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Economic, social and environmental consequences of the use of genetically modified organisms

Abstract

Object: to analyze the effectiveness of the use of genetically modified organisms in terms of economic efficiency, as well as environmental and social consequences.

Methods: a theoretical review of the scientific literature on the research topic.

Results: on the basis of literature data arguments are presented in favor and against the introduction of genetic modification technology in agriculture. Potential benefits and risks this technology may entail are considered.

Conclusions: it has been established that genetic modification of crops provides multiple benefits, contributing to the simplification of production processes, an increase in profit margins, and a reduction in losses caused by diseases and pests. Lower cultivation costs, in turn, lead to lower food prices, which may be the key to solving the issue of hunger in developing countries. It was revealed, among other things, that the use of genetically modified crops not only does not harm biological diversity, but, on the contrary, contributes to its expansion. The findings could be utilized when justifying a regional agricultural development program.

Keywords: agriculture, agro-industrial complex economics, genetic engineering, GMO, biotechnology, economic efficiency, crops.

Introduction

The processes of globalization, which have been rapidly developing in recent decades, have had a significant impact on the agro-industrial complex of the world economy. The unprecedented challenge of preserving the global environment today means that most countries, unfortunately, can no longer increase agricultural production through environmental sustainability alone. This sad fact leaves humanity with three main possible ways to reconcile agricultural productivity with environmental sustainability: reducing food waste, switching to less meat-based diets, and making better use of existing resources.

The state policy of the Republic of Kazakhstan, like many other developing countries of the world, is aimed at the rational distribution and use of resources in all sectors of the economy to ensure economic security. The key elements of the food security system are rational consumption rates, food safety, physical availability of food, economic accessibility of food, and development of economic potential and reduction of crime in the agro-industrial complex (AIC), food independence. Agro-industrial complex enterprises ensure the political and financial independence of the country by supplying the population with food and consumer goods. Despite the existence of negative factors, under the influence of which the enterprises of the agro-industrial complex conduct the economy, they continue to function, and identify new ways of development and improvement.

The use of new food technologies will allow Kazakhstan to compete with other countries in the context of global integration. The introduction of new technological methods, as a rule, is aimed at achieving high profits, improving conditions and profitability of production. The economic efficiency of the technology is possible with a combination of factors, such as the type of product, the market situation, the organization of production, the type of technology and raw materials used, the tax system and non-tax methods of supporting production, permitted by the legislation of a particular country (Ślusarczyk, 2020; 108).

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Literature review

Genetically modified organisms (GMO) have been used since the mid-1990s, and have been recognized by agricultural workers around the world as they have proven to be effective and relatively safe technologies for increasing agricultural production. Genetic engineering and plant transformation have played a key role in the evolution of crops by introducing useful foreign genes or suppressing the expression of endogenous genes in crops. Genetically modified crops have one or more useful traits, such as herbicide resistance, insect resistance, abiotic stress resistance, resistance to various kinds of diseases, and an increased growth rate compared to their counterparts free from GMO. As noted earlier, they are widely used throughout the world. To date, about 525 different transgenic plants of 32 crops have been approved for cultivation in various parts of the world.

GMO have been used commercially for more than 20 years, when it was found that the introduction of transgenic technology increases crop yields, reduces the use of pesticides and insecticides, reduces CO_2 emissions, and, most importantly for the economy of the vast majority of countries, GMO reduce costs in the field crop production. Available research in recent years describing the effects of insect- and herbicide-resistant crops shows that these technologies can be beneficial to both farmers and consumers, providing significant cumulative welfare gains as well as positive impacts on the environment and human health. Until now, this technology has been limited to weed and pest control, while the second generation of GMO, according to researchers in the field, helps agricultural workers to achieve resistance to abiotic stress or improve the nutritional properties products. If an enabling institutional framework is in place, GMO can make a significant contribution to global food security, including the potential for poverty reduction.

Nevertheless, doubts about the widespread and fast spreading use of GMO, and, most importantly, their safety for human health, still raise a number of unresolved issues that have led to strict regulations on the use of GMO, and bodies of standardization control their use. GMO have caused controversy in both separating and non-sharing countries, although stringent regulatory processes have been introduced and applied with regard to food, feed and environmental safety. In addition, in some countries, and especially in the countries of the Eurasian Economic Union (EAEU), including our Republic of Kazakhstan, mandatory labeling of GMO has been introduced at the moment, while other countries prefer voluntary labeling of goods containing GMO.

