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Moral assessment of the use of genetic engineering for the production of GM crop plants used in agriculture

Introduction

After the domestication of plants and the invention of agriculture, that is from 12,000 to 10,000 years ago, man began to strive to obtain the desired characteristics of organisms that are components of his diet. To this end, he acquired the ability to control the reproductive process, which allowed him to select offspring and choose the one that better meets his needs[1]. However, the process itself was tedious and time-consuming, and to speed it up, scientists in the 20th century began to develop genetic engineering.

The term genetic engineering was introduced in the 1970s. The work of two American scientists, H. Boyer and S. Cohen, contributed to the creation of this technique. In the years 1972–1973 Boyer and Cohen transferred DNA fragments from one bacterium to another in such a way that the foreign DNA would be able to replicate naturally[2]. The use of genetic engineering in agriculture became possible, in turn, thanks to the works carried out, in the years 1947–1980, by M. van Montagu and J. Shell from Belgium, M.-D. Chilton from the United States, and R. Schilperoort from the Netherlands. They discovered a natural mechanism for the transfer of a DNA fragment from bacteria to plants. Thanks to this, in 1983, M. van Montagu and J. Shell created the first artificial transgenic plants[3]. In this article, following D. Bodin, the author has adopted the following understanding of this technique: "genetic engineering, broadly

1 N. Brown, *Plant Domestication*, 2015, http://plantbreeding.coe.uga.edu/index.php?title=2.History_of_Plant_Breeding, accessed 30 Oct 2021.

2 Science History Institute, *Herbert W. Boyer and Stanley N. Cohen*, https://www.sciencehistory.org/historical-profile/herbert-w-boyer-and-stanley-n-cohen, accessed 30 Oct 2021.

3 W. Grunewald, J. Bury, D. Inzé, Thirty years of transgenic plants. *Nature*, 2013, 497, p. 40, https://doi.org/10.1038/497040a.

defined, means that you are taking pieces of DNA and combining them with other pieces of DNA"[4].

The initial aim of this theoretical article is to present selected, some of the first large-scale produced types of genetically modified crops, that is: *Flavr Savr* tomato, herbicide- and pest-resistant plants, and *Golden Rice*. Describing GM plants is a prerequisite for a reliable moral assessment of the activities that were necessary to produce them. The main goal, therefore, is a moral reflection on the use of genetic engineering to produce transgenic plants, considering the economic and social context. The author's choice of these four GM crops was firstly dictated by the fact that, because of their introduction to the market, GMOs appeared in the public space and thus materialized in human consciousness. Second, the possibilities of acquiring and consuming them were initially accompanied by great controversy and ethical dilemmas. For example, in the year 2005, Europeans raised objections to the production of GMOs more often than in the year 2019. Although there are many artificial techniques by which changes are made in the genetic material of organisms, such as grafting, hybridization, somaclonal variation, or induced mutagenesis, it is genetic engineering that causes the greatest social concerns and moral dilemmas[5].

To resolve moral dilemmas, two ethical theories were used: utilitarianism and deontologism. The author's choice of these approaches was arbitrary and resulted from the fact that they take into account those aspects of the process that influence the choice of certain actions. In the case of utilitarianism, these are the consequences of the actions, and in deontologism – the motivations to undertake the process and its object, that is, what it aims at by its very nature. The choice of ethical theories, as well as the topic itself, encourages the formulation of the following three research problems: How is the production of selected crops by means of genetic engineering assessed in utilitarianism? How, according to the assumptions of deontology, is the production of the described GM plants judged? Do the assessments of the two approaches differ, and if so, for what activities?

Among the few scientists who carried out to similar research, one can distinguish D. Gregorowius (2012), who, together with his colleagues investigates whether the production of GMOs is morally acceptable and whether such organisms have a negative impact on the environment.

4 National Human Genome, Research Institite, Bodine D, https://www.genome.gov/genetics-glossary/Genetic-Engineering, accessed 30 Oct 2021.

5 European Food Safety Authority, Special Eurobarometer Wave EB91.3, *Report: Food Safety in the EU*, 2019, https://www.efsa.europa.eu/sites.default/files/corporate_publications/files/Eurobarometer2019_Food-safety-in-the-EU_Full-report.pdf, accessed 30 Oct 2021.

Similarly, K.N. Ajoykumar (2021), together with his team members, presents the moral reflection of the gene transfer as well as the influence of GM plants on biodiversity. Another scientist, A. Weale (2010), in addition to the two above-mentioned aspects, analyzes the way GM plants influence human health and traditional agricultural practices. He also studies the monopolistic practices of corporations trading in GM plants and, finally, explores the essence of the "unnatural" nature of genetic engineering itself. Then, Z. Robaey (2015) deals with the issue of moral responsibility in the context of the distribution of GM seeds. A. Ricroch (2018), and colleagues, study the effects of growing transgenic plants in developed and developing countries, using various ethical theories. In the context of the above-mentioned works, this article is closely linked to and complements the topics related to GMOs undertaken by other scientists.

The assessment issued by competent experts or scientific institutions is very important as it often determines the future of a given technology, whether it will be supported and developed, banned, or strictly controlled. Thus, such a moral judgement influences the decisions of individual people, including politicians, interest groups, e.g., farmers, and entire societies.

