

GMO - BLESSING OR CURSE?

Tamás Mizik

Corvinus University of Budapest, Fővám tér 8., Budapest 1093, Hungary

Abstract

Genetic engineering is a rapidly emerging issue all over the world. Regulation systems are totally different, the product-based one focuses on the product (substantial equivalence), while the process-based main characteristic is precautionary. There are still some countries where there is no GMO law or regulation. The topic itself is controversial.

The USA is the leading producer of genetically modified products, however, developing countries have higher (and continuously growing) share in production since 2011. GMO provides an answer to important questions like food security (malnutrition and hunger) or industrial production (e.g. biofuels) but raises many others such as food safety (health risks) or different side effects. This article focuses on the economic aspects of the topic.

Key words: GMO, product- and process-based regulation, price premium, food chain

1. INTRODUCTION

Both agriculture and food industry face severe global challenges such as the continuously growing population and food security in line with the decrease in arable land per person, which should be solved as soon as possible. In order to either minimize production costs or maximize profit, innovations and technological developments are becoming more and more important. One of the most controversial solutions is genetic engineering. It is used to make better products by the artificial way. The DNA (Deoxyribonucleic acid) structure of a given species is changed by inserting a gene from a different species. Due to genetic modification, new species arise on an artificial, precisely planned way. DNA structure is changed by inserting an individually selected gene from another organism in order to reach the desired characteristic. This is the way how genetically modified organisms come into existence.

The reasons for genetic engineering are multifold, such as medical, industrial or other purposes. Researches are already started at the beginning of the 20th century, however, the term GMO (Genetically Modified Organism) spread worldwide only in the '70s. According to WHO (World Health Organization) GMO can be defined as "Organisms (i.e. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination" (WHO n.d.). This article deals only with genetically modified crops.

The origin of biotechnology goes back to prehistoric times when e.g. fermentation was in use (Chawla, 2004). The first, modern genetic engineering took place in the Rockefeller Institute, New York in 1944 when a group of scientists was able to transform a harmless bacteria into a virulent type by an extracted DNA (Brown & Fedoroff, 2004). Since then many other types of research were carried out, most notably the Chargaff's rules on the structure and composition of the DNA in 1950 (Kresge et al., 2005) or Pauling's and Corey's work on the configuration of DNA from 1951 (Pauling & Corey, 1951). Last but not least, Watson and Crick published their article on the double helix structure of DNA in 1953 (Watson & Crick, 1953). The whole process has been boosted in the '70s by the discovery of restriction enzymes (Chawla, 2004). The first genetically modified organism, a transgenic mouse was made in 1980, while the first US production permission was given in 1994 to a delayed-ripening tomato called Flavr Savr (Zhang et al., 2016). Since that time the GMO progress has been speeded up, especially in last 10-15 years.

2. MATERIALS AND METHODS

The article is based mostly on scientific literature in order to give comprehensive and dispassionate picture on a very controversial topic. Majority of the data used are from different ISAAA (International Service for the Acquisition of Agri-biotech Applications) publications. As the major focus of the article is economic, results are taken from comparative studies as much as it was possible.

Major research questions are the followings:

- Why do we need GMO?
- What are the major benefits and drawbacks of GMO?
- Is the process reversible?
- Are there any other solutions to the same problems?

3. GMO GENERATIONS

Based on appearance and utilization, transgenic crops can be divided into different groups and generations. DaSilva (2004) gave a comprehensive summary of the different colours used for different biotech activities.

Colour type	Area of the biotech activities
Red	Health, Medical, Diagnostics
Yellow	Food Biotechnology, Nutrition Science
Blue	Aquaculture, Coastal and Marine Biotech
Green	Agricultural, Environmental Biotechnology – Biofuels, Biofertilizers, Bioremediation, Geomicrobiology
Brown	Arid Zone and Desert Biotechnology
Dark	Bioterrorism, Biowarfare, Biocrimes, Anticrop warfare
Purple	Patents, Publications, Inventions, IPRs
White	Gene-based Bioindustries
Gold	Bioinformatics, Nanobiotechnology
Grey	Classical Fermentation and Bioprocess Technology

Table 1. Colours of the biotech areas

Source: DaSilva, 2004, p. 2.