In connection with the above, economic research on the benefits or harms of GMO plays an important role in the development of effective regulatory mechanisms for the agricultural innovation system.

Genetic modification of plants can be characterized as a change in the structure, composition, or development of a plant organism by changing its genome as a result of the introduction of specific deoxyribonucleic acid sequences from other organisms. The ultimate goal of such technology is to alter the biological properties of proteins by manipulating the expression of the genes that encode them. For centuries, breeders and farmers have given plants the desired properties through crosses. However, genetic modification differs from traditional breeding in the accuracy of gene transfer and short-term, since it allows to remove biological barriers to genetic exchange and recombination between incompatible organisms through the generation of transgenes (Holst-Jensen, 2009; 1071).

The widespread adoption of transgenic crops carrying foreign genes is hampered by concerns about potential toxicity and allergenicity to humans, potential environmental risks such as the potential for gene transfer, adverse effects on non-target organisms, and the evolution of resistance in weeds and insects. These concerns have prompted the introduction of alternative technologies such as cisgenesis, intragenesis, and genome editing. Some of these alternative technologies, according to researchers in the field, can be used to grow crops that are free of any foreign genes, so it is expected that such crops can receive greater consumer acceptance than transgenic crops and easier to obtain regulatory approval organs.

A number of studies on the agronomic, environmental and socio-economic consequences of the introduction of GMO have generated interest in intensive study of issues related to the biological safety of agricultural biotechnologies (Nuthalapati, 2020; 118). However, the fragmentation of information about GMO circulating in the information field, together with coordinated information campaigns that incite public opinion against genetic engineering, creates the need to streamline the research data obtained in recent years on the properties and effects of GMO. In view of the above, the purpose of this work is to analyze the effectiveness of the use of GMO in terms of environmental and social consequences, as well as economic efficiency.

Methods

The article examines the development trends of the GMO production industry. The indicators reflecting the effectiveness of the application of this technology are analyzed; its positive and negative aspects are assessed. The article considers internal and external factors leading to stimulation or inhibition of the development of technology for genetic modification of crops in various regions of the world. The analysis of the current state of knowledge about GMO technology and its multidimensional assessment by specialists was carried out using publications of authoritative researchers. The data was extracted from materials posted on official information platforms and scientific research published in peer-reviewed publications. For various decisions in the research process, appropriate qualitative and quantitative research methods were used: analytical, synthetic, logical, and so on.

Results and discussion

The introduction of GMO into agriculture is currently being widely discussed in both positive and negative contexts, being the subject of debate at various levels. The main arguments of supporters and opponents of GMO are presented in Table 1.

Table 1. Arguments for and against the use of GMO

Arguments for using GMO
Reduced agricultural production (due to reduced use of pesticides)
Increased productivity (due to the resistance of crops to pests and diseases)
The ability to use previously uncultivated land (saline, dry, and swampy).
Production of fortified food products (in particular, vitamins and microelements).
Increasing the resistance of crops to environmental conditions (frost, drought, salinity).
Arguments against using GMO
The impact of GMO on humans, animals and various biomes is still poorly understood.
Natural biodiversity may be threatened
Genetically modified plants can interbreed with wild plants and create «superweeds»
Market monopolization risk
Note — compiled by the author

Consequences in terms of economy. According to Ślusarczyk et al. (2020; 108), the most common economic benefits resulting from the introduction of GMO into agricultural practice are a decrease in crop losses and an increase in farm productivity, minimization of costs for plant protection products; reduction in labor costs; reduced consumption of diesel fuel and agricultural machinery, improving product quality.

The positive changes associated with the introduction of crop genetic engineering technology also include the possibility of using a cropless farming system that is more environmentally friendly. One of the most important arguments in favor of GMO production in agriculture is reducing the use of pesticides. This has a positive impact on the environment and allows producers to save money on the purchase of crop protection products (Szkarłat, 2011).

Experts' calculations show that from 1996 to 2018 the use of GMO brought economic profits to farms in the amount of $225.1 billion. 72 % of the profits came from increased yields and productivity, and the remaining 28 % came from cost reductions. In terms of investment, for every dollar invested in genetically modified crop seeds (over and above the cost of regular seeds), farmers received $3.75 in additional income. In developing countries the average return was $4.41 on every additional dollar invested in GMO; in developed countries the figure was $3.24 (Brookes & Barfoot, 2020; 242).