Genetic engineering as a technological process

Following the invention of genetic engineering, the barriers that prevented the crossing of organisms belonging to different species disappeared. The most common type of genetic modification requires the following two steps: identifying and isolating the gene encoding the polypeptide of interest to the researcher, and transferring and inserting a copy of this DNA fragment into the recipient genome[6]. The first stage became easier when advanced gene identification methods were invented, such as: genome sequencing, screenings[7] and reverse genetics, which includes: virus-induced gene silencing (VIGS), RNA-mediated interference (RNAi), insertional mutagenesis, fast-neutron mutagenesis, chemical mutagenesis and TILLING, as well as sequence candidate amplicons in multiple

6 A. Sudarić, M. Vratarić, S. Mladenović-Drinić Z. Zdunić Genetic improvement: Molecular Based Strategies. *Soybean – Molecular Aspects of Breeding*, Publisher InTech, 2011 https://cdn.intechopen.com/pdfs/14930/InTech-Genetic_improvement_molecular_based_strategies.pdf.

7 Merck https://www.sigmaaldrich.com/PL/pl/applications/genomics, accessed 2 Nov 2021.

parallel reactions (SCAMPR)[8]. As a result of the second stage, the final product is created in the form of a genetically modified organism. In the biotechnology industry, among the most important methods of genetic engineering allowing for plant modification are the following:

• "Gene-editing techniques – 're-write' parts of the genome by deleting, substituting, or adding DNA sequences in predefined locations:

– zinc finger nucleases (ZFN), TALENs, CRISPR/Cas, meganucleases,

– oligonucleotide-directed mutagenesis (ODM).

• Cisgenesis and intragenesis – insert DNA sequences derived from the same or a crossable species.

• RNA-dependent DNA methylation (RdDM) – silence specific genes in a way that will usually disappear after several generations.

• Agro-infiltration ("sensu stricto", agro-inoculation, floral dip) – deliver genetic material to a plant transiently, for a maximum of one generation.

• Reverse breeding – silence genes in charge of genetic recombination in the sexual reproduction process (as one step in the overall process).

• Grafting – combine a non-GMO scion with a GMO rootstock (or vice versa)."[9]

"Synthetic genomics – the engineering of biological components and systems that do not exist in nature and the re-engineering of existing biological elements."[10]

Characteristics of utilitarianism

Two ethical theories – utilitarianism and deontoligism have been used to make a moral assessment of activities leading to the production of genetically modified organisms. The term "utilitarianism" (Latin *utilis* – useful) was popularized by J.S. Mill. In a broad sense, utilitarianism refers to the moral position that an activity is right or wrong depending on the consequences it will have. In a narrower sense, in turn, utilitarianism is equated with the views according to which happiness is the only good thing in itself, constituting the goal of not only individual activities,

8 E. Gilchrist, G. Haughn, Reverse genetics techniques: engineering loss and gain of gene function in plants. *Briefings in Functional Genomics*, 2010, vol. 9, iss. 2, pp. 103–110, https://doi.org/10.1093/bfgp/elp059, accessed 2 Nov 2021.

9 https://corporateeurope.org/sites/default/files/attachments/joint_position_new_techniques_of_genetic_engineering_february_2017.pdf, accessed 2 Nov 2021

10 M. Lusser, C. Parisi, D. Plan, E. Rodrigues-Cerezo New plant breeding techniques. State-of-the-art and prospects for commercial development Reference Report, 2011 pp. 18-22, European Commission, http://dx.doi.org/10.2791/60346.

but also those carried out by social institutions[11]. In this case, utilitarianism is an ethical theory that promotes "as much happiness [common good] as possible for as many people as possible."[12] One of the leading representatives of G.E. Moore claimed that all human actions – considering the proportion between the sum of pleasure and suffering they cause – could be placed on a scale that is a kind of continuum. Balancing good and bad caused by an act requires taking into account all its effects: short-term and long-term, direct and indirect, as well as concerning other species, not only humans. Thus, human actions cause good and evil of varying sizes[13]. Under utilitarianism, an action is right when the acting person could not, instead, perform any other action that would give more pleasure than the action he or she has taken. On the other hand, an action is unfair when the acting person could perform some other action that would give more pleasure than the action taken by him or her. An action is considered right when it causes at least as much pleasure as any other action that might be taken in return[14].

On the grounds of one of the versions of utilitarianism, the issue of the fair distribution of economic goods is also raised. People are constantly distributing goods. What is subject to division is not general welfare, but the material medium that defines it, e.g. money. Utilitarians do not regard wealth equality as a value in itself, i.e., if it increases with an extremely unequal distribution, then they favour inequality. In other words, in utilitarianism, equality is subordinated to the magnitude of welfare and is sacrificed in return for even the slightest increase in wealth. The utilitarian theory recommends "to divide according to such rules, the common conscientious respecting of which will maximize the total expected utility."[15]

Characteristics of deontologism

Deontological ethics (Greek *deon* – duty, responsibility and *logos* – science) is a concept according to which human activities are right or wrong in themselves, regardless of their consequences. Deontology is based on the premise that, no matter how much a person tries to act right, the

11 G. Varner, Utilitarianism and the Evolution of Ecological Ethics. *Science and Engineering Ethics* 2008, 14(4), pp. 551-573, DOI: 10.1007/s11948-008-9102-5.

