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GENETIC TRANSFORMATION IN AGRICULTURE: THE REAL CHANCE FOR ENSURING WORLDWIDE SUSTAINABLE FOOD SECURITY

Elena BONCIU

University of Craiova, Faculty of Agronomy, 19 Libertatii Street, Craiova, Romania, Phone/Fax: +40251418475, Email: elena.agro@gmail.com

Corresponding author: elena.agro@gmail.com

Abstract

Obtaining genetically modified (GM) organisms, with superior biological and productive performances, represents the priority objective of modern applied genetics research, oriented towards the development of effective procedures for increasing genetic variability, according to the requirements of breeding programs of economically interesting species. GM crops can contribute essentially to the millennium development goal, that of reducing poverty and increasing food security, by optimizing agricultural productivity. GM plants have improved traits that include herbicide tolerance, disease and pest resistance, drought tolerance, health or nutritional benefits, a longer shelf life, or a more efficient industrial use. Also, the GM crops contribute to sustainable environmental protection by reduction of the pesticides application amount and reduction of CO2 emissions. In this context, the aim of the present paper is the worldwide brief radiography of transgenesis, in terms of surfaces, the main producing countries, but also of the main GM crops and their market. The research method consisted in selecting of several scientific results from the WOS, Clarivate Analytics, Scopus and Springer databases. Also, were accessed several statistical data of the ISAAA, USDA, Research and Market, MADR, etc. The main producing countries of GM crops are USA, Brazil, Argentina, Canada, India, Paraguay and China. The largest GM areas are occupied by soybean, maize, cotton, canola and alfalfa. The global agricultural biotechnology market for transgenic crops is expected to reach 12.07 billion USD in 2026, growing by 18.2% compared with 2021. Genetic transformation and GM agricultural crops represent an effective strategy and real chance to counteract climate change and food insecurity, and recently developed genetic engineering techniques will play an important role in the future.

Key words: *GM crops, biotechnology, food security, sustainability, environment*

INTRODUCTION

Genetics is the key to deciphering the quintessence of life on Earth and genetic discoveries will certainly solve the most spectacular problems that this science raises. The most important result of biological evolution is genetic engineering, which creates unlimited possibilities of direct intervention on genetic material, with economic and social implications among the most promising.

Genetic engineering, known as recombinant DNA techniques or genetic modification/transformation, refers to changing of the genetic makeup of an organism using transgenesis. GM organisms are modified through the application of transgenesis or DNA recombination technology, the transgene being incorporated into the host genome or a host gene having its expression modified [15]. The terms genetically modified organism, transgenic organism and genetically configured organism are similar.

Genetic transformation techniques aim to substantially increase the food production for a continuously growing human population. In this context, modern biotechnology is a high-tech version of conventional breeding, able to achieve innovative products (plants and animals with superior productive qualities), within record time, unimaginable in practices of the conventional agriculture [9, 10].

The climate changes directly influence crops yield and indirectly might result in increase invasion of weeds, pests and pathogens [18, 22]. Current conditions require essential changes to be made in classical plant breeding technologies, and one of the ways is genetic modification. Transgenesis ensures the creation of new plants with targeted performance – increased productivity and quality, disease resistance and tolerance to adverse climatic factors [4, 5].

The importance of GM plants is extremelly important given that a still essential problem is the consequences caused by fungal and viral diseases in agricultural crops [6, 7, 8]. The resistance of agricultural plants to various diseases is, in most cases, a polyfactorial genetic trait. Transgenic plants until recently interested only agriculture and the food industry, but at the beginning of the new millennium, the trend of their use in many other fields is already obviously: the wood and paper industry, textile, pharmaceutical, etc. It is anticipated that the maximum potential value added to transgenic crop plants resides in the modifications of the finished products, such as, for example: increasing the content of starch, proteins, oils and sugars; modification of the baking properties of cereals; increasing the content of β-carotene; increasing the shelf life of fruits or vegetables, etc.

Globally, there are two attitudes towards the use of new cropping systems based on transgenic plants: (i) increasing the number of transgenic species and extending the areas allocated to them and (ii) limiting or even banning their cultivation [25, 26]. In Europe, where genetic transformation faces the strongest public resistance, many politicians, experts and agricultural leaders have nevertheless started to support it.

Food security is political at the state and global level, involving the intervention of most domains that ensure the development of a population's well-being. In this regard, the World Declaration on Nutrition states that "*every Government is responsible above all for the protection and promotion of food security and the good nutritional status of its population and in particular for the protection of vulnerable groups of the population and must be a key objective of human development; it must be in the center of socio-economic development plans and strategies*" [24].

Considering the immense potential of agricultural genetic transformation in ensuring food security, considerable financial efforts are being made worldwide for the development of this field, for the training and improvement of specialists and the creation of innovative techniques.