This study concentrates only on the green, agricultural GMO. Transgenic crops were initially developed in order to meet farmers' needs, namely to help them against pests, weeds, to get resistant crops which do not require significant pest control. The first GMO generation was dedicated to increased biotic resistance in order to develop crops resistant to different pests (Bt) or to herbicides (HT). Bt got his name after *Bacillus thuringiensis* bacteria which is inserted into the DNA structure of the crop. Therefore e.g. Bt maize is artificially resistant to the European corn borer. Its weapon is the Bt toxin gene which allows the crop to produce Bt toxin poisonous to the larva of the European corn borer. HT stands for Herbicide Tolerance, this trait allows crops to survive herbicide treatment that would be lethal normally. The most common type is glyphosate-resistant, almost 90% of all transgenic crops grown worldwide fall into this category (Duke & Powles, 2008).

The second generation GMO is an improved version of the first generation. These crops are not only even more resistant but also their nutrition values are higher. Good examples are amylose-free potato

for industrial purposes, golden rice enriched with beta-carotene, the precursor of vitamin A or genetic engineering to delay ripening to enable products for sea transport.

The major characteristic of the third generation organisms is to be able to deal with extreme weather and regional conditions, e.g. salt and drought tolerance. Global warming is a real challenge and these innovations may answer it.

Last but not least, fourth generation crops are able to produce vaccines, active ingredients, basically medicines. These crops can be used only for industrial purposes, like anti-hepatitis B vaccina-producing banana and potato (Pepó et al., 2011). Generations are summarized in table 2.

Generations	Purpose of engineering	Example(s)
1	Higher resistance to pests, diseases, weeds or herbicides/pesticides, lower costs of pest control	Bt maize (MON810), HT soybean (Roundup Ready)
2	Higher resistance, improved nutrient profile	Golden rice (Vitamin A), Amflora GM potato (amylose-free)
3	Higher tolerance to extreme regional or weather conditions (better adaptability)	Drought tolerant maize
4	Production of pharmaceutical agents or vaccine (pharmaceutical industry)	Anti-hepatitis B vaccina-producing banana and potato

Table 2. The GMO generations

Source: Author's composition

However, it is an important question of why we need GMO. The three major challenges that call out for a solution are (Zhang et al., 2016):

1. Expansion of population along with malnutrition and hunger
2. Available arable land per person for food production is decreasing which underlines the above-mentioned problems. Higher yields can be reached by greater use of inputs.
3. Conventional and modern breeding technologies are time-consuming and trials/results are based on luck.

GMO is one answer, but there are many others starting from more efficient raw material and food management to precision farming.

4. REGULATION SYSTEMS

Regarding GMO regulation systems, countries can be classified into three major groups. The USA or Canada follow the so-called product-based regulation where the genetic engineered products are equivalent to conventional ones, therefore there are no tracking or labelling requirements. The European Union or Australia stand on the other side where the regulation system is process-based. It means that not only the final product is important but also the way how it was produced. This system is based on precautionary, therefore traceability and labelling have utmost importance. The threshold for the latter one is 0.9%¹ in the European Union. Figure 1 gives a comparative overview of these two regulation systems.

¹ Zero tolerance cannot be maintained because low GMO content can be accidental or technically unavoidable.

