnological tool.

People are using biotechnologies every day, though they do not often realize that. Biotechnology is described according to Cartagena protocol (Convection on Biological Diversity 1992) as technological application that uses biological organisms, or derivates thereof, to make or modify products or process for specific use. While traditional biotechnologies such as cheese production, fermented beverages or bread production are known for thousands of years, genetically modified crops are only known from the end of 20th century.

Since 1994, when the first commercial biotechnology-derived tomato crop was commercialized, the cultivated area for genetically modified crops has reached 185.1 million hectares worldwide (Mall et al. 2018). After the tomato, other genetically modified crops have made their way to market such as *Glycine max, Zea mays, Gossypium sp., Brassica napus* and so on. The new era of farmers adopting this promising technology has started

3 Literature overview

As genetic engineering allows us to do precise changes, and modern scientists can incorporate genes from unrelated organisms that bring opportunities to optimize agricultural performance. According to T. Phillips (2008), agricultural plants are one of the most frequently cited examples of genetically modified organisms.

3.1 Genetically modified crops

Genetically modified crops are plants in which the hereditary material (DNA) has been altered with the aid of gene technologies (Křístková 2010). These gene technologies (also so-called genetic engineering) are capable of transferring genes of one organism into another organism, cloning or deletion of some desirable genes. Sometimes, it is more appropriate to use the specific term transgenic crops, which describes the use of unrelated organisms. This modified organism will gain new and expedient properties.

3.1.1 Generations of genetically modified crops

The most common classification of genetically modified plants is division in so-called generations. This classification is based on their qualities. They are divided into 5 groups (5 generations): I. Generation - protection against diseases, pests and weeds, II. Generation – resistance to abiotic factors (droughts, coldness, salinization, light deficiency), III. Generation – improved nutritional value (preferable composition of fatty acids, modification of vitamin content), IV. Generation- ecologically profitable plants, V. Generations – replacement of fossil fuels, materials for industry (production of ethanol, biodiesel, starch) (Stratilova 2012).

3.1.1.1 First Generation

As pests, weeds and diseases have huge impact on yield, the first generation is mainly beneficial to farmers, helping them to fight against these threats. The benefit is better thriftiness to environment as a result of simplification of current technologies (Holec & Soukup 2006).

3.1.1.1.1 Tolerance to herbicides

Weeds are a common part of agriculture. The frequent way to minimize them are herbicides that are divided into selective and non-selective weed killers. Herbicide resistant crops are known for tolerance to non-selective herbicide. In a normal situation, non-selective herbicide has detrimental consequences to non-tolerant crops and weeds. It is much easier protection against weeds that are closely related to crops and usually it is very difficult to control them with classical selective herbicides (Holec & Soukup 2006).

According to Schutte (2017), tolerance to herbicide is the predominant trait of cultivated genetically modified crops and will remain so in the near future. Scientist were able to express this trait in *Glycine max, Medicago sativa, Zea mays, Gossypium sp., Brassica napus* and *Beta vulgaris.* The typical is resistance to Roundup herbicide that has glyphosate as an active ingredient.

3.1.1.1.2 Tolerance to pests

Pests can lower the yield and play role in the distribution of diseases thus chemical control is very common. Unfortunately, it can be detrimental to a beneficial insect as well. Transgenic plants that are known as "Bt" (*Bacillus thuringiensis*) can produce toxins, which are common for soil bacteria, and they are lethal to insects. Examples of pest tolerant plants available on a market are *Zea Mays, Solanum melongena, Gossypium sp.* and so on.

3.1.1.2 Second Generation

The natural heterogenic field conditions and global climate change are causing abiotic stress which is nowadays part of plant production. Only 10% of world's arable land may be categorized as free from stress (Bidhan et al. 2011). The second generation can sustain against abiotic stresses and shows acceptable yields under stress settings. This group is also primary beneficial to farmers.

3.1.1.2.1 Tolerance to drought

Water is essential for plants and they have different critical requirements during the growing season. If these requirements are not fulfilled, it can end up as a total crop failure. Obviously, drought is currently the leading threat to the world's food security (Liang 2016). Therefore, drought-tolerant crops bring opportunity to grow them in a usually unsuitable environment for agriculture and possibly expanding the arable land. Genetically modified crops with drought tolerance are under development, but few of them have reached the market (Liang 2016).

3.1.1.3 Third Generation

Into the third generation belongs transgenic crops with higher nutritional value (for example enriched with vitamins or adjusted content of fatty acids) and can have another advantageous medicinal effect. Therefore, these plants represent benefits to consumers.

The great example is a golden rice. In developing countries, where vitamin A deficiency prevails, grain from Golden Rice is expected to provide this important micronutrient sustainably through agriculture (Al-Babili & Beyer 2005). Provitamin A is accumulating thanks to genes from unrelated organism that are not naturally occurring in rice.

3.1.1.4 Fourth Generation

The fourth generation is focused on crops that can produce environmentally beneficial commodities. The new application from crops is the production of biopolymers in the transgenic plants with the advancement of genetic engineering (Mohanty et al. 2011). The biopolymers are suitable as plastic materials that are easily degradable by soil organisms, but these traits are still under development.