12 F. Hutcheson, *An Inquiry Into the Original of Our Ideas of Beauty and Virtue* 1729, p. 180.

13 G.E. Moore, *Ethics*, Humphrey Milford, 1945, London, New York, Toronto, Oxford University Press.

14 Ibidem.

15 Ibidem, p. 55.

effects of his or her actions are influenced by circumstances beyond human control; therefore, only the motive of an act may be good or bad, not the result. In deontologism, the main sources of morality are, therefore, motivations appearing in the philosophy of Immanuel Kant and the very object of actions, which appears in the approach of W.D. Ross[16].

In Immanuel Kant's conception, the starting point was the ascription of absolute moral value to the factor called "goodwill", which is the motive of behaviour. According to Kant, only good will determines the moral value of an action. The will is a "tool" that defines what the mind knows as good. What is good, in turn, is that what stimulates the will with reason that is, objectively, i.e. based on principles that are important to all rational beings[17].

Understanding the concept of good will falls under the category of duty – it is the willingness to fulfill it. In the classification of human acts, Immanuel Kant distinguished three kinds: acts contradictory to duty; acts consistent with it, which a person performs because a certain tendency (e.g. a feeling) drives him or her to act; and actions born out of duty, that is out of the sense of obligation. Acts "consistent with duty" and "out of duty" are – in terms of physical actions – identical, but their motivation differs. Behaviour determined by the sense of duty – and only such behaviour – was, in Immanuel Kant's belief, an area of moral good[18].

Another representative of deontologial ethics was W.D. Ross for whom, unlike for Kant, the criterion of moral evaluation was the nature of the acts themselves. Even though he also considered as right actions taken out of a sense of duty[19], he was looking for the very existence of duty in direct and spontaneous common intuitions. This is how W.D. Ross justified deeds recognized as ethical duties: "the fact that we have made a promise is in itself sufficient to create a duty of keeping it, the sense of duty resting on remembrance of the past promise (...)".[20] He argued that the righteousness of actions is related to the directly tangible object of the actions themselves, independent of the values embedded in their motivations or consequences. According to W.D. Ross, the object of actions which does not require justification alone constitutes the general nature of what is just and valid.

Developing his approach, W.D. Ross began to argue for the moral judgement to what precedes the act. In his opinion, the space between the motive and the act is filled with psychological phenomena of two

16 D. McNaughton, P. Rawling, *On Defending Deontology*, Oxford 1998.

17 I. Kant, *Uzasadnienie metafizyki moralności*, przeł. M. Wartenberg, przekł. przejrzał R. Ingarden, Warszawa 1984.

18 Ibidem.

19 D. McNaughton, P. Rawling, *On Defending Deontology*, Oxford 1998.

20 W.D. Ross, *The Right and the Good*, Oxford 1930, p. 37.

kinds: decisions (resolutions, choices) and efforts. Together with the motives, they formed the element of actions subject to moral qualifications. In W.D. Ross's thought, the scope of ethical obligations shifted therefore from acts in the physical sense to the activities of the mind. Ethical obligation, then, grew out two premises: an opinion about facts, and a moral conviction about what should be undertaken in light of this opinion. According to W.D. Ross, the ideal type of endeavour was one that consisted of accurate moral intuitions and opinions corresponding to an objective situation[21].

Moral evaluation of the use of genetic engineering to create the *Flavr Savr* tomato

The development of technology allows for a more and more effective control over, among others, cultivated plants like, for example, the tomato. Present-day tomatoes are, however, often considered tasteless and not very "fleshy". The main reason for this is picking the tomatoes before they are ripe, which allows them to be transported without risking damage. This has created the desire to grow harvestable tomatoes that are ripe and taste better but are, at the same time, harder. In 1994, a genetically modified tomato with these properties appeared on the market for the first time in the United States. A variety called *Flavr Savr* was developed by scientists at the biotechnology company Calgene. They isolated the polygalacturonase (PG) gene, which is responsible for the synthesis of the tomato softening enzyme, and then reinserted it into the DNA of the fruit cell in the antisense orientation. The modification consisted in reducing the enzyme activity to the level of 1%. Naturally, the enzyme is synthesized in the ripening tomato. As a result of its action, substances that bind tomato cells are broken down[22].

However, the use of genetic engineering to create the *Flavr Savr* tomato did not break down barriers between species. Even though the created fruit was genetically modified, as it contained a new piece of DNA that had been inserted into it – it was a gene complementary to the gene responsible for the synthesis of the PG enzyme. It was an artificial gene, synthesized in the laboratory in such a way as to inhibit the action of one of the natural genes of this tomato variety, and not of another species[23].

21 Ibidem.

22 M.G. Kramer, K. Redenbaugh, Commercialization of a tomato with an antisense polygalacturonase gene: the Flavr Savr? tomato story. *Euphytica*, 1994, 79(3), pp. 293–297, DOI:10.1007/BF00022530.

23 Ibidem.

The most important effect of modifying the tomato was to be a fruit that stayed firm for about 10 days longer than their traditional counterparts. It was precisely such a change that producers and consumers wanted. However, with the creation of the transgenic tomato, The Advisory Committee on Novel Foods and Processes indicated a risk of negative health consequences of its consumption. It was related to the fact that the so-called marker gene was used when introducing the antisense gene. The marker gene is used to select plants which contain the transgene and those without it, but it is also responsible for the production of proteins that confer resistance to the Kanamycin antibiotic (the Kanamycin resistance protein). The conducted studies showed, however, that the penetration of the marker gene from the plant into the intestinal bacteria of mammals, including humans, and consequently, the induction of resistance to kanamycin[24], was very unlikely. Likewise, a negligible risk of allergic reactions by consuming the *Flavr Savr* tomato was shown[25].