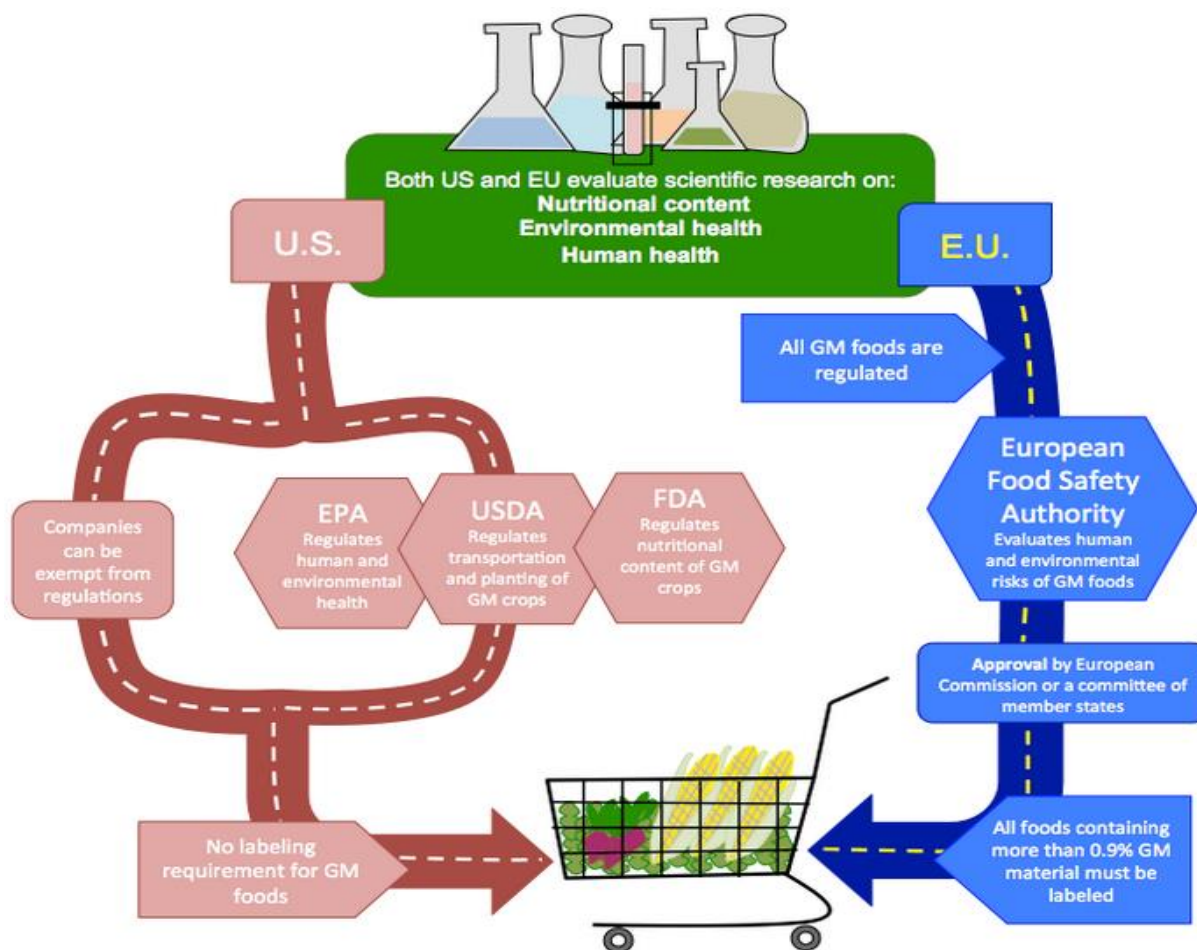


Figure 1. Comparison of the product- and process-based regulation systems

Source: Lau (2015)

The beginning of the process is similar in the US and the EU, it has the scientific basis. Then the next step is straightforward in the EU, all GM foods are regulated and evaluated by the European Food Safety Authority (EFSA). This authority monitors GM products and assesses potential risks (EFSA, 2006). EFSA requires the detailed description of the genetic modification as well as every potential effect of the GMO. Biotechnology is regulated by Directive 98/81/EC on GMO. Finally, all foods containing more than 0.9% GM part must be labelled in order to give proper information to the consumers.

The second step is totally different in the USA as some of the companies are exempt from regulations and their products reach the consumers directly. Otherwise, different aspects of the GM foods are regulated by different bodies. The Environmental Protection Agency (EPA) deals with human and environmental health issues, the United States Department of Agriculture (USDA) regulates transportation and planting of GM crops, while the Food and Drug Administration's (FDA) major responsibility is the nutritional content of GM crops. According to the regulations system, there is no labelling requirement for GM foods in the United States.

Majority of the countries, such as Brazil, Argentina or India, fall into the third category where there are no laws on GMO and regulation system is defective (Szabó, 2015).

It should be highlighted that zero tolerance for transportation cannot be guaranteed because it would be way too costly due to cleaning and disinfection. It is simply not possible to load GMO-free commodities in both directions. The majority of GM crops are bulk products; their transportation is economic only by sea transport but US export is dominated by genetic engineered products. For example, the most significant import product of the European Union is soybean where the share of genetic engineered

soybean is 90-95% (Popp et al., 2016). At this moment, the EU is not self-sufficient and has no real alternative of soybean in animal feeding.

Another interesting issue is coexistence or how to grow genetically modified and conventional crops together including segregation of crops in order to limit fertilization of plants. There are various tools available from isolation distance, buffer zones, pollen traps/barriers, adjusted crop rotation and optimal sowing date, carefully planned crop production cycle or proper cleaning of machinery (EC, 2003).