3.1.1.5 Fifth Generation

Into the fifth group belongs transgenic plants use as a replacement of fossil fuels (production of ethanol and biodiesel) (Holec & Soukup 2006). Ethanol from plant biomass is being pursued as an alternative to fossil fuels. The ethanol production is based on digestion of cellulose. Current production systems for cellulase enzymes, i.e. fungi and bacteria, cannot meet the cost and huge volume requirements of this commodity-based industry (Hood et al. 2007). Therefore, *Zea mays* containing cellulase protein from unrelated organisms seems very promising.

3.2 United States of America

3.2.1 History

In 1973-1974 Stanley N. Cohen of Stanford and Herbert W. Boyer of the University of California, San Francisco, developed a laboratory process for joining and replicating DNA (deoxyribonucleic acid) from different species (Hughes 2001). Thanks to this success a new chapter of possibilities has started, but with this action, the scientific world had to deal with doubts about a potential risk.

By the middle of 1974, a moratorium on genetically engineered projects was universally observed, allowing time for experts to come together and consider the next steps during what has come to be known as the Asilomar Conference of 1975 (Johnson & Lichtveld 2017). The best professionals from different fields agreed on a continuance of projects with adequate guidelines. Therefore, the National Institutes of Health (hereinafter referred to as NIH) established a set of rules in 1976. Following the NIH, The United States Department of Agriculture (hereinafter referred to as USDA), Environmental Protection Agency (hereinafter referred to as EPA) and Food and Drug Administration (hereinafter referred to as FDA) established a set of similar mandatory rules. These actions made the research controlled and regulated.

The possibilities for a huge commercial boom came up in 1980 when the Supreme Court of United States approved patenting of genetically engineered bacteria. This ruling legally permitted ownership rights over genetic modified organisms, giving large companies the incentive to rapidly develop genetic modified organism tools that could both be useful and profitable (Rangel 2015). Consequently, a genetically engineered medication was observed, including human insulin from bacteria. Regardless of that fact, the plants for food production seemed more controversial and needed more time to get to cognizance.

Transgenic plants made their lab and greenhouse appearance in 1983 as three independent groups reported their development at Miami winter symposium, and other groups followed quickly (Neal Stewart 2016). Two of these three early agricultural biotechnological groups were based in the United States of America. Dr. Mary-Dell Chilton was a leader of a research group in the Washington University in St. Louis, who demonstrated the transgenic plant, a tobacco resistant to antibiotics (kanamycin). Needless to say, the first transgenic plant did not meet all expectations: it could not express the transgene's proteins (Pellegriny 2013). The goal was to confirm that transgenic plants are feasible and difficulties with the protein expression were secondary.

Later, many field trials were observed. Anyway, the first commercial plant production was approved 11 years after the first transgenic plant when Californian company Calgene started selling Flavr Savr tomatoes with extended shelf life. The Flavr Savr failed because of inconsistent production capacity and delivery to market (Neal Stewart 2016). By 1995, other crops were introduced, including cotton, canola, potatoes and maize (Wozniak & McHughen 2012) and immediately farmers started adopting these promising technologies.

3.2.2 Legislation

As the government regulations differ across the world, they all have the same goal to ensure safety. Scientific data are used as standards to evaluate the effects of genetically modified crops on human health and environmental safety, but other facts can be analyzed such as economic or cultural impacts. In the United State of America, the same regulations apply to genetically modified and conventional foods because despite the different processes used to make them, the final products are considered to be similar (Lau 2015).

The Coordinated Framework for regulation of biotechnology from 1986 is the base regulatory policy, which specifies current roles and responsibilities of agencies. Since then this framework has been updated a few times to meet ongoing demands. Figure 1 schematically represents all possible interactions from crop development to market. There are three main agencies involved in the regulation of biotechnology such as USDA, EPA and FDA.

Under the USDA, Animal and Plant Health Inspection Service (hereinafter referred to as APHIS) and Plant Protection Act are involved in protecting agriculture and control products of biotechnology, which could potentially cause dispersion of pests and diseases. The EPA is involved in regulation of pesticides, toxic substance and chemical residues that could be detrimental to human health and environment. Thus, a plant-incorporated protectant (for example, a Bacillus Thuringiensis toxin) is subject to EPA's pesticide regulations (National Academies of Sciences 2017). The FDA controls the safety of human food and animal feed, including those that come from genetically modified crops.