When making a utilitarian moral evaluation of the use of genetic engineering to produce the *Flavr Savr* tomato, it can be stated that the producer and some consumers benefited from it more than they lost. The company gained publicity by introducing a new product to the market, and the consumers, thanks to the longer shelf life of the fruit, wasted less and thus saved money. But could the production of GM tomatoes benefit more people? It was produced in the United States. Despite initial consumer approval, in 1997, following the acquisition of Calgene by Monsanto, the tomato was withdrawn from the US market[26]. The decision was motivated, among others, by the fact that its production costs were higher than the expected sales revenues. At that time, the profits achieved by the corporations that owned patents on GM plants began to gain more significance than the benefits that consumers could obtain, and which were more difficult to estimate[27].

Other rich countries, in turn, refused to give permission for the cultivation and sale of the *Flavr Savr* tomato. Their position resulted from a lack of knowledge about transgenic plants and concerns about their potential negative effects on human health and the environment. It was the effect of an improperly conducted marketing strategy for this prod-

24 At present, Kanamycin is not used to treat people.

25 ACNFP, https://acnfp.food.gov.uk/sites/default/files/mnt/drupal_data/sources/files/multimedia/pdfs/acnfparmsfactsheet.pdf, accessed 8 Nov 2021

26 M.G. Kramer, K. Redenbaugh, Commercialization of a tomato with an antisense polygalacturonase gene: the Flavr Savr? tomato story. *Euphytica*, 1994, 79(3), pp. 293297, DOI:10.1007/BF00022530.

27 B. Martineau, *First Fruit: The Creation of the Flavr Savr Tomato and the Birth of Biotech Food*, McGraw Hill, 2001 New York, Chicago et al., printed by R.R. Donnelly&-Sons Company.

uct. The tomato itself and its longer shelf life did not encourage poor countries to buy an expensive license to cultivate it. Legal and economic barriers therefore prevented the spread of the *Flavr Savr* tomato production and, as a result, it could not contribute, for example, to limiting the problem of hunger in the world[28]. Given that under the circumstances it was impossible to obtain benefits for a larger number of people, the actions that led to the creation of the *Flavr Savr* tomato should be considered rightful.

The above considerations will now be complemented by a judgement made on the basis of the deontological criterion. In the case of the object of the act itself, that is the creation of an edible plant with improved characteristics for consumptions, the evaluation is not difficult – it was the right thing to do. The matter becomes complicated when determining the motivation of the act. The production and marketing of the transgenic tomato served Calgene and consumers alike. Thus, it can only be considered as an undertaking that is compliant with the obligation, i.e., as motivated by both parties obtaining benefits. It was not, however, a disinterested act – born of duty. Interesting from the deontological point of view was also the withdrawal of the tomato from sale when it ceased to bring expected financial profits. This action was contrary to obligation, as it deprived many consumers of the possibility to choose and to purchase a valuable edible product. Therefore, when assessing the very production of the *Flavr Savr* tomato, taking into account the object and motive of the act, it can at best be regarded as morally neutral.

Moral evaluation of the use of genetic engineering to create herbicide- and pest-resistant plants

Genetic engineering was also used, among others, to create herbicide resistant plants. One such agent was Monsanto's Roundup, active in Glyphosate (N-(phosphonomethyl)glycine). The mechanism of glyphosate is based on blocking the activity of the enzyme EPSPS (5-enolpyruvylshikimate-3-phosphate) which is involved, among others, in the synthesis of aromatic amino acids which leads to the death of the weed. A gene called cp4 epsps, which encoded a protein for this enzyme, was isolated from the cells of the soil microbe *Agrobacterium*, which is highly tolerant to glyphosate[29]. In 1996 this gene was then cloned and introduced

28 Planet Natural Research Center, https://www.planetnatural.com/flavr-savr-tomato/ accessed 8 Nov 2021.

29 L. Harrison, M. Bailey, M. Naylor, J. Ream, B. Hammond, D. Nida, B. Burlette, T. Nickson, T. Mitsky, M. Taylor, R. Fuchs and S. Patgette The Expressed Protein in Gly-

using viral promoters, among others, to soybeans, in which it was expressed. It gave beginning to the first-generation GM herbicide-resistant (HR) plants. The second generation GMHR crops were commercialized in 2009 as Roundup Ready 2 Yield®.[30]

GMHR plants introduced to the US market by Monsanto quickly spread especially in developing countries. Until 2018, they occupied the largest area of any GM crop in the world[31]. The most important economic and environmental benefits brought by the cultivation of GMHR plants includes: more complete protection of crops against weeds, higher yields and greater food supply, less herbicide use[32], thus reducing groundwater and soil pollution and slowing down its erosion, as well as reducing CO2 emissions. The latter two benefits result from the reduction of the work related to the cultivation of the land. On the other hand, concerning the costs of growing GMHR plants, there are economic consequences: monopolistic practices on the seed market, including the need to purchase new, sterile GM seeds each year by farmers, and the violation of their property rights and privacy during controls on the seed use[33]. In turn, among the environmental effects, scientists mention: 34 species of weeds gaining resistance to herbicides, and the risk of a decline in biodiversity as a result of the dissemination of GMHR plant monocultures[34]. Concerning health consequences, it is indicated that glyphosate is a toxic and dangerous substance, the intensity of which depends on the concentration. In 2015, The International Agency for Research on Cancer reported that there was some risk that glyphosate could be carcinogenic to people directly exposed to it. The research is ongoing[35].