5. CURRENT GMO SITUATION

The global area of biotech crops is continuously growing since 1996 when they were first used in cultivation. Their size went up to 185.1 million hectares from the initial 1.7 million hectares. There was only a slight, 1% drop in 2015 but followed by 3% growth in 2016. It is demonstrated on figure 2, broken down by country groups.

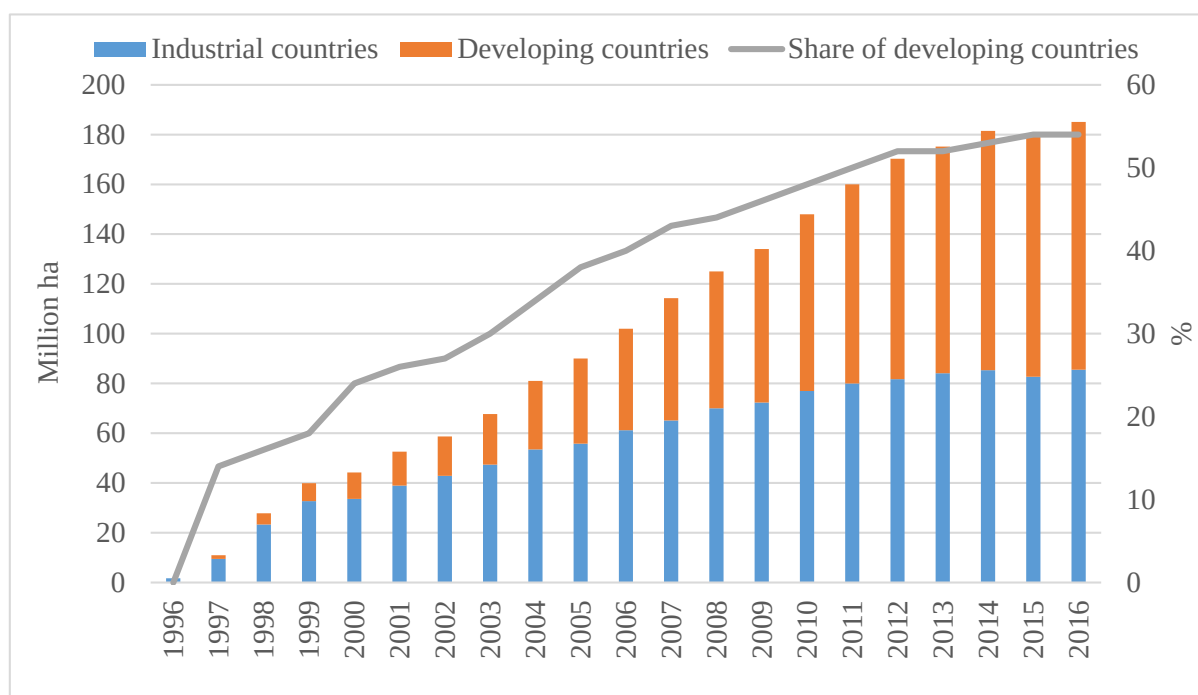


Figure 2. The state of GM crops by country groups, 1996-2016

Source: Author's calculation based on Clive (2016)

It is remarkable that the share of developing countries within the biotech area is higher since 2011. It is represented by the orange parts of the columns and the grey line measured on the the secondary vertical axis.

Taking a deeper look at the country level, GM crops are produced in 28 countries. Table 3 gives an overview of the TOP10 countries.

Country	GM crop area (million ha)	GM crops
USA	72.9	maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash, potato
Brazil	49.1	soybean, maize, cotton
Argentina	23.8	soybean, maize, cotton
Canada	11.6	canola, maize, soybean, sugar beet, alfalfa
India	10.8	cotton
Paraguay	3.6	soybean, maize, cotton
Pakistan	2.9	cotton
China	2.8	cotton, papaya, poplar
South Africa	2.7	maize, soybean, cotton
Uruguay	1.3	soybean, maize

Table 3. The TOP10 GM crop producers, 2016

Source: Author's composition based on Clive, 2016

As it can be seen from table 3, the USA is the leading GM crop producer by 72.9 million ha. The widest range of GM crops are produced, there are nine different ones. In the other countries generally three or less GM crops are produced. The USA is followed by Brazil and Argentina, where GM crop varieties are the same. In India and Pakistan, only genetic engineered cotton is produced. The most frequent GM crop is maize, it is produced in 17 countries. The first European country on the list of biotech crop countries is Spain with 0.1 million ha maize.

