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GENETICALLY MODIFIED CROPS FOR ADAPTATION OF THE AGRICULTURAL SECTOR TO CLIMATE CHANGE

ГЕНЕТИЧНО МОДИФІКОВАНІ КУЛЬТУРИ ДЛЯ АДАПТАЦІЇ АГРОСЕКТОРУ ДО ЗМІН КЛІМАТУ

Abstract. Global climate change poses serious challenges for agriculture, requiring adaptation and the introduction of innovative agricultural technologies. The study examines the potential of genetically modified organisms (GMOs) as a tool for adapting the agricultural sector to climate change, and identifies possible benefits and risks of their use. The results of this analysis will allow us to assess the prospects for using GMOs to adapt agriculture to climate change and identify potential ways of their effective use.
Keywords: climate change, agriculture, GMOs, biotechnology, crops, innovation, ecosystems.

Анотація. Глобальна зміна клімату створює серйозні виклики для сільського господарства, вимагаючи адаптації та впровадження інноваційних сільськогосподарських технологій. У дослідженні розглянуто потенціал генетично модифікованих організмів (ГМО) як інструменту адаптації аграрного сектору до зміни клімату, а також визначено можливі переваги та ризики їх використання. Результати цього аналізу дозволять оцінити перспективи використання ГМО для адаптації сільського господарства до змін клімату та визначити потенційні шляхи їх ефективного застосування.
Ключові слова: кліматичні зміни, сільське господарство, ГМО, біотехнології, вирощування культур, інновації, екосистеми.

Climate change exacerbates food insecurity in Kenya, with 4.2 million people facing acute hunger in 2022 due to disruptions in food systems [Mwasiaji et al., 2022, p. 392]. Extreme weather events such as droughts, floods, and heat waves negatively impact crop yields and nutritional quality [1, p. 393]. Biotechnology, in particular genetic modifications, can be a key tool for ensuring food security and sustainable development of the agricultural sector. The use of GMO soybeans and corn to reduce the need for ploughing (no-till technology), which also reduces CO_2 emissions [2, pp. 224-225]. In the future, we can expect numerous innovations that will allow crops to adapt to extreme conditions such as droughts, high temperatures, saline soils and new pests. Drought, salinity, heat stress, and waterlogging significantly affect agricultural productivity in Pakistan [3, pp. 3-4]. The losses in crop yields due to salinity and drought have reached up to 50%, with economic losses exceeding $475 million annually [3, pp. 4-5]. Since drought is one of the biggest threats to agriculture in the context of climate change, one of the most promising areas is the development of crops that can withstand limited amounts of water. Research is already underway to modify crops to improve their ability to retain water and use available water resources more efficiently. Heat stress is an important issue for many crops. Predicting the results of genetic modifications will be significantly improved by integrating machine learning and big data analytics. This approach will allow us to optimise the selection of crops for specific conditions, predict their behaviour in different climatic zones and speed up the process of developing new varieties. While GMOs promise increased productivity, they raise concerns about ethical considerations, seed sovereignty, and the dominance of multinational corporations in the agricultural sector [1, p. 400]. The study focuses on the role of genetically modified organisms (GMOs) in increasing the resilience of crops to extreme climatic conditions, such as droughts, rising temperatures and heavy rainfall. An overview of biotechnological developments that facilitate plant adaptation to environmental changes will be provided, as well as an analysis of the experience of countries where GMOs are most widely used, including the United States, Brazil, India and China. In addition to assessing the effectiveness of such crops in different climatic conditions, attention will be paid to possible challenges and risks associated with their use. An important aspect is the impact on the environment, including biodiversity, soil conditions and the spread of pests and diseases. The economic impacts will also be examined, including changes in production costs, farmers' incomes and the availability of biotechnology. The social aspects of GMO introduction, such as food security, the impact on farming communities and ethical issues, will also be considered. The main method of research is a review of modern scientific papers analysing the effectiveness of genetic modifications in adapting crops to climate change. Particular attention is paid to the long-term impact of GMOs on yields, stress resistance and environmental consequences. Climate change is causing the spread of new pests and diseases that threaten agriculture. Rising temperatures, changing precipitation patterns and extreme weather events create favourable conditions for their spread. In response to these challenges, genetically modified (GMO) crops are being developed with increased resistance to pests and diseases. Genetic modifications allow for the creation of new plant varieties with improved yields, productivity and adaptability. Biotechnology is also an important tool for developing Ukraine's agricultural sector and ensuring its resilience to global challenges, including climate change [4, pp. 10-12]. One of the most successful examples is plants with genes from the bacterium Bacillus thuringiensis (Bt) that produce proteins that are toxic to insects but safe for humans and the environment. GM insect-resistant maize, with healthier cobs, is much less infested with mycotoxins and presents significant health benefits [5, p. 33]. The BioCassava Plus project has developed a cassava variety with high levels of β-carotene and other nutrients (i.e. zinc, iron, and proteins) using modern biotechnological methods [5, p. 39]. It contains a gene that improves moisture utilisation, reducing yield losses. Also, Bt corn, which produces the toxic protein Cry, significantly reduces insect populations, reducing the need for chemical pesticides and increasing yields by 10-20%.Transgenic crops with genes for resistance to drought, salinity, and temperature fluctuations (examples: GM tomatoes, rice, corn, tobacco) [2, pp. 225-226]. In Brazil, GMO soya plays a key role in the fight against drought and weeds. Herbicide-tolerant varieties introduced in 2012 allow for effective weed control without compromising yields. Modified soybeans developed for arid regions yield 15-20% more than traditional varieties, which contributes to the sustainability of agriculture in a changing climate. China is actively implementing biotechnology to improve crops. One example is genetically modified rice, created to increase resistance to drought and pests. In the face of climate change, accompanied by unstable rainfall, traditional rice varieties have become less efficient. The GMO rice tested in southern China demonstrates high resistance to extreme temperatures and water shortages, which allows it to maintain crops even during periods of drought. This is an important step towards ensuring the country's food security.