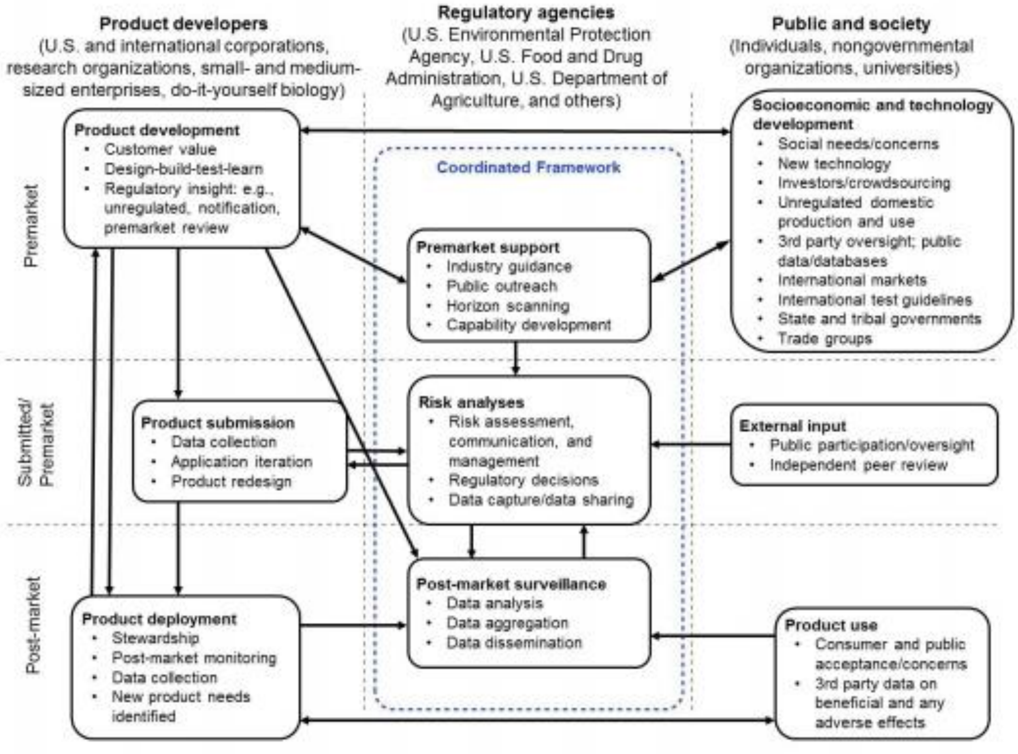

Figure1: Schematic diagram of regulatory framework

Source: Coordinated Framework for Regulation of Biotechnology, 2017

The USDA requires from product developers to submit a range of data before genetically modified crops can be introduced in US fields under regulated or non-regulated cases. According to Coordinated Framework for the Regulation of Biotechnology (2017) a genetically engineered organism is considered a regulated article if the donor organism, recipient organism, vector, or vector agent used in engineering the organism belongs to one of the taxa listed in 7 C.F.R. Section 340.2 and is also considered a plant pest. If there is any reason for APHIS to believe that the organism is a plant pest, this organism is also regulated. The regulated plants have strict regulations from how many plants can be planted to where they can be transported. APHIS can conduct a plant pest risk assessment and if there is improbable potential for a risk, this plant will be moved from regulated to nonregulated status.

Like novel whole foods developed through conventional breeding, most foods derived from novel genetically engineered crop varieties are not required to be reviewed or approved for safety before going to market (National Academies of Sciences 2016). The producers are liable for the safety and lawfulness of their product.

The total number of approved traits is higher in the United States than in the Europe and usually, in the Europe the traits are approved with a delay which is visible in Figure 2. While the United States of America are focused on the product, the European Union is focused on the process.

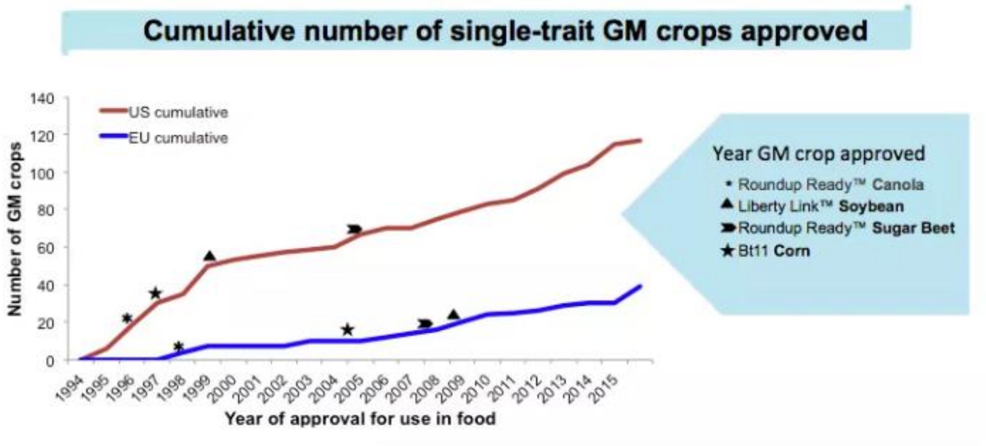

Figure 2: USA has approved more GE crops than EU

Source: Lau, 2015

3.2.3 Labeling

The FDA has not required special labeling for genetically modified crops present in the food as they are recognized to be equivalent to their convectional varieties for two decades until 2016 when National Bioengineered Food Disclosure Standard was signed by Barack Obama. That law was intended to override a patchwork of State statutes, such as the Vermont law that called for strict and transparent labeling of foods that contain genetically modified organisms (Congressional Digest 2018). A preemption section in the bill prohibits individual states from applying their own mandatory GMO labeling laws (Castellari et al. 2018). This action brought great attention of media and wide public.

The United States of America have two years to establish this policy and procedures necessary for implementation. Linnekin (2018) reported that the USDA received more than 14,000 comments on the proposed rules from individuals, nonprofits, businesses, and others. The USDA approach differs from other countries. For example, the proposed law allows that genetically modified organism content could be represent via text, symbol, electronic or digital link. This brings a new opportunity that food producers could easily use QR codes.