FAO is concretely involved both in the development programs of genetic bioengineering and biotechnologies, as well as in the processes of transferring their results to underdeveloped or developing countries, which do not have the possibility, by their own means, to achieve the biotechnological revolution. In this way, the respective countries will be able to improve their food security situation and, at the same time, align with current trends in environmental protection and biodiversity conservation.

MATERIALS AND METHODS

For a truly revolution in plants genetic transformation field, the main objective is the combination of modern molecular tools, sustainable screening technologies and economic evaluation.

The main objective of this paper was to review the importance of GM crops for the sustainable food security and environmental protection at the global level; the presentation of the areas and the most important producing countries of GM crops, the main cultivated GM species as well as some aspects of the GM agricultural crops market.

The research method consisted in selecting of several scientific results from the WOS, Clarivate Analytics, Scopus and Springer databases. Also, were accessed several statistical data of the ISAAA, USDA, Research and Market, and MADR.

RESULTS AND DISCUSSIONS

Transgenesis given a new tool to improve food security and reduce poverty. In recent years, new genetics modification techniques have been developed, such as TALENs, zinc finger nuclease and CRISPR/Cas9, also called gene editing, site-directed mutagenesis or novel breeding techniques. TALEN technology can be useful in this regard for precisely introducing genes of interest into plants and understanding how plant genes are regulated, how they respond to foreign molecules and how they repair their DNA [17, 23].

Millions of farmers around the world continue to choose transgenic crops due to the socio-economic and environmental benefits, as well as the important role they play in addressing food security.

Advances in plant biotechnology and agriculture depend on the efficient combination and application of various scientific inputs: phytovitroculture, cell biology, biochemistry, informatics, etc., and these advances can generate new solutions for food security [3]. The combination of new molecular tools, screening technologies and economic evaluation thus becomes the main objective of the revolution in the field of plants genetic transformation [16].

Genome editing is an extremely complex process, with a rather long history, which intervenes on the genetic code of an organism, with the help of editing or transformation at the level of genes and DNA. The modern genetic editing techniques like Zinc finger nucleases (ZFNs), Transcription Activator-Like Effector-based Nucleases (TALENs), CRISPR-Cas [14] or next generation sequencing (NGS) system [19] have a huge potential in the future for solving many issues related to plant resistance to diseases and pests and implicitly increasing food security worldwide. It is forecast that the genetic editing of pathogen targets in host will help the global Gene Editing market to reach USD 5441.3 million in 2028 [14].

Worldwide surfaces and the main transgenic crops

More than 25 years have passed since the approval of the cultivation of the first transgenic plants (1996). Since then, the areas allocated to genetically modified plants (soybean, maize, cotton, canola, etc.) tolerant to herbicides and/or resistant to attacks of some pests have increased continuously, exceeding 190 million hectares in 2020 (Figure 1) [12].

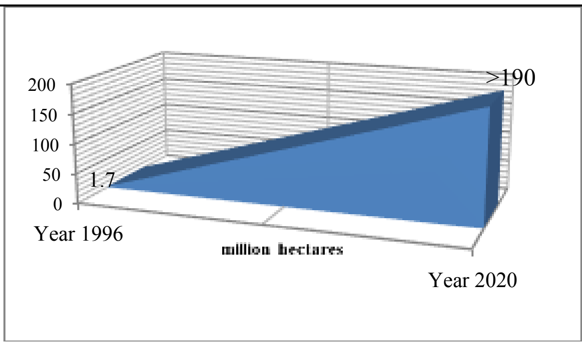

Fig. 1. Global area of biotech crops (million hectares) (1996-2020)
Source: Own design based on [12].

Transgenic plants fully contribute to ensuring food security by increasing productivity, conservation of biodiversity, reduction of gas emissions and the impact of pesticides on the environment, etc. Globally, the main producing countries of GM crops are USA, Brazil, Argentina, Canada and India (Figure 2). In 2018, Canada overtook India (6.3% of global biotech crops) [12].

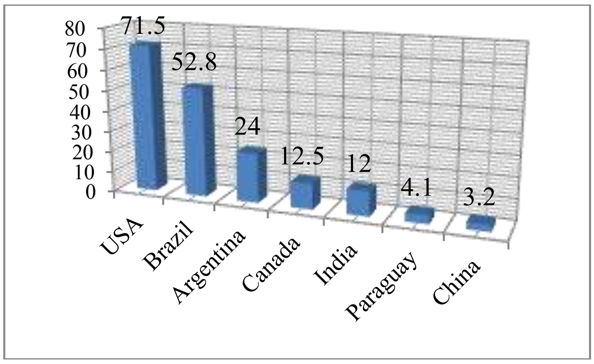

Fig. 2. The main producing countries of GM crops (million hectares)
Source: Own design based on [12].