Genetic modifications are also aimed at increasing plant resistance to diseases. GMO tomatoes have received genes that provide protection against the Tomato Mosaic Virus (ToMV), which significantly reduces the risk of infection. To combat late blight, which is one of the most destructive diseases of potatoes, GMO potatoes with genes that promote the production of natural antimicrobial compounds have been developed. This helps to reduce the need for pesticides and preserve the crop even in humid conditions. Rising temperatures also contribute to the emergence of new types of pests that have not previously been found in certain regions. The development of transgenic crops (GMOs) with increased yields, resistance to drought, pests and diseases, and improved nutrient absorption [2, pp. 223-224]. Comparison of traditional farming and biotechnology, including the use of genetically modified organisms (GMOs), allows us to assess the advantages and limitations of each method in the current climate conditions. Traditional farming is based on natural plant breeding, organic fertilisers, soil cultivation and mechanical or chemical pest control. It relies on the adaptation of local varieties to the natural conditions of the region. Genetically modified organisms are created by making targeted changes to the DNA of plants, which gives them new properties, such as resistance to drought, pests or extreme temperatures. This can significantly increase yields and reduce dependence on agrochemicals, which is an important factor in a changing climate. Genetically modified organisms (GMOs) play a key role in increasing crop yields, especially in the face of drought, soil salinity and other extreme climatic factors. Biotechnology allows us to create plants with increased resistance to such stresses, which helps to minimise crop losses and ensure food security in regions where conventional farming does not produce sustainable results. Soil salinity is one of the main problems of modern agriculture, as high salt content in the soil impairs the absorption of water and nutrients by plants. Molecular breeding and GWAS are discussed in detail on pages 11-12 (sections '7.3.1. Omics-Led Breeding and Marker-Assisted Selection' and '7.3.2. Genome Wide Association Studies") [6, pp. 11-12]. For examples of the use of genetically modified plants for climate change adaptation, see pages 13-15 [6, pp. 13-15]. The possibilities of CRISPR/Cas9 for editing the plant genome and creating climate-resilient crops are described on pages 15-16 (section '7.4. Genome Editing Strategies') [6, pp. 15-16]. Transgenic crops, including Bt cotton and herbicide-tolerant maize, have shown promising results in addressing abiotic stresses like drought and salinity [3, pp. 11–12]. Biotechnological interventions, such as introducing genes for salinity and drought tolerance (e.g., DREB2A, NAC), have significantly improved stress resistance [3, pp. 7–9]. CRISPR/Cas9 technology is emerging as a powerful tool for precise genetic modifications to combat abiotic stresses, including heat and drought tolerance [3, pp. 12–13]. One of the main advantages of genetically modified organisms (GMOs) is the reduced need for chemical plant protection products. For example, GMO Bt corn and GMO cotton produce proteins that kill pests, which can significantly reduce the use of chemical pesticides. The TELA Maize Project, a public–private partnership managed by the African Agricultural Technology Foundation (AATF), is working towards development and commercialization of transgenic drought-tolerant (and IR) maize varieties in order to boost food security in SSA [5, p. 38]. Nigeria's new Bt cotton, which is suitable for cultivation in all of Nigeria's cotton-growing zones, can produce 4.1 to 4.4 tons per hectare as compared to the local variety, which yields just 600 to 900 kg per hectare [5, p. 39]. Brookes and Barfoot (2020) reported an 11% yield gain for IR maize resistant to maize-boring pests and a 24% yield gain for IR cotton in South Africa between 1996 and 2018 [5, p. 39]. For Bt maize, farmers can reduce insecticide use by 30-50%, which helps improve soil quality, conserve biodiversity and reduce harm to beneficial insects such as bees and pollinators. One of the main risks is the possibility of cross-pollination of GMOs with wild relatives of crops, which can change the genetic composition of populations and create new hybrids that may have unexpected environmental