Another peculiarity is that the food containing genetically modified crops would not be labeled as genetically modified organism, instead they came up with term Bioengineered or just BE as is shown in Figure 3. The amended Act defines “bioengineering” with respect to a food, as referring to a food “(A) that contains genetic material that has been modified through in vitro recombinant deoxyribonucleic acid (DNA) techniques; and (B) for which the modification could not otherwise be obtained through conventional breeding or found in nature (USDA 2018b).

Food labels have great impact on decision-making of consumers, therefore the mandatory labeling could increase demand for non-genetically modified products. Currently, the proposed rule leaves some room for other factors and conditions, and the USDA plans to finalize the law by the end of 2018.

Figure 3: Bioengineered labels, United States of America

Source: USDAb, 2018

3.2.4 Plant Production

In 2017, the United States of America grew transgenic plants on 75 million hectares, which is around 40% of global transgenic plant production. They ranks as the number one in the world in the use of this modern technology and in 2016 the profit reached $ 7.3 billion.

A total of 75 million hectares of biotech crops were planted comprised of 34.05 million hectares biotech *Glycine max*, 33.84 million hectares biotech *Zea mays,* 4.58 million hectares biotech *Gossypium hirsutum*, 1.22 million hectares biotech *Medicago sativa,* 876,000 hectares biotech *Brassica napus,* 458,000 hectares biotech *Beta vulgaris,* 3,000 hectares biotech

Solanum tuberosum, and some 1,000 hectares each of biotech *Malus pumila*, *Cucurbita sp.*, and *Carica papaya* (ISAAA 2017). There is over 190 approved single traits in 19 crops. *Zea mays* and *Solanum tuberosum* have the highest number of approved traits.

The biotech *Zea mays* area of 33.84 million hectares was comprised of 1.1 million hectares insect resistant, 4.4 million hectares herbicide tolerant and 28.34 million hectares stacked varieties with insect resistance and herbicide tolerance traits (ISAAA 2017). The transgenic *Zea mays* reached 93.4 % from whole maize production.

Biotechnological *Glycine max* reached 94 % of the adoption rate and the most common traits is herbicide tolerance. Other interesting traits incorporated in *Glycine max* include improved monounsaturated oleic acid composition or enriched omega3-fatty acid composition.

Medicago sativa is the third most planted crop in the USA at 8.5 million hectares, with 14.4% or 1.2 million hectares being biotech (ISAAA 2017). The most common traits are herbicide tolerance and low lignin traits.

The *Gossypium hirsutum* reached 96% of adoption rate in 2017. The 4.6 million hectares were comprised of 239,000 hectares insect resistant, 525,000 hectares herbicide tolerant, and 3.8 million hectares of stacked traits (ISAAA 2017).

The adoption rates of the main three crop (*Zea mays*, *Glycine max* and *Gossypium hirsutum*) are very high, therefore the future expansion of genetically engineered crops will also depend on other crop species.

3.3 European Union

In the global scale, genetically modified crops are important part of agricultural production, but the area in the European Union is insignificant (Trnkova 2017).

3.3.1 History

Europe also contributed to obtaining the first transgenic plant. The group from University of Gent, Herrera-Estrella et. al. (1983) almost simultaneously reported with other two American groups the success of the first transgenic plant.

The countries of European Communities created guidelines for manipulating with DNA (deoxyribonucleic acid) based on the recommendation of scientific authorities (Drobník, 2006). The review of risks of this new technology started to be based on the obtaining method, but not on the characteristics of the organisms, and guidelines were established in 1990. When looking at these first European rules it is clear that the intention was not to avoid the use of genetically modified organisms since it is considered beneficial for the economic development in the Member States (Andersen 2010).

In January 1997, an insect tolerant *Zea mays* was the second genetically modified plant authorized for food and feed use and the first crop to be cultivated in the European Union (Schauzu 2013). In the same year, mandatory labeling was established to inform the consumer about novel food product. It is specifically pointed out that the presence of genetically modified organism is a feature the causes a novel food product to differ from its conventional counterpart (Andersen 2010).

3.3.2 Legislation

Despite using identical technologies, genetically engineered food regulations in the United States of America and European Union vary widely (Gostek 2016). The European Union has a very strict system, where the aims are to protect human and animal health and the environment, put in place harmonized procedures for risk assessment and authorization of genetically modified organisms, ensure clear labelling and ensure the traceability.

There are two main authorities: The European Commission and European Food Safety Authority. The European Food Safety Authority provides scientific viewpoints to the European Commission and the commission based on them makes final decisions (Rakouský 2008).

The fundamental legislation law is a Directive 2001/18/EC about releasing genetically modified organisms into environment. Another important law is the Directive (EU) 2015/412, which brings a possibility for each member to prohibit the cultivation in their territory. Companies hoping to sell and market their genetically modified organism-containing foods in a certain European country must apply for approval at the country level first; if approved, the company can proceed by notifying other countries via the European Commission (Wang 2016).

In the European Union, all genetically modified organisms are regulated and must go through a centralized process for premarket approval and follow labeling guidelines.