The biotech area can be analysed by crops and table 4 gives an overview of it. The share within GM crops is the area of the given GM crop divided by the total GM crop area (185.1 million ha). GM adoption rate is the area of the given GM crop divided by the total area of the given crop (GM and conventional).

Type of GM crop	Global GM area	The share within GM crops	GM adoption rate
Soybean	91.4 million ha	49%	78%
Maize	60.6 million ha	33%	33%
Cotton	22.3 million ha	12%	64%
Canola	8.6 million ha	5%	24%

Table 4. Significance of GM crops, 2016

Source: Author's composition based on Clive, 2016

As it can be seen from table 4, soybean is the leading GM crop by 91.4 million hectares (49% of total biotech area), followed by maize (33%), cotton (12%) and canola (5%). These four crops give 99% of the total biotech area. Regarding GM adoption rates, it is the highest for soybean (78%), cotton comes second by 64%, while one-third of maize and one-fourth of canola are genetically modified. As a matter of irreversibility, it is a real question for cotton and especially for soybean where the GM adoption rate is the highest. Although it should be noted that, contrary to the latter one, the first one cannot be used for human or animal consumption.

As a matter of the type of the genetic engineering, herbicide tolerance is the most common. It occupies almost half of the global biotech area (86.5 million ha out of 185.1 million ha), although its size has decreased by 16 million ha compared to the peak value in 2014. HT is followed by stacked traits

(HT+Bt), its share shows a dynamic increase since 2002. Its value was 75.4 million ha in 2016. Excluding virus resistant and other traits, the share of Bt is the smallest among the traits. Although it was the most important type in the beginning, its share is decreasing since 2013. Bt type GM crops were used on 23.1 million ha in 2016. It is summarized in figure 3.

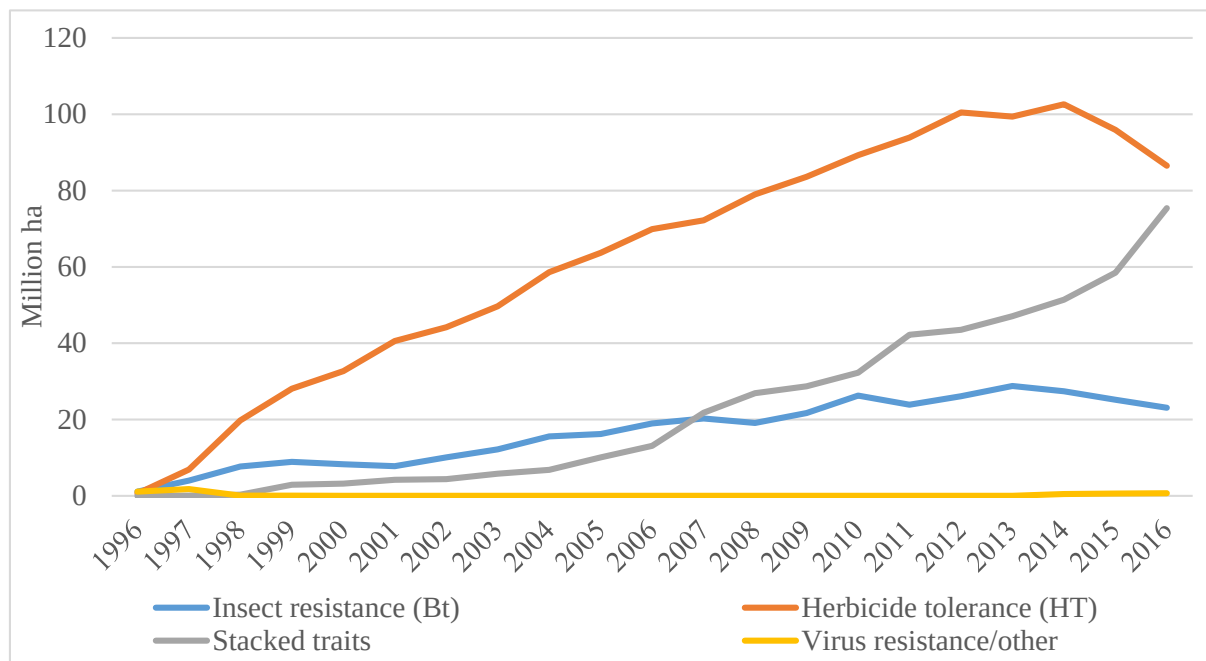


Figure 3. GM crops by trait, 1996-2016

Source: Author's composition based on ISAAA Global Status of Commercialized Biotech/GM Crops 1996-2016