In terms of the share of the main genetically modified crops, ISAAA Report (2021) shows that approximately 20 million farmers from 67 countries have cultivated approx. 191 million hectares of genetically modified (GM) plants, the largest areas being occupied by the following crops (Figure 3): GM soybean – 96 million hectares (50% of the global area); GM maize – 59 million hectares (30%); GM cotton – 25 million hectares (13%); rapeseed (canola) – 11 million hectares (5%) and alfalfa – 2 million hectares (2%). The leader in the field is USA; over two-thirds of food produced in USA contains at least one ingredient derived from a genetically modified plant [12]. In fact, USA grows transgenic plants on 73.1 million hectares (equivalent to 40% of the area allocated to transgenic plants globally) and having an average adoption rate of new technologies of 93% for maize, 94% for soybeans and 96% for cotton.

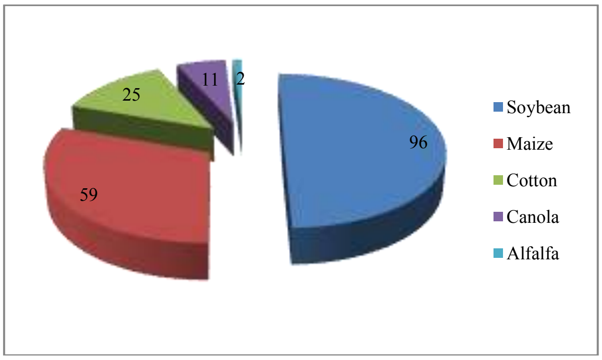

Fig. 3. The areas occupied by the main transgenic crops worldwide (million hectares)
Source: Own design based on [12].

GM soybean represents 50% of all biotechnological crops in the world. Over 96 million hectares, representing 78% of the total 124 million hectares dedicated to this crop, are cultivated with transgenic soybean. The largest growers of GM soybean are the USA (32 million hectares), Brazil (31 million hectares), Argentina (19 million hectares), Paraguay (3 million hectares), Canada (2 million hectares), Uruguay (1 million hectares), Bolivia (1 million hectares) (Figure 4) and, on smaller areas, South Africa and Chile.

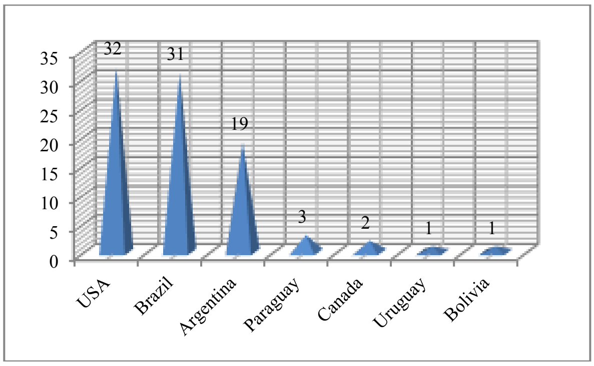

Fig. 4. The largest growers of GM soybean (million hectares)
Source: Own design based on [12].

The amount collected by GM soybean growers is over US$5 billion from each year.

GM maize production is concentrated in the USA, Brazil, Argentina, Canada, Paraguay and South Africa, but also other countries, their number being 14. The areas cultivated with GM maize worldwide are over 59 million hectares [12].

As for the areas cultivated with canola (GM rapeseed), they increased, worldwide, from 8.5 million hectares in 2016 to 10.5 million hectares in 2020. The increase was due to the global demand for edible oil. The big growers are the USA, Canada and Australia and Chile, which annually collect approx. $0.7 billion for canola production. It can be appreciated that areas sown to canola could increase significantly in the coming period, in response to the demand for vegetable oil and biodiesel [12]. Of the global total of 35 million hectares cultivated with rapeseed, 29%, i.e. 10.1 million hectares are cultivated with canola genetically modified hybrids.

Total intended area to GM sugar beet crops is about 480,000 hectares and is grown only in USA and Canada.

Other transgenic crops grown worldwide are:
- DroughtGard™ maize, drought tolerant (275,000 hectares in USA);
- Sweet corn (1000 hectares in USA);
- Papaya (8550 hectares in China and 1000 hectares in USA);
- Innate™ potato (2500 ha in USA). This GM potato can be stored for a longer time, does not brown after peeling and, prepared at high temperatures, has a low content of acrylamide, a potentially carcinogenic substance;
- Arctic GM apples oxidation-resistant (USA)
- Bt eggplant (700 hectares in Bangladesh), etc.