A meta-analysis of the results of studies, on the effects of GMO (Klümper, 2014; 1), shows a 22 % increase in yields from the use of GMO, with a 68 % profit and a 38 % reduction in pesticide costs. It is estimated that it would take more than 300 million acres of unmodified crops to achieve these targets, which in turn would further exacerbate the current environmental and socio-economic problems in the agricultural sector (Zhang, 2016; 116).

After examining the database of the International Service for the Acquisition of Agri-biotech Applications for the period from 1993 to 2016, researchers from the United States of America (Nes, 2021; 18) calculated that the rejection of the use of GMO led to higher food prices (by 1.09 % compared to countries where the use of GMO is approved) and reduced access to food from abroad in many of the world's poorest foodstuffs. In addition, the authors concluded that the total cost of abandoning the introduction of GMO is reflected in a reduction in the country's access to food from international markets by an average of 25.69 %.

In India growing cotton with the genome of *Bacillus thuringiensis* has increased employment and household incomes, as well as increased calorie intake (Nuthalapati, 2020; 122).

Saputri et al. (2019; 1) developed and applied a model for measuring the performance of sustainable agri-food supply chains for GMO and non-GMO, which includes the calculation of adjusted profit based on total recoverable costs and total factor productivity. The authors' calculations on data from Indonesia showed that the value of the adjusted profit was higher for the supply chains of genetically unmodified rice compared to that for genetically modified rice.

Despite the numerous advantages of GMO, there are concerns about the existence of economic, social and environmental risks that may arise when using transgenic products, among which the increased cost of products is distinguished (due to the high cost of GMO production technology, its development and implementation may be inaccessible for developing countries) coupled with the emergence of dependence of farmers on agricultural technology and seed companies (Szkarłat 2011). Farmers who grow unlicensed seeds of transgenic plants can be held liable for violation of property rights. In addition, the market for genetically modified seeds is currently consolidated by such giants as Bayer-Monsanto, DowDuPont and Syngenta (ChemChina). In recent years, the global market for genetically modified seeds has become the scene of large-scale mergers and acquisitions carried out by these corporations. These trends are of concern to the global seed industry, as they lead to reduced economic efficiency and market disruptions. Estimates of the degree of market consolidation by the above companies vary from 48 % in 2012 to 58 % in 2018. The trend towards consolidation is unlikely to change in the near future, as entry into the market for new players is complicated by barriers such as large initial investment requirements and relevant experience (Gmeiner & Puls, 2019).

Consequences in terms of society. Proponents of green biotechnology and the commercialization of new varieties of genetically modified plants are convinced of the promise of using GMO to fight hunger and malnutrition in the world. Unfortunately, despite a significant increase in agricultural production, according to the estimates of world organizations, the level of hungry and malnourished people is still high: according to current estimates, 820 million people worldwide are getting insufficient calories from food (Lloyd, 2021; 1).

According to some estimates, about 30 % of the world's crops are damaged by pests and diseases. First generation genetically modified crops are aimed at improving agronomic characteristics such as resistance to pests, diseases, drought and herbicides, which primarily benefits farmers and seed companies. First-generation insect-resistant transgenic plants, created by the targeted transfer of genes responsible for the production of insecticidal crystalline proteins (Cry proteins) from the bacterium *Bacillus thuringiensis*, into the plant's genetic material, solve such problems. For example, YieldGard corn is resistant to the European corn moth (Ostrinia nubilalis) and other lepidoptera insect pests due to the introduction of a gene encoding the Cry1Ab insecticidal protein obtained from the soil bacterium Bacillus thuringiensis (Petrick, 2020; 30).

Genetically modified cultures of the second generation have characteristics that are valuable for the end user: hypoallergenicity, increased shelf life, increased nutritional value. Also, the development of genetically modified cultures of the third generation is underway for the production of therapeutic drugs, vaccines, biosensors and industrial products. As natural resources dwindle, increasing productivity in global agriculture is essential to ensure the availability of food and other raw materials for the world's growing population (Desai, 2020; 65).