6. EFFECTS OF GMO

An overall study carried out by the United States National Academies of Sciences underlined that the use of genetic engineering has beneficial economic effects, however, they depend on the number and type of pests, production technologies and agricultural infrastructure. Crops with inserted Bt toxin gene result in lower herbicide use and pest density. The latter one is favourable for the conventional agriculture as well. On the other hand, the study emphasizes that excessive use of the technology may lead to resistance. One of its sign is the so-called GMO superbug. Gassmann and his fellows have found Bt maize resistant American corn borer in four plots in Iowa state and attracted farmers' attention to the more integrated use of the GMO technology (Gassmann et al., 2011). But it should be mentioned that GM maize was seeded in the same plot in three successive years.

Klümper and Qaim made keyword searches in ISI Web of Knowledge, Google Scholar, EconLit, and AgEcon Search and compared the results of 147 scientific articles (Klümper & Qaim, 2014). Based on this dataset they have concluded that the use of GMO results in 37% less herbicide use and 22% more yields. Altogether it makes farmers' profit higher by 68%. As a matter of traits, positive effects are higher in case of pest-resistant crops compared to herbicide tolerant ones. Regarding country groups, the growth of yields and profit is much higher in the developing countries. It is connected to the fact that yields are already at a very high level in the industrial countries due to the advanced agricultural technology and its small increase can have only a small impact on profit.

Based on Brookes and Barfoot's calculations, use of GM technology resulted in 150.3 billion US dollar extra income between 1996 and 2014 and this amount was 17.7 billion USD only in 2014 (Brookes & Barfoot, 2016). The share of the three major GM crops (sequentially HT soybean – 46.6 billion USD,

pest-resistant cotton – 44.8 billion USD and Bt maize – 41.4 billion USD) was 88% out of it. On the country level extra income is cardinally in line with the production of GM crops, USA (65.8 billion USD, mostly maize and soybean) is followed by Argentina (19.3 billion USD, basically soybean) and Brazil (13.8 billion USD, mostly soybean and maize). Beside extra income, the lower production cost is also important and it was 7 billion USD less only in 2014. In quantity, it meant 581.4 million tonnes less herbicide use between 1996 and 2014.² They have recalculated these economic benefits and it amounted to 186.1 billion USD for 1996-2016 and 18.2 billion in 2016 (Brookes & Barfoot, 2018). According to their results, an extra dollar invested into GM seeds resulted an average five dollar plus revenue in the developing countries.

However, it should be noted that GMO-free crops enjoy significant price premium on the international commodity markets. Let's take soybean as an example. According to the FAO database, major exporting countries are the USA, Brazil and Argentina and they produce almost entirely genetic engineered soybean. The European Union is not self-sufficient in soybean, so it should be imported because it is the best source of protein in the livestock sector. Importing from the major exporting countries means import of GM crop. Of course, GMO-free soybean is also available, but its price was 40-120 euro/t higher in some of the EU member states between 2005 and 2015 (Popp et al., 2016). Practically it meant a 10% price premium, but in some countries (e.g. Austria or the United Kingdom) it has exceeded 30% in 2015 (Tillie & Rodríguez-Cerezo, 2015).

The major advantage of the GM crops is higher yield. In case of first generation crops, its major reason is the lower pests-resulted loss. However, it should be kept in mind that there are huge losses in the production or food chain part. According to Oerke, pests caused global potential loss is about 26-40%, lower for wheat and soybean, higher for maize and rice (Oerke, 2006). Overall it results in 35% pre-harvest loss on an average. Although pesticide use increased significantly in the last 40 years, crop losses remained more or less on the same level. Besides these potential losses, similar quantity arises in the food chain. It is summarized in table 5.

Stages of the food chain	Reasons of losses	Size of the loss (%)
Field losses	Pests, diseases, rodents, etc.	20–40
Preprocessing	Drying, milling, etc.	in quantity: 10–15 in value: 25–50
Transportation	Spillage, leakage, etc.	
Storage	Technical deficiencies, etc.	
Processing and packaging	Excessive peeling, washing, etc.	developing countries: 2–20 rich countries: 5–30
Marketing	Insufficient logistics	
„Plate loss”	Retailers and consumers	

Table 5. Losses in the food chain

Source: Molden ed. (2007)

The process starts at the producer level and ends at the consumer level. By using more efficient distribution technics and methods, most of the losses in table 5 would be avoided and the world would be fed without e.g. using less fertile soils for production or even without genetic engineering. It is important to underline that developing countries face higher losses in the first part of the food chain, mostly during harvest, transport and storage. In contrast with it, rich countries face with much higher losses in the last part of the food chain, especially plate loss is high when consumers throw away some of the raw materials or processed food.