3.3.3 Labeling

The mandatory labelling requirement is defined in Regulation (European Commission) 1830/2003 Genetically Modified Traceability and Labelling Regulation. The European labeling requirements are to label any food with a genetically modified organism content above a 0.9 % threshold. Presence under 0.9 % does not require labelling under the condition that the presence is adventitious or technically unavoidable (Andersen 2010)

Carter & Gruere (2003) reported a problem related to DNA detection, because the measurement of genetically modified material become difficult or almost impossible if the crop is highly processed. For example, soybean oil does not contain any genetically modified substance and according to requirements it is still labeled as you can see in figure 4.

The words genetically modified or produced from genetically modified needs to be present clearly on the list of the ingredients. If the food does not contain package, the information must be permanently and visibly displayed either on the food display or immediately next to it.

GM product	**Example**	**Labeling requirement**
GM plants, seeds, and food	Maize, maize seed, cotton seed, soybean sprouts, tomato	Yes
Food produced from GMOs	Maize flour, soybean oil, rape seed oil	Yes
Food additive/flavouring produced from GMOs	Highly filtered lecithin extracted from GM soybeans	Yes
GM feed	Maize	Yes
Feed produced from a GMO	Corn gluten feed, soybean meal	Yes
Feed additive produced from a GMO	Vitamin B2	Yes
Food from animals fed on GM feed	Eggs, meat, milk	No
Food produced with the help of a GM enzyme	Bakery products produced with the help of amylase	No

Figure 4: Labeling requirement in EU

Source: Wesseler & Kalaitzandonakes, 2011 modified from Commission of the European Communities (2003).

3.3.3.1 Labels: free from genetically modified organisms

The increasing consumer interest in labelling transparency boost the free-form category globally. Transgenic crops are imported to EU as feed for farm animals and products from these animals do not have to be labeled. As a result, a growing number of European Union member states have established non-GMO or “fed without GMOs” labeling programs for animal-derived products (Roseboro 2017). For example, Germany and France established this strategy in their legislation.

3.3.4 Plant Production

ISAAA (2017) reported that in 2017 the total biotech crop area was 131,535 hectares. Spain and Portugal were the biggest and the only cultivators in 2017 as you can see in the figure

5. Spain planted 124,227 hectares and Portugal planted 7,308 hectares (ISAAA 2017). The only genetically modified plant approved for cultivation in the European Union is MON810 corn (USDA 2018a), which is an insect resistant variety.

The European Union mainly import genetically modified crops and around 100 events are approved for food and feed. The common are herbicide and insect tolerant traits in *Zea mays*, *Gosypium hirsutum*, *Glycine max* and *Brassica napus*. *Glycine max* with improved oleic composition is also available on the European market.

Crop developers are dealing with common delays up to 7 years. There were instances when commodity product shipments were stopped at the European border if they contain traces of products which have not yet been approved in the European Union (ISAAA 2017).

Acceptance of genetically modified crops varies greatly among countries (USDA 2017a). Since 2015, nineteen European countries have "opted out" of genetically modified crops cultivation for all or part of their territories under Directive (European Union) 2015/412 (USDA 2018a). Some states that decided for this strategy, cultivation of genetically engineered crops had been banned before this directive for example Austria, Bulgaria and France.

Some countries of the European Union are in partnership with research institutions around the Europe and America and they are actively conducting biotech research but will not likely lead to the commercialization of new biotech crops in the short term (ISAAA 2017).

The most common reasons why framers are not growing genetically modified crops are strict reporting requirements and difficulties connected with marketing these crops.

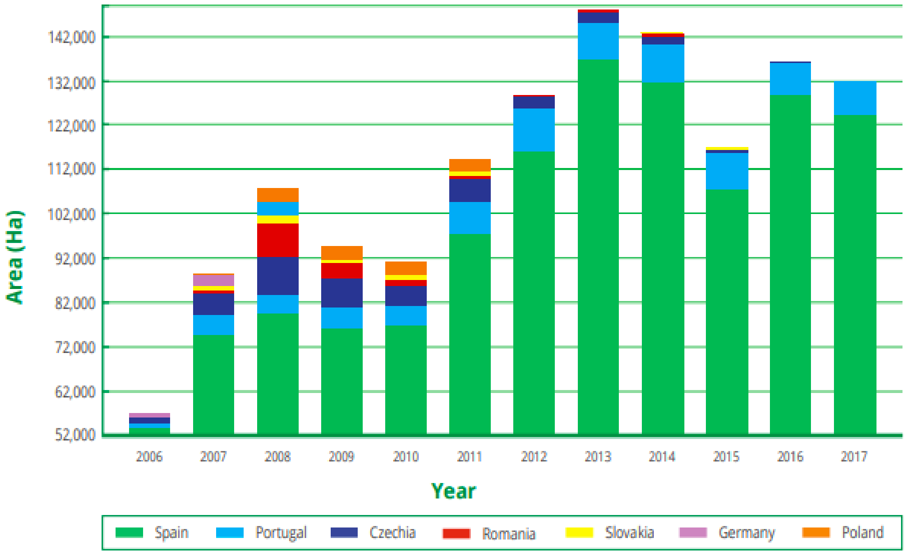

Figure 5: Genetically modified *Zea mays* area in EU, 2006 to 2017
Source: ISAAA, 2017

3.3.4.1 Czech Republic

Czechia had supported the science-based approach to biotechnology and started planting biotech crops in 2005 at 250 hectares and peaked in 2008 at 8,380 hectares (ISAAA 2017). Since then the planted area was decreasing every year and in 2017 production stopped completely.