Experts regard biofortification and increasing stress resistance of agricultural crops with the help of GMO as extremely promising areas for future research. While biofortification can contribute to addressing malnutrition and micronutrient deficiencies, plant stress tolerance is a potential solution to biodegradation, climate change, and declining acreage (Raman, 2017; 205). Thus, the introduction of targeted changes in the genomes of Arabidopsis and barley led to an increase in their resistance to stress and an increase in biomass under unfavorable conditions (Mendiondo, 2016; 40). And since the development of vitamin A-fortified rice in 2000 (Ye, 2000; 303), further research has only confirmed the efficacy of biofortification (in particular, iron and zinc) of food through genetic engineering (Bouis, 2017; 49).

Technological solutions are under development, such as herbicide-resistant cotton and maize resistant to cassava viruses and brinjal containing the pesticide gene *Bacillus thuringiensis* (Ashok, 2017; 223).

One popular argument against the use of GMO, made by critics of biotechnology and genetically modified crops such as Vandana Shiva, is that in India, genetically modified cotton is allegedly the cause of the suicide of thousands of smallholders every year. At the same time, Shiva and others like her deliberately ignore the facts and continue to perpetuate misinformation about the catastrophic situation with farmers' sui-

cides. Research data (Smyth, 2017; 80) indicate that after the introduction of cotton containing the Bacillus thuringiensis gene, there was a decrease in the number of suicides among Indian farmers by one third compared to the same indicator recorded before the commercialization of this cotton variety in India.

Regarding the frequently repeated concerns about the harm of GMO consumption to mammals, scientists from the University of California, Davis (Van Eenennaam, 2014; 4255) after careful and extensive analysis concluded that data from field studies on the impact of genetically modified crops conducted on more than 100 billion farm animals indicate that there are no adverse trends in the health and productivity of the studied livestock due to experimental feeding with GMO.

In general, the negative public perception of the use of GMO in food production has entailed significant difficulties for the development of genetically modified crops and their commercialization in both developed and developing countries. A number of publications that have argued that genetically modified crops may not be equivalent to conventional crops and may pose a health hazard to the consumer have sparked much debate that continues to this day. For example, some researchers have reported a reduced content of *Lactobacillus bacteria* in the cecum of laboratory rats fed GMO compared to counterparts that did not receive GMO (Xu, 2011; 88), or even increased mortality (Séralini, 2013; 476) due to unexplained mechanisms. However, having applied the Bonferroni correction for multiple comparisons to the primary data from seven publications containing such statements (including those cited above), Russian researchers (Panchin, 2017; 216) came to the conclusion that the obtained intergroup differences are not statistically significant and, therefore, the data presented in those articles does not provide any considerable evidence of harm to living organisms from genetically modified crops.

Consequences in terms of ecology. Globally, gene modification technologies have significantly reduced the negative environmental impacts associated with the use of insecticides and herbicides. Thanks to the use of GMO since 1996, the spraying of pesticides on the cultivated area was 8.3 % lower than the amount of the substance that would be used if using conventional crops. In the America, the use of genetically modified herbicide-tolerant crops (especially soybeans) has contributed to the widespread adoption of shallow or no-till systems. As a result, along with a reduction in the consumption of tractor fuel for tillage, the quality of the soil has increased, and the level of its erosion has decreased. At the same time, more carbon remains in the soil, which leads to a decrease in greenhouse gas emissions. For example, in 2018, an additional 5,606 million kilograms of soil carbon were sequestered, equivalent to the removal of 13.6 million vehicles from roads in one year (Brookes & Barfoot, 2020; 215).

It was found that the development of genetically modified potatoes, which are resistant to pulp pigmentation, late blight and low temperatures, reduced the costs of producers by 28 %, and also, reduced the area of pesticide sprayed by 2.5 million acres, carbon dioxide emissions by 740 million pounds and 84 billion gallons of water consumption (Nuthalapati, 2020; 122).

However, some researchers have also expressed concerns about the threats to the environment that may arise from the introduction of GMO. Among them displacement of natural species, the emergence of «superweeds», that is, weeds obtained as a result of uncontrolled gene transfer; the emergence of resistance of pests and weeds to insecticides and herbicides; risks associated with the use of genetically modified monocultures. In order to prevent the phenomenon of resistance, some companies advocate the cultivation of areas free of genetically modified crops around transgenic plantings. This fragmentation of plots is likely to reduce the economic incentive to use GMO, especially in the case of small-scale farmers (Kaya, 2020; 67).