² Although it is another question what happens to those herbicides what the pest-resistant crop has produced and stored within its leaves.

Apart from the reduction of losses and waste in the food chain, precision farming is another tool which allows to reach higher yields and less herbicide use, therefore higher profit. This technology is based on the conventional agriculture but uses the modern technology (machinery, GPS systems, automated seeding or harvest, etc.). Fertilizer use is adjusted to the need of the soil, seed density is automatically regulated, herbicide use is also differentiated. All of these elements point to less input use and higher yields, so higher farmers' profit.

At the same time, judgement of GM food as food aid is also controversial. Malawi, Mozambique, Zambia and Zimbabwe refused American GM food in 2002 by the following reasons (Zerbe, 2004):

- potential negative health impact of GM food;
- potential negative impact of GM food on the domestic agricultural biodiversity;
- potential negative impact of GM food on their future export abilities because the major export market of the African countries is the EU.

Finally, a SWOT analysis gives a summary of the above-mentioned pros and cons in table 6.

Strengths	Weaknesses
– higher yields, lower production cost – higher profit – less herbicide use – more tolerant crops – higher nutrition value – delayed ripening – easier transportation	– lack of independent researches – no accurate measurement of GMO content – labelling issues – moral problems – coexistence/contamination – extra logistics cost
Opportunities	Threats
– vaccine or medicine production – a possible solution to malnutrition and hunger – individually „tailored”, perfect crops – easier substitution of crops	– possible negative long-term effects on the human body – cross-pollination of organic and conventional crops or transit countries – up to one point, it may become irreversible – possible allergic reactions – GMO superbug

Table 6. SWOT analysis of GMO

Source: Author's composition

7. CONCLUSIONS

GMO is not only controversial but also a very complex topic, therefore the initial question cannot be answered simply by one single word, either blessing or curse. The GM crops provide an answer to many challenges (global food security, malnutrition and hunger, better adaptation to extreme weather conditions) and by the use of genetic engineering higher yields and lower production cost is available. The latter ones result in higher profit, especially in the developing countries. These advantages can be quantified, it amounted to 186.1 billion USD between 1996 and 2016. By using less herbicides, this production method could be more environmentally friendly. However, on the other hand, this technology raises many questions and concerns, like the lack of independent researches, coexistence/cross-pollination, problems with the measurement of GMO-content as the significant part of animal feed is already genetically modified. Proper labelling points toward to it, as its major aim is to provide reliable information to the consumers. Consumers should be well informed in order to be able to make adequate choices.

As a matter of irreversibility, it should be distinguished between crops whether they are used in human or animal feeding or only for industrial purposes. Soybean has the highest GM adoption rate (78%) and this raw material is globally used for both human and animal feeding. The major exporters are the USA, Brazil and Argentina, therefore 90-95% of total export is genetically modified. There is a special market for non-GM soybean but its price premium is so high that the majority of the producers simply cannot afford it because consumers are not willing to pay the up to 30% extra price for the final product. Therefore better-informed consumers are even more important.

It should be aware of the fact that mankind has other tools or options to deal with the above-mentioned global problems. Higher yields and less herbicide use are the major characteristics of the precision farming technologies which are based on the conventional agriculture by using advanced information technologies. Besides, the food chain suffers from huge losses which could be easily reduced by the use of proper technologies (harvesting, transporting, storing, processing, etc.) and by changing people's mentality in the rich countries (food waste, plate loss, etc.).

ACKNOWLEDGMENT

The author gratefully acknowledges the support of the Scientific Committee of the Corvinus University of Budapest.