Another way to increase yields is by creating varieties that are resistant to insect feeding. One of the most commonly grown grains is

phosate-Tolerant Soybean, 5-Enolypyruvylshikimate-3-Phosphate Synthase from *Agrobacterium* sp. Strain CP4, Is Rapidly Digested In Vitro and Is not Toxic to Acutely Gavaged Mice. *The Journal of Nutrition*, 1996, vol. 126, iss. 3, pp. 728–740, https://doi.org/10.1093/jn/126.3.728.

30 V. Nandula, Herbicide Resistance Traits in Maize and Soybean: Current Status and Future Outlook. *Plants (Basel)*, 2019, 8(9) 337, doi: 10.3390/plants8090337.

31 International Service for the Acquisition of Agribiotech Applications (ISAAA) 2019, https://www.isaaa.org/resources/publications/briefs/55/executivesummary/default.asp, accessed 20 Nov 2021.

32 L. Gianessi Economic impacts of glyposhate – resistant crops. *Pest Managment Science*, 2008 64(4), pp. 346–352, doi: 10.102/ps.1490.

33 CFS, https://www.centerforfoodsafety.org/files/cfsmonsantovsfarmerreport11305.pdf, accessed 20 Nov 2021.

34 K.N. Reddy V.K., Nandula, Herbicide resistant crops: History development and current Technologies. *Indian Journal of Agronomy*, 2012, vol. 57, iss. 1, pp. 1–7.

35 G. Schütte, M. Eckerstorfer, V. Rastelli, W. Reichenbecher, S. Restrepo-Vaselli, M. Ruohonen-Lehto, A.-G. Wuest-Saucy, M. Martens, Herbicide resistance and biodiversity: agronomic and environmental aspects of genetically modified herbicide-resistant plants. *Environmental Sciences Europe*, 2017 29(1): 5, doi: 10.1186/s12302-016-0100-y.

maize; its most serious pest in the USA and in Europe is an insect from the order of butterflies – the moth – the European corn borer. An effective compound used to combat it is Cry toxin – insecticidal crystal protein produced by certain strains of *Bacillus thuringiensis* (Bt) bacteria. Researchers introduced into crops a copy of the gene isolated from the bacteria (cry1Ab, cry1Ac or cry9C) along with a marker gene and a plasmid-promoter responsible for the location and amount of the Cry protein produced. When a small amount of the GM Bt plant is ingested by the European corn borer, the toxin becomes activated in its intestines. As a result of this process, after a few hours, the insect stops feeding, and, after a few days, it dies. GM Bt maize was the first crop created in 1996 by Ciba Seeds and Mycogen Seeds[36]. Advances in genetic engineering saw the arrival of the second generation of GM Bt plants in 2003. It was followed by the third generation of GM plants[37].

Some of the effects of cultivating GMIR crops are analogous to those of cultivating GMHR crops. In addition, there have been concerns that Bt maize pollen is harmful to the larvae of the Monarch butterfly, popular especially in North America. However, research by the US National Academy of Sciences has shown that the concentration of the toxin in pollen is so low that it does not pose a threat to these insects. Cry proteins are also not dangerous to other insects, such as bees or soil organisms, as they are quickly degrade in the soil. The negative impact of Bt plants on human health has also not been demonstrated, as there are no receptors in the human digestive system that would bind the toxin, as in the case of insects. What is worrying, especially among biotech companies, however, is the evidence that a population of insects resistant to the Bt toxin has emerged in Texas[38].

When making a utilitarian moral evaluation of GM herbicide-resistant and insect-resistant plants, it should be mentioned that scientists are already equipping plants with both of these properties at the same time. In 2019, such crops covered an area of 85,1 million ha, i.e. 45% of the total GM crops[39]. The spread of GM crops around the world has brought massive financial gains to biotech companies, farmers and con-

36 K. Ostlie, W. Hutchison, R. Hellmich, *Bt corn and European corn borer*, University of Nebraska – Lincoln, 1997, https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1633&context=entomologyfacpub, accessed 20 Nov 2021.

37 M.S. Tawfik Abbas Genetically engineered (modified) crops (Bacillus Thuringiensis crops) and the Word controversy on their safety. *Egyptian Journal of Biological Pest Control*, 2018 28, 52 doi.org/10.1186/s41938-018-0051-2.

38 Ibidem.

39 ISAAA 2019, https://www.isaaa.org/resources/publications/briefs/55/executivesummary/default.asp, accessed 20 Nov 2021.

sumers also benefited[40]. The results of 147 studies conducted around the world in the years 1996-2014 indicate that farmers growing GMHR and GMIR crops reduced the use of pesticides and herbicides by an average of 37% (and their consumption costs by 39%); their yields increased by 21%, and profits increased by as much as 69%. The cost of more expensive GM seeds (compared to traditional seeds) was compensated by savings from the reduction of the use of plant protection products. They also found that the yields of GM crops were 14% higher in developing than in developed countries. In addition, growth was on average 7% higher for the pest resistant plants than for the herbicide resistant plants[41].