It is often believed that GMO are detrimental to biological diversity in agricultural ecosystems (Azadi & Ho, 2010; 166). For example, Garipov et al. (2016; 107) express the opinion that the achieved productivity indicators of cultivated plants are practically at the maximum level of their genetic potential, while the range of genetically modified crops is rather scarce, which casts doubt on the justification of the potential risks associated with the use of similar technologies. At the same time, there is evidence that the implementation of genetically modified crops has reduced the negative impact of agriculture on biodiversity through increased use of gentle tillage methods, reduced insecticide spraying, more environmentally friendly herbicides, and reduced land area required to be converted to farmland for enhancing yields (Carpenter, 2011; 18). Modifications in the genetic material of a cell make crops compatible with various ecosystems. Thus, such technological advances may contribute to improved nature diversity (Juma, 2015).

Conclusion

Genetically modified crops can alleviate a number of problems in the commercial agriculture today. Current market trends make this technology one of the fastest growing and most innovative industries in the

world, which benefits not only manufacturers, but also consumers, as well as the economies of developed and developing countries. Reducing cultivation costs results in lower food prices, which can help fight hunger and malnutrition in developing countries. However, to tackle the problem of unethical research and misinformation, it is imperative that the agricultural industry and academia work closely together. Thanks to key innovations in gene integration technologies along with new research in stress tolerance and plant biofortification, genetically modified crops are predicted to increase productivity and profitability in commercial agriculture.

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Генетикалық түрлендірілген организмдерді қолданудың экономикалық, әлеуметтік және экологиялық салдары

Аңдатпа

Мақсаты: Генетикалық түрлендірілген организмдерді қолданудың тиімділігін экономикалық тиімділік, сондай-ақ экологиялық және әлеуметтік салдарлар тұрғысынан талдау.

Әдістері: Зерттеу тақырыбы бойынша ғылыми әдебиеттерге теориялық шолу.

Нәтижелер: Әдеби мәліметтер негізінде ауылшаруашылығына генетикалық модификация технологиясын енгізудің пайдасы мен қарсы дәлелдері келтірілген. Осы технологияны қолдануға әкелуі мүмкін ықтимал артықшылықтар мен тәуекелдер қарастырылған.

Қорытынды: Дақылдардың генетикалық модификациясы өндірістік процестерді жеңілдетуге, өндіріс маржасын арттыруға, аурулар мен зиянкестерден болатын шығындарды азайтуға көмектесетін көптеген артықшылықтар беретіні анықталды. Өсіру шығындарының төмендеуі, өз кезегінде, азық-түлік бағасының төмендеуіне әкеледі, бұл дамушы елдердегі аштық мәселесін шешудің кілті болуы мүмкін. Анықталғаннан басқа өзге гендік түрлендірілген дақылдарды қолдану биологиялық әртүрлілікке ғана зиян келтірмейді, бірақ оны кеңейтуге қарама-қарсы ықпал етеді. Зерттеу нәтижелері өңірлердің аграрлық даму стратегиясын негіздеу кезінде көрініс табуы мүмкін.

Кілт сөздер: ауылшаруашылығы, агроөнеркәсіптік кешен экономикасы, гендік инженерия, ГМО, биотехнология, экономикалық тиімділік, дәнді дақылдар.

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Экономические, социальные и экологические последствия применения генетически модифицированных организмов

Аннотация

Цель: Проанализировать эффективность применения генетически модифицированных организмов с точки зрения экономической эффективности, а также экологических и социальных последствий.

Методы: Теоретический обзор научной литературы по теме исследования.

Результаты: На основе литературных данных приведены аргументы в пользу и против внедрения технологии генетической модификации в сельское хозяйство. Рассмотрены потенциальные выгоды и риски, которые может повлечь за собой применение данной технологии.

Выводы: Установлено, что генетическая модификация сельскохозяйственных культур предоставляет множество преимуществ, способствуя упрощению производственных процессов, повышению маржинальности производства, сокращению убытков, вызванных болезнями и вредителями. Снижение затрат на выращивание, в свою очередь, приводит к снижению цен на продукты питания, что может стать ключом к решению проблемы голода в развивающихся странах. Выявлено, что использование генномодифицированных культур не только не наносит вреда биологическому разнообразию, но, напротив, способствует его расширению. Результаты исследования могут найти отражение при обосновании стратегии аграрного развития регионов.

Ключевые слова: сельское хозяйство, экономика АПК, генетический инжиниринг, ГМО, биотехнология, экономическая эффективность, зерновые культуры.

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