consequences. This can threaten biodiversity and ecosystem stability. The cost of licences for the use of GMO varieties, patenting of technologies and dependence on large corporations can lead to higher costs for farmers for seeds. This can become an economic burden, especially for small farmers who cannot afford expensive licences. In addition, farmers may become dependent on large agrochemical companies for seeds and crop protection products, leading to market concentration and a reduction in the number of small farms. This could contribute to increased economic inequalities in agriculture.As climate change contributes to soil salinisation in many regions, biotechnology is enabling the development of crops that grow on such land, opening up new opportunities for agriculture in areas of low fertility. Biotechnology also helps to significantly reduce crop losses caused by pests, diseases and extreme weather conditions. Genetic modifications make it possible to create crops with increased resistance to new pathogens that emerge as a result of climate change. Genetically modified crops, such as Bt GMO corn and GMO cotton, which produce natural toxins, can reduce the need for pesticides, which helps maintain yields and reduce the impact of pests and diseases. This not only reduces the cost of chemicals, but also reduces the risk of environmental pollution. The safe introduction of biotechnology can make a significant contribution to increasing yields, food security and adaptation of the agricultural sector to climate change [2, p. 229]. The use of GMOs that are resistant to pests and diseases reduces the need for pesticides and herbicides, which saves farmers money. The study recommends enhancing infrastructure for irrigation and efficient food distribution to complement the benefits of GMOs in addressing food insecurity [1, p. 403]. Sustainable food systems should integrate both biotechnology and traditional farming practices for long-term agricultural resilience [1, p. 404]. Drought-tolerant crops also reduce the need for irrigation, which is important in areas with limited water resources. GMO crops adapted to extreme weather conditions can provide high and stable yields even in adverse conditions. This allows farmers not only to maintain their incomes but also to increase them when traditional crops fail to produce the desired results. While biotechnology can make a significant contribution to food security, it also faces a number of regulatory, social and ethical challenges. Defining the legal framework for the use of GMOs and shaping public opinion about these technologies are key elements for their successful introduction into the agricultural sector. Regulation of GMOs is essential to ensure their safety and control their impact on the environment and human health. However, creating effective and balanced legislation is a complex task. Many countries have their own legislation on GMOs, often based on international agreements such as the Protocol on Biosafety (Cartagena Protocol) or recommendations of the World Health Organisation (WHO). However, in practice, there are significant differences in the approaches to GMO regulation between different countries. For example, in the European Union, GMOs are usually regulated more strictly, while in some countries in Latin America or Africa they are widespread. Fear of genetic modification, in particular the mixing of genes between different plant species, often causes great opposition. Favourable perceptions of GMOs can also hinder their adoption due to concerns about 'corporate technology'. Many consumers are concerned about the control of food resources by large agricultural corporations, fearing that market monopolisation through seed and technology licences could lead to increased dependence of farmers on corporations and higher prices for agricultural products. To change public perceptions of GMOs, it is necessary to conduct active educational work aimed at explaining the benefits and risks of using GMOs. The role of government agencies, scientific institutions and international organisations in developing information campaigns that can reduce the level of distrust and fears among the population is important. In addition, it is important to organise open discussions involving independent experts and farmers to discuss the benefits and possible risks associated with the use of GMOs in agriculture.

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