While profits are easily quantified, it is more difficult to estimate the number of losses incurred as a result of the production of GMHR and GMIR crops. The costs include: potential health risk; farmers' dependence on transgenic seeds, despite the increase in the supply of GM food – unfair and unequal access to them, especially in developing countries; or, finally, the threat that GM monocultures pose to native plant species, which are often of great importance not only in environmental, but also in cultural and religious terms[42].

The utilitarian evaluation raises the question of whether the production of GMHR and GMIR crops could benefit more people. Legal and economic reasons made that it was impossible, and therefore, the production of GMHR and GMIR crops should be considered a rightful action.

The utilitarian moral evaluation is complemented by the deontological approach. On the basis of the subject-matter criterion, the actions serving to create and cultivate GMHR and GMIR plants are legitimate in themselves, as they are an expression of the advancement of science used in practice. Greater difficulties appear in the case of determining scientists' motivations. On the one hand, the production of such plants was only a duty-compliant act, as it was motivated by specific benefits and not by a sense of duty under the moral law. On the other hand, the creation of GMHR and GMIR plants was preceded by a process of decisions and efforts which included, inter alia, colloquial intuitions and opinions about facts. One of the important facts is the increasing number of people in the world who are in need of food[43]. In the face of this

40 F. Dizon, S. Costa, C. Rock, A. Harris, C. Husk, J. Mei Genetically Modified (GM) Foods and Ethical Eating, 2016 *Journal of Food Science* vol. 81, iss. 2.

41 W. Klümper, M. Qaim, A Meta-Analysis of the Impacts of Genetically Modified Crops. *Plos One* 2014, 9 (11), Special Collection, Meta Research, https://doi.org/10.1371/journal.pone.0111629.

42 F. Dizon, S. Costa, C. Rock, A. Harris, C. Husk, J. Mei Genetically Modified (GM) Foods and Ethical Eating, 2016 *Journal of Food Science* vol. 81, iss. 2.

43 United States Government, https://www.census.gov/popclock/world, accessed 2 Dec 2021.

situation, common intuitions call for increasing food supply and limiting losses in its production, and these are the goals GM crops serve. It can even be said that their creation constitutes a moral duty of man. Therefore, considering the object and motive of an act, the production of GMHR and GMIR plants can be considered rightful.

Moral evaluation of the use of genetic engineering to create *Golden Rice*

In many African and South Asian countries, hundreds of millions of preschool children and pregnant women are deficient in vitamin A. This vitamin is lacking in a diet consisting mainly of rice, the grains of which do not contain beta-carotene, or provitamin A. For this reason, World Health Organization says, blindness affects between 250,000 and 500,000 children, and as a result of a weakened immune system, half of them die within a year of going blind[44]. One way to solve this problem was to create GM rice which was named *Golden Rice* (GR). The Golden Rice Project was initiated by Gary Toenniessen (Rockefeller Foundation); in the 90s of the twentieth century, the following men were also involved: Ingo Potrykus (Swiss Federal Institute of Technology), Peter Beyer (University of Freiburg in Germany) and Adrian Dubock (Syngenta). Dubock was the architect of public-private partnership and the creator of the Golden Rice Humanitarian Board concept, which was responsible for the free provision of the technology to international and national research organizations in developing countries[45].

A team of researchers used genetic engineering to work on reconstituting the carotenoid pathway in rice grains[46]. The GR prototype accumulating 1.6 μg/g beta-carotene was created in 1999. Further work allowed to create the first generation of *Golden Rice*, (GR1) in which the level of beta-carotene was 6 μg/g. The genetic modification consisted of introducing two genes into rice. One was derived from a daffodil and coded a plant phytoene synthase (psy) with the GGPP precursor (geranyl-pyrophosphate)[47]. The second gene was isolated from the bacterium

44 https://www.who.int/data/nutrition/nlis/info/vitamin-a-deficiency, accessed 5 Dec 2021

45 Golden Rice Project, http://goldenrice.org/Content1-Who/who.php#:~:text=It%20was%20this%20initiative%20that%20brought%20together%20Profs,countries%20requires%20a%20highly%20professional%20and%20interdisciplinary%20team, accessed 5 Dec 2021.

46 GRP, http://www.goldenrice.org/Content1-Who/who2_history.php accessed 5 Dec 2021.

47 S. Amna, Qamar, A.Y. Tantray, S.S. Bashir, A. Zaid, S.H. Wani, Golden Rice: Genetic Engineering, Promises, Present Status and Future Prospects. *Rice Research for Quality*

Pantoea ananatis, it encoded the carotene desaturase (crtI), the bacterial structure of which allowed to create four double bonds. The combined action of the crtI and psy enzymes led to the formation of lycopene in the plant – a red compound from the carotenoid family. In addition to two genes, a rice glutelin promoter was introduced into rice, which allowed for the production of beta-carotene in the seed of the plant. The plant was improved in 2005; thus a second generation of rice (GR 2) was created, which accumulated 31 μg/g beta-carotene[48].

The Philippines was the first Asian country to commercially grow GRs, but only 20 years after its prototype was created. The main reason for this delay were legal barriers. In the case of other developing countries, the problem with the adaptation of GR, apart from the lack of appropriate regulations on cultivation of GM crops, also results from the lack of social acceptance of GM plants, the lack of funds for research and of specialized staff, and the widespread concern about the safety of GM plants[49].