REFERENCES

1. Brookes, G., & Barfoot, P. 2018, "Farm income and production impacts of using GM crop technology 1996–2016", *GM crops & food*, DOI: 10.1080/21645698.2018.1464866
2. Brookes, G. & Barfoot, P. 2016, "GM crops: global socio-economic and environmental impacts 1996–2014", *PG Economics Ltd.*, Dorchester, UK
3. Brown, N. M. & Fedoroff, N. V. 2004, "Mendel in the kitchen: a scientist's view of genetically modified foods", *Joseph Henry Press*, Washington, D.C., USA
4. Chawla, H. S. 2004, "Introduction to plant biotechnology", *Science Publisher Inc.*, Enfield, New Hampshire, USA
5. Clive, J. 2016, "Global Status of Commercialized Biotech/GM Crops: 2016", *ISAAA Brief 52*, Ithaca, NY, USA
6. DaSilva, E. J. 2004, "The colours of biotechnology: science, development and humankind. *Electronic Journal of Biotechnology*", vol. 7, no. 3, pp. 1-2.
7. Duke, S. O. & Powles, S. B. 2008, "Glyphosate: a once-in-a-century herbicide. *Pest management science*", vol. 64, no. 4, pp. 319-325.
8. EC 2003, "Commission recommendation on guidelines for the development of national strategies and best practices to ensure the co-existence of genetically modified crops with conventional and organic farming", *European Commission*, C(2003), Brussels
9. EFSA 2006, "Guidance document of the scientific panel on genetically modified organisms for the risk assessment of genetically modified plants and derived food and feed", *European Food Safety Authority*, EFSA-Q-2003-005, 105. p.
10. Gassmann, A. J., Petzold-Maxwell, J. L., Keweshan, R. S. & Dunbar, M. W. 2011, "Field-evolved resistance to Bt maize by western corn rootworm", *PloS one*, vol. 6, no. 7, e22629
11. Klümper, W. & Qaim, M. 2014, "A meta-analysis of the impacts of genetically modified crops", *PloS one*, vol. 9, no. 11, e111629
12. Kresge, N., Simoni, R. D. & Hill, R. L. 2005, "Chargaff's Rules: the Work of Erwin Chargaff", *Journal of Biological Chemistry*, vol. 280, no. 24, pp 21.

13. Lau, J. 2015, "Same Science, Different Policies: Regulating Genetically Modified Foods in the U.S. and Europe", Science in the News, Harvard University, Cambridge, USA
14. Molden, D. ed. 2007, "Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture", Earthscan, London and International Water Management Institute, London, UK
15. NAS 2017, "Genetically Engineered Crops: Experiences and Prospects", National Academies of Sciences, Engineering, and Medicine, National Academies Press
16. Oerke, E. C. 2006, "Crop losses to pests", The Journal of Agricultural Science, vol. 144, no. 1, pp. 31–43.
17. Pauling, L. & Corey, R. B. 1951, "The structure of synthetic polypeptides", Proceedings of the National Academy of Sciences, vol. 37, no. 5, pp. 241–250.
18. Pepó, P., Kovácsné Oskolás, H., Tikász, G., Szabó, E. & Tóth, Sz. 2011, "Növénygenetikai és nemesítési kutatások a génmódosítás tükrében", Debreceni Szemle, vol. 19, no. 4, pp. 415–420.
19. Popp, J., Oláh, J., Harangi-Rákos, M. & Fári, M. 2016, "A fehérjetakarmány helyettesítése alternatív fehérjeforrásokkal az EU-ban", Gazdálkodás, vol. 60, no. 6, pp. 506–531.
20. Szabó, A. 2015, "A genetikailag módosított szervezetek szabályozásának kérdései az EU egyes tagállamaiban", Képviselői Információs Szolgálat, Budapest
21. Tillie, P. & Rodríguez-Cerezo, E. 2015, "Markets for non-Genetically Modified, Identity-Preserved soybean in the EU", JRC Science and Policy Reports, no 72.
22. Watson, J. D. & Crick, F. H. 1953, "The structure of DNA", Cold Spring Harbor symposia on quantitative biology, vol. 18, pp. 123–131., Cold Spring Harbor Laboratory Press, New York, USA
23. Zhang, C., Wohlueter, R. & Zhang, H. 2016, "Genetically modified foods: A critical review of their promise and problems", Food Science and Human Wellness, vol. 5, no. 3, pp. 116–123.
24. Zerbe, N. 2004, "Feeding the famine? American food aid and the GMO debate in Southern Africa", Food Policy, vol. 29, no. 6, pp. 593–608.
25. WHO n.d., *What are genetically modified (GM) organisms and GM foods?*, viewed 3 July 2018, <http://www.who.int/foodsafety/areas_work/food-technology/faq-genetically-modified-food/en/?utm_source=rss&utm_medium=rss>