Aside from insect resistant maize, ISAAA (2017) reported that the country also planted 147 hectares of Amflora potatoes in 2010. These potatoes were genetically engineered to produce only the amylopectin component in its starch (Abdallah 2010). This is a very useful trait for industrial purposes because isolating amylopectin and amylose in starch is energetically challenging and water-demanding process.

Czech Republic is active in research and field testing.

3.4 South America

Brazil, Argentina, Paraguay and Bolivia are four South American countries that belong to the top ten world producers. Uruguay, Mexico, Colombia, Honduras, Chile, and Costa Rica also commercially produce genetically modified crops. On the other side Venezuela, Ecuador and Peru banned the cultivation.

3.4.1 Brazil

Brazil is the second largest producer after the USA and their production was distributed over 50.2 millions of hectares in 2017. The dominant biotech crop is *Glycine max,* followed by *Zea mays* and *Gossypium hirsutum* with an average adoption rate of 90%. From 2013 to 2017, Brazil has approved 68 biotech events for food, feed, processing, and cultivation for bean (1), cotton (15), eucalyptus (1), maize (39), soybean (11), and sugarcane (1) (ISAAA 2017). The popular traits are herbicide tolerance, insect tolerance and stacked varieties. The stacked events make around 20% of the total cultivation. The unique event developed in Brazil is a golden mosaic virus resistant bean.

Marinho et al. (2014) reported that the number of conventional varieties is decreasing, and they are replaced by transgenic crops. For example, there have been more transgenic soybeans varieties than non-transgenic soybeans varieties since 2006.

The labeling history started in 2003 when Brazil approved that all food and food ingredients for human and animal consumption must be labeled if they contain 1% or more of genetically modified material. In 2015, the new Draft Bill establishes that only products which have more than 1 percent of genetically engineered material in its final composition must be labeled (USDA 2017b). Moreover, it suggested withdrawing the conditions for a transgenic crops label of black “T” symbol in a yellow triangle. However, this has not been approved yet due to major elections in 2018.

Brazil is a leader in exporting transgenic commodities. China is the main purchaser of Brazilian soybeans and cotton. According to ISAAA (2017), the acceptance of biotech crops in Brazil is exemplary and could influence adoption in neighboring countries.

3.5 Africa

About 50–75% of the labor force in Africa is involved in agriculture and the majority of its population depends on agriculture, either directly or indirectly (Thomson 2015). However, the production is very low due to the environmental condition therefore genetically modified crops represent tremendous potential. Nevertheless, the hesitance of adoption has more reasons. Somebody decides to believe discredited publications of Seraliny et al. (2012), where he described the appearance of tumors in animals after consumption of herbicide tolerant maize, but the other main factors are culture, religion and education.

In 2017, a total of 13 countries sustained various activities from planting, evaluating trials or granting approvals for the general release of various biotech crops (ISAAA 2017). South Africa and Sudan commercially grow genetically modifies crops, with South Africa being in the top 10 world producers. The ongoing trials are in Ethiopia, Kenya, Uganda, Tanzania, Mozambique, Malawi, Swaziland, Ghana, Nigeria and Cameroon. In all countries that have adopted genetically modified crops, political will and high-level government support has played a key role (Otunge et al. 2018).

Among the traits under research are draught tolerant maize, disease resistant cassava and sweet potatoes, bio-fortified sorghum, nitrogen and water efficient and salt tolerant rice, soybean with modified fatty acid composition and much more. These traits are supposed to target African challenges associated with environmental conditions. For example, the WEMA (water efficient maize for Africa) maize is expected to address the water deficiency that affects South Africa periodically (ISAAA 2017).

There is an expectation for further expansion of traits.

3.6 Asia and the pacific

Three countries in Asia and the Pacific belongs to top ten world producers such as India, Pakistan and China. Australia, Philippines, Myanmar, Vietnam and Bangladesh also planted genetically modified crops in 2017.

3.6.1 China

China belongs to the top ten world producers and the production was distributed over 2.8 millions of hectares in 2017. Their history dates back to 1997 when they planted genetically modified cotton. Farmers have greatly benefited from the technology due to cost effectiveness, better yields and labor use. Quiao et al. (2017) reported that adoption of pest-resistant cotton not only led to a reduction of the mean of pesticide use but also contributes to the stability of pesticide use among farmers.

Apart from herbicide tolerant and pest resistant cotton China planted genetically modified papaya resistant to papaya ringspot virus with adoption rate 86% in 2017. Since 1997, China has approved 64 biotech events for food, feed, and cultivation: Argentine canola (12), cotton (11), maize (18), papaya (1), petunia (1), poplar (2), rice (2), soybeans (12), sugar beets (1), sweet pepper (1), and tomato (3) (ISAAA 2017). China is a large exporter of products from genetically engineered cotton.