When making a utilitarian assessment of GR, the resulting gains and losses should be compared. Obtaining a rich source of vitamin A was the main effect of its production. Rice grains producing beta-carotene, with regular consumption, allow (especially among children) to reduce the risk of blindness, reduce the susceptibility to various types of infections, and reduce the number of premature deaths. At the same time, no negative health effects of consuming GR have been report. There are also financial benefits, mainly for Filipino farmers who are allowed to sell their GR and earn profits of up to $10,000 a year[50]. After all, Syngenta's free license to cultivate GR was an act of charity to increase the amount of good in the world. It could only be possible in the case of a fair distribution of GR, i.e. one that would contribute to maximizing the total expected utility.

Furthermore, creating, growing, and consuming GR poses potential dangers. One of them is the risk of overabsorption of beta-carotene, which can turn vitamin A into a toxic substance in the human body. Moreover, GR cannot replace a complete, balanced diet, ensure self-sufficiency in developing countries, or solve the problem of world hunger. On the other hand, negative economic consequences include the risk of making farmers from developing countries dependent on GR crops. Fi-

Improvement: Genomics and Genetic Engineering, 2020 pp. 581–604.

48 GRP, http://www.goldenrice.org/Content2-How/how1_sci.php, accessed 5 Dec 2021.

49 GRP, http://www.goldenrice.org/Content1-Who/who2_history.php, accessed 5 Dec 2021.

50 GRP, https://www.goldenrice.org/Content3-Why/why3_FAQ.php#Funding, accessed 8 Dec 2021

nally, GR is also endowed with the insect resistance feature, which can cause environmental risks analogous to those in GMIR plants[51]. Most importantly, however, the basic goal of the GR was not achieved, it did not contribute to reducing the problem of blindness among children from Asian and African countries. It is therefore legitimate to ask the question whether, from the utilitarian point of view, the creation of the GR was the right thing to do. The main barrier to tackling the problem of blindness was and still is the lack of political will and significant opposition in societies to genetic engineering used in agriculture. Given that a genetically modified GR can make the difference between life and death, an unfavourable attitude towards it is morally reprehensible. GR is a cultivated plant, created with the use of genetic engineering, which in agriculture sometimes means methods of cultivating plants and breeding animals contrary to traditional, well-known practices. For this reason, in the public consciousness, GR is often considered a potentially dangerous product[52]. It was not possible, however, to avoid legal and social barriers in the attempt to disseminate the GR around the world. Therefore, benefitting a larger number of people has also been unrealistic and is still very difficult. Thus, according to the utilitarian approach, the creation of the GR should therefore be considered to be a legitimate undertaking as it has brought more positive effects than if it had not been undertaken.

In the case of the deontological evaluation of GR, making a judgement is more straightforward than in the utilitarian approach. The very object of the act, which is the creation of GR has been the right thing to do. Likewise, the motivations of the members of the research team were commendable, as GR was not created with the intention of making profits by a specific biotechnology company, but was intended to serve the inhabitants of poor countries whose diets are poor in vitamin A. The actions that led to the creation of GR were, therefore, undertaken as an obligation, which means they resulted from the moral law, and not from, e.g. the willingness to gain profit. The decision to create the GR was taken, among others, by considering significant facts that show that between 250,000 and 500,000 children worldwide suffer from blindness[53]. In this situation, common intuitions told scientists to fulfill their moral obligation and enrich the plant with beta-carotene, which is the main component of the diet of half of the Earth's inhabitants. According

51 A. Hamza, A. Tariq, M. Ahmad, M. Bilal Anjum, S. Irfan, Golden Rice and its impact on human life, 2018, https://www.researchgate.net/publication/329737805_Golden_Rice_and_its_impact_on_human_life, accessed 8 Dec 2021.

52 GLP, https://geneticliteracyproject.org/2018/08/22/americans-think-they-know-about-gmos-but-poll-shows-consumers-still-badly-confused/ accessed 8 Dec 2021.

53 https://www.who.int/data/nutrition/nlis/info/vitamin-a-deficiency, accessed 5 Dec 2021.

to the deontological approach, both the object and motives of the actions leading to the production of GR were rightful.

Conclusion

This article described four GM crops and made a moral judgement on the way they are produced. The judgement was based on in-depth reflection which resulted in the classification of selected actions on the scale: right – neutral – wrong (no case of a GM plant production was considered inappropriate). This division is largely simplified. Classifying a given action as morally good or neutral means only that the arguments provided in each case were slightly more in favour of assigning it one moral value, and not another. All but one action was ranked right. (Table 1) The only exception was the production of the *Flavr Savr* tomato, which, according to the assumptions of deontological ethics, was considered neutral. This assessment was made by considering the sum of the object and the motive of the act. The object was considered rightful, as it concerned the improvement of a popular edible plant. Correcting or enriching a thing raises it to a higher level, and, therefore, actions that serve that purpose fall within the scope of a moral good. The neutral moral value of producing the *Flavr Savr* tomato was determined by the motive, which was wrong, as it did not result from a sense of moral obligation. Often, however, a wrong motive for an act produces good consequences, and these are the most common measure that determines whether human behaviour is right or wrong[54].

Table 1. Comparison of the moral assessment of selected crops created by genetic engineering.