China requires mandatory labeling of products that are produced from genetically engineered materials or contain the following genetically engineered substances: 1. Soybean seeds, soybeans, soybean flour, soybean oil, and soybean meal; 2. Corn seeds, corn, corn oil, and corn flour 3. Rapeseed for planting, rapeseeds, rapeseed oil, and rape seed meal; 4. Cottonseed; and 5. Tomato seed, fresh tomato, and tomato paste (USDA 2019). This labeling is based on qualitative characteristics.

Recently, the Ministry of Agriculture has been trying to regulate and minimize the GMO-free and non-GMO labels for products that do not have a genetically engineered version approved in China. Non-GMO labels can be used for products for which genetically engineered versions are available, but the labeling must be accurate and cannot use misleading words such as “healthier” or “safer” (USDA 2019).

Research and innovation are highly supported by the government. Nowadays they are focused on the development of disease-free and drought-resistant wheat, disease-resistant rice, drought-resistant maize, nutritionally improved soybeans and antioxidant purple rice.

3.6.2 India

Insect resistant cotton is the only genetically engineered crop currently approved for commercial cultivation, and vegetable oils derived from selected soy and canola are the only products approved for imports in India (USDA 2018c). The adoption rate reached 93% of the total cotton area, which represented 11.4 million hectares in 2017.

As the population of India is over one milliard of people, there is a huge demand for oil crops. Therefore, there is a great interest to improve the productivity of mustard, soybeans and other oil crops. Transgenic mustard DMH-11 looks very promising to fulfill India's demands.

In 2017, media sources reported that cotton, soybean and eggplant seeds with unapproved events were being clandestinely sold by 'nefarious' producers and cultivated by farmers across the country (USDA 2018c). The Government of India started an investigation and initiated procedures to stop the distribution of illegal seeds. The USDA (2018c) reported that the cultivation of the unapproved genetically engineered seeds reflects farmers need for new technologies while the government continues to delay approvals of genetically modified crops in various stages of the regulatory pipeline.

3.6.3 Japan

Japan has the greatest number of events approved (ISAAA 2017), which means over 600 traits for food, feed and cultivation. However, there is not any cultivation yet. Japan remains one of the world's largest per-capita importers of food and feed produced using modern biotechnologies (USDA 2017a). The regulations are based on science and the new events are approved in a foreseen timeframe that aligns with industry and market demands.

3.7 Risks

As it is a new technology, the risks are not always known. The research results and thorough testing bring parameters to evaluate the relative magnitude of the potential risks. Genetically modified crops are creating ethical, environmental, social and health concerns (Roudna 2008). It is important to realize that every human activity has risks and it is the same for genetically modified crops.

The potential risks can be divided into two groups: 1) impact on human and animal health and 2) impacts to the environment (Roudna 2008). It is known that the main concerns about adverse effects of genetically modified foods on health are the transfer of antibiotic resistance, toxicity and allergenicity (Bawa & Anilakumar 2012). The second group includes creating superweeds by crossing related species. Another possibility is a reduction of biodiversity (substitution of local cultivars by genetically modified organisms) (Roudna 2008).

It is very difficult to demonstrate allergies because people have different sensitivity levels to allergenic substances. Generally, transgenic crops can contain common allergens as their commercial varieties, and they are tested before entering the market. The opportunity to be exposed to a new allergenic factor is not excluded. However, there is no evidence that genetically modified organisms are any more or less allergenic than their non-modified counterparts (Xu 2015).

There is also a possible risk in disease resistant plants. According to Bawa & Anilakumar (2012) is possible that viral resistance can lead to the formation of new viruses and therefore new diseases because it has been reported that naturally occurring viruses can recombine with viral fragments that are introduced to create transgenic plants, forming new viruses. The possible variance of newly formed viruses is enormous.

The ability of plant crossbreed with other related plants and create resistant weed variety is another concern. Resistance can evolve whenever selective pressure is strong enough (Bawa & Anilakumar 2012). Large commercial planting increases selective pressure, which could cause the evolution of resistant weeds and insects.

Global cultivation of herbicide-tolerant crops has led to increased use of broad-spectrum herbicides that pose serious threats to ecosystems (Tsatsakis et al. 2017). This reduces biodiversity and disrupts ecological food webs. Broad-spectrum herbicides are not only used in genetically modified crop fields, but also in intensive agriculture, thus the impacts cannot be generalized.

The process of evaluating possible risks is very sophisticated and brings a good assurance. There have been done more than 3000 of studies that have assessed the safety of biotech crops in terms of human health and environmental impact and these studies have enabled a solid and clear scientific consensus: genetically modified crops have no more risk than those that have been developed by conventional breeding techniques (Bonea & Urechean 2017).

3.8 Benefits

Genetically modified crops have many benefits and the potential to solve some global problems. They can be divided into benefits to produces, consumers or the environment.

Malnutrition contributes to or causes 24,000 deaths per day worldwide (Potrykus 2003). The most common deficiencies are iron, zinc, vitamin A, iodine and protein in developing countries. For example, the Australian researches Paul et al. 2016 demonstrated an enriched pro-vitamin A banana, which could decrease microelement deficiencies in Africa.

Bonea & Urechean (2017) reported that between 1996-2015, the use of pesticides on the genetically modified crops area was reduced by 618.7 million kg active ingredient (8.1% reduction), and the environmental impact (associated with herbicide and insecticide use on these crops), as measured by the EIQ indicator (Environmental Impact Quotient), fell by 18.6%. This was obtained thanks to an adoption of insect resistant and herbicide tolerant technologies. However, it should be noted that in some regions where herbicide-tolerant crops have been widely grown, some farmers have relied too much on the use of single herbicides like glyphosate to manage weeds and this has contributed to the development of weed resistance (Brookes & Barfoot 2012).

Transgenic plants can help control plant viral diseases. Hawaii is a producer of *Carica papaya*, but the production almost ended up due to a severe virus infection. Papaya ringspot virus (PRSV) is the causal agent of ring spot disease in papaya and the characteristic symptoms of which are mottling, blister-like patches, and distortion of leaves associated with ring spots on papaya fruits (Mishra et al 2016), which affects growth and reduces yields. Licenses to commercialize the transgenic papaya were obtained by the Papaya Administrative Committee in Hawaii by April 1998 (Gonsalves 2004). Since then, farmers have successfully adopted this technology, continued in papaya production and export. This success shows a great experience in controlling plant viral disseats.

For the medical system, the transgenic foods offer the possibility to be used as oral vaccines in order to increase the immunity (Bonea & Urechean 2017). However, this is a very challenging process due to medical, legal, ethical, and environmental uncertainties. Thus, there is active research and testing. In addition to their possible benefits, edible vaccines will decrease the costs of vaccination and allow minimally invasive vaccine administration (Concha et al. 2017).

Bo-Ran et al. 2019 reported a transgenic rice plant that showed significant increases in photosynthesis efficiency, biomass yield, and nitrogen content, under both greenhouse and field conditions. This could help fight the increasing population.

Many people feel that genetic engineering is the inevitable wave of the future and that we cannot afford to ignore a technology that has such enormous potential benefits (Bawa & Anilakumar 2012).

3.9 Future possibilities

The future is very promising. Genetically modified crops can play a key role in solving many global problems such as hunger, malnutrition, overpopulation, increase yield and to help to protect the environment. There are many challenges connected with safety, risk, ethics and attitudes towards this technology. It is difficult to predict certain traits that will make it to the market. The specific traits that will be available to farmers and the specific crops and varieties in which the traits will be available will depend on the extent of investment in crop improvement by the private and public sectors (National Academies of Sciences 2016).

Until now, commodity crops were predominant, but the expectations are that the variety of species will expand as genetic engineering develops rapidly. According to National Academics of Sciences 2016, emerging genetic-engineering technologies have the potential to increase the complexity of engineered changes substantially because multiple genes can be introduced or “stacked” into a single target.

Tilman et al 2011 reported that forecasts of global crop demand will double up from 2005 to 2050. Therefore, sustainable intensification is crucial. Genetic engineering is already trying to increase yields and reduce food waste thanks to prolonging life shelf. There are other important traits that need to be further examined such as drought tolerance, temperature and stress tolerance. Another promising traits are production of human vaccine and pharmaceuticals.

While their practicality or efficacy in commercial production has yet to be fully tested, the next decade may see exponential increases in genetically modifies product development as researchers gain increasing access to genomic resources that are applicable to organisms beyond the scope of individual projects (Bawa & Anilakumar 2012).

4 Conclusion

The global area of genetically modified crops is increasing every year and the research is evolving rapidly. The new traits have great potential; therefore, it is certain that they will continue expanding. The adoption rate of the major crops (*Zea mays*, *Glycine max*, and *Gossypium hirsutum*) is reaching 95% in the top ten world producers which means that there is not much left for further expansion. The possible expansion can be in another species or favorable traits.

The attitudes towards this technology differ across the world. It seems like the world is divided into two groups. Supporters who are rapidly adopting this technology and focus on benefits and on the other side, opponents who are banning the production. It is not always easy to pick a side because genetically modified crops represent a wide group of crops, thus they can be as beneficial as harmful. We should more focus and judge based on specific traits as there is a great variety among them.

Genetically modified crops are considered generally safe based on the science, current testing and production and the fact that there is no proof that they have an impact on human health to this point.

I would like to end this thesis with one interesting quote. Civilization could not exist without agriculture, and agriculture could not sustain the civilized world without modern crop varieties (Harlan 1992).

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6 List of abbreviations and symbols

APHIS - Animal and Plant Health Inspection Service

EPA - Environmental Protection Agency

FDA - Food and Drug Administration

ISAAA - International Service for the Acquisition of Agri-biotech Applications

NIH - US National Institutes of Health

PPA - Plant Protection Act

USDA - United States Department of Agriculture

7 Enclosures

Figure1: Schematic diagram of regulatory framework, Coordinated Framework for Regulation of Biotechnology, National Academies of Sciences, 2017.

Figure 2: United States of America has approved more genetically modifies crops than European Union, Lau, 2015.

Figure 3: Bioengineered labels, United States of America, USDA 2018b.

Figure 4: Labeling requirement in European Union, Wesseler & Kalaitzandonakes, 2011 modified from Commission of the European Communities 2003.

Figure 5: Genetically modified *Zea mays* area in European Union, 2006 to 2017, ISAAA, 2017.