Ethical theory	Evaluation of actions	*Flavr Savr*	GMHR, GMIR	*Golden Rice*
utilitarism	right	+	+	+
deontologism	right	-	+	+
	neutral	+	-	-

Source: the result of the author's theoretical reflection

54 Internet Encyclopedia of Philosophy, https://iep.utm.edu/util=-a-r/#:~:text-Utilitarianism%20is%20one%20of%20the%20best%20known%20and,the%20good%20and%20bad%20results%20that%20they%20produce, accessed 11 Dec 2021.

For more than a quarter of a century, the knowledge about the GM plants described in the article has been providing evidence mainly in the form of the effects of their cultivation, which, according to utilitarian ethics, prove the legitimacy of their further production. At the same time, the use of genetic engineering to create plants with new characteristics poses greater economic, political, legal, and social challenges than the production of plants that uses other methods. These challenges turn into barriers that hurdle the achievement of greater benefits from the invention of GM crops, making it possible, for example, to combat hunger in the world more effectively[55]. An example of political barriers is the adoption by different countries of a range of strategies, according to which some GM crops are allowed to be grown in a given country and others are not. In India, for example, GM cotton has been grown since 2002, but there is still no consent to plant *Golden Rice*[56]. Economic barriers, in turn, make difficult, for example, international trade in GM seeds and plants. Legal restrictions, on the other hand, apply to, e.g., labeling such products. All these conditions do not keep pace with the advances in genetic engineering itself. In addition, they are associated with the lack of full awareness and social approval, and, in the last decade, also a general decline in interest in the subject of GMOs[57]. Educating societies – both the political elites, including decision-making entities, as well as farmers and consumers – in the matter of GM plants is as important as the production and improvement of these plants. Not only schools, but also the media, scientists, and authorities, including local government units, are responsible for the process of educating and informing about the benefits and risks of the production and consumption of GMOs in general. The basis of this education is the presentation of an evaluation of the moral application of genetic engineering in agriculture, issued by competent experts and specialized institutions. This article is also helpful in carrying out this process. Getting to know scientific moral judgement protects societies against the spread of prejudices, fears, and the reluctance to grow and eat GM crops, and it thus provides the chance to gain greater benefits from their production. While the current resistance to GMOs by European countries with an abundance of food does not significantly affect the quality of life of Europeans, such opposition from poor Asian and African countries, where the number of inhabitants

55 L. Herrera-Estrella, Genetically modified crops and developing countries. *Plant Physiology* 2000, vol. 124, iss. 3, pp. 923-926, https://doi.org/10.1104/pp.124.3.923.

56 GLP, https://geneticliteracyproject.org/2015/05/26/golden-rice-in-india-is-it-necessary-what-are-impediments-to-adoption/, accessed 11 Dec 2021.

57 https://gmoinfo.eu/uk/files/510-briefing-eurobarometer-19june-2019-.pdf, accessed 11 Dec 2021.

is growing, and the area of farmland is shrinking – is for the local populations pernicious[58].

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Moral assessment of the use of genetic engineering for the production of GM crop plants used in agriculture

Abstract

The aim of the article is to describe selected genetically modified organisms constituting crop plants and to make a moral assessment of the actions that led to their creation. The introduction explains the importance of the development of genetic engineering. Next, the article presents assumptions of two selected ethical theories – utilitarianism and deontologism, which have been used to formulate a moral assessment of activities leading to the production of selected GM plants. In the second part of the text, theoretical reflection is devoted to the nature of activities as well as the social context that accompanied the production of: the *Flavr Savr* tomato, herbicide- and pest-resistant plants and *Golden Rice*. In line with the utilitarian approach, practices leading to the creation of all described GM plants were considered rightful. In the case of the deontological approach, in turn, activities that led to the creation of plants resistant to herbicides and pests, as well as to the creation of *Golden Rice*, were assessed as rightful, while the creation of the *Flavr Savr* tomato – as morally neutral.

Keywords: genetic engineering, genetically modified organism, agriculture, utilitarianism, deontology, bioethics

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Ocena moralna wykorzystania inżynierii genetycznej do produkcji roślin uprawnych GM stosowanych w rolnictwie

Streszczenie

Celem artykułu jest opisanie wybranych organizmów genetycznie zmodyfikowanych stanowiących rośliny uprawne oraz dokonanie moralnej oceny działań, które doprowadziły do ich powstania. We wprowadzeniu wyjaśnione zostało znaczenie inżynierii genetycznej. W dalszej części artykułu przedstawiono założenia dwóch wybranych teorii etycznych – utylitaryzmu i deontologizmu, które posłużyły do sformułowania oceny moralnej działań prowadzących do produkcji wybranych roślin GM. Druga część tekstu dotyczy refleksji teoretycznej, poświę-

conej charakterowi działań oraz kontekstowi społecznemu, który towarzyszył produkcji: pomidora *Flavr Savr*, roślin odpornych na herbicydy i szkodniki oraz *Złotego Ryżu*. Zgodnie z podejściem utylitarnym za słuszne uznano praktyki prowadzące do powstania wszystkich opisanych roślin GM. Z kolei w przypadku podejścia deontologicznego za słuszne uznane zostały działania, które doprowadziły do wyprodukowania roślin odpornych na herbicydy i szkodniki, a także *Złotego Ryżu*, natomiast stworzenie pomidora *Flavr Savr* ocenione zostało jako moralnie neutralne.

Słowa kluczowe: inżynieria genetyczna, genetycznie modyfikowany organism, rolnictwo, utylitaryzm, deontologia, bioetyka

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