Three types of GM soybeans were authorized by the European Commission in 2020 for food use and fodder production, namely soybeans *MON 87708* (Genuity Roundup Ready *2Xtend*), *MON 89788* (Genuity Roundup Ready *2Yield*), respectively *A5547-127* (Liberty Link) [2]. The three GM soybean varieties went through a complex authorization procedure, which included a comprehensive favorable assessment by the European Food Safety Authority (EFSA). Even if it seems like good news for many Romanian farmers, who depend on imports of groats (mostly from transgenic soybeans), the authorization decision does not cover the cultivation process. European officials say that all member countries of the community block (EU27) had the right to express their point of view in the Permanent Committee and, subsequently, the Appeal Commission [2].

Future transgenic agricultural crops include beta-carotene-enriched golden rice tested in the Philippines and Bangladesh; Fusarium-resistant bananas and disease-resistant and drought-tolerant biotech wheat tested in Australia; high yielding and high biomass wheat in the United Kingdom; Uganda's *Desiree* and *Victoria* blight-resistant potato varieties; *Maris Piper* potato variety, resistant to nematodes and lower acrylamide content in EU; insect resistant chickpea and biotech mustard as a source of oil in India; drought-tolerant sugar beet in India and Indonesia; omega-3 enriched camelina in EU, etc. [11].

Starting with 2016, for the first time since Romania's accession to the European Union, the area cultivated with genetically modified plants locally reached zero [13]. The only genetically modified plant allowed by the European Commission, the *MON810* maize resistant to lepidopteran insects (produced by the American company Monsanto), was introduced into crops less and less until 2015, when it was still present on only 2.5 hectares at the Secuieni Agricultural Development Research Station, in Neamţ County [13].

According to Ministry of Agriculture data, in 2007, Romanian farmers they cultivated 332.5 hectares with GM maize, after which the areas suddenly increased to over 6,100 hectares in 2008, when 58 growers introduced it into cultivation. 2008 was, however, the only "boom" year for GM maize MON 810 in Romania because, subsequently, the areas significantly decreased year by year [13].

In 2015, in Romania began the field testing of GM plums, resistant to the plum virus (Bistrita Pomiculture Research and Development Station obtained the approval of the European Commission as early as 2011). The area cultivated with GM plums was 1200m^2 in 2015. However, the Research Companies in the field were no longer interested in doing tests on the EU territory, considering that the authorizations cost a lot and the prospects are limited [21].

Aspects of GM crops market

The global market of biotechnological agricultural crops reached the spectacular figure of over 186 billion dollars annually, of which approx. half the amount for the main GM crops (soybean, corn, cotton and canola), grown by farmers worldwide [12].

EU is one of the largest importers of agricultural products in the world. A substantial – and growing – share of these imports is transgenic crops. They are grown almost entirely in countries outside Europe, where farmers are free to choose between conventional and transgenic hybrids. The EU's import dependency is particularly high in the case of forage soybeans for the European livestock sector, as the production of bean soybeans in the EU states covers less than 5% of its own demand. The EU also imports significant quantities of GM maize and GM canola to meet domestic demand. For cotton, the EU is almost entirely dependent on imports in finished product form.

The amounts of transgenic soybeans imported annually by the EU are almost 34 million tons, i.e. over 60 kg for each of the approx. 500 million EU citizens. In terms of costs, the EU spends approx. €13 billion for imports of GM soybeans and groats, more than any other agricultural product. Almost all soybean production comes from America, where the adoption rate of GM technology exceeds 90%. The global agricultural biotechnology market for transgenic crops was USD 5.23 billion in 2021 and is expected to reach USD 12.07 billion by 2026, growing by 18.2% [20]. The respective estimates are stipulated in the US/Canada Report ″Global Agricultural Biotechnology Market for Transgenic Crops (2021-2026) by Type, Crop, Geography, Competitive Analysis and Covid-19 Impact″. The report provides a comprehensive assessment of the global agricultural biotechnology market for transgenic crops, including in-depth qualitative analysis, verifiable data from authentic sources, and market size projections. The projections are calculated using proven research methodologies.

Currently, given the context of the war between Russia and Ukraine, European farmers are preparing to buy more genetically modified feed from the US and Latin America, after the Russian invasion interrupted maize supplies from Ukraine [1]. The war in Ukraine has already forced companies to look for alternatives to sunflower oil, and the change in trade would also include maize, which is mainly used as animal feed. Non-genetically modified maize from Ukraine accounts for about half of the European Union's imports. Conversely, in the case of USA maize, approximately 92% is genetically modified, a similar percentage being valid in the case of that in Brazil. As the EU moves towards guaranteeing food security, the EU the community block also relaxes rules on imports [1].

The Academy of Agricultural and Forestry Sciences (ASAS) Romania has issued a statement regarding genetically modified plants, and the conclusion was that they do not pose risks to human health; the transgenic plants bring considerable benefits to farmers and are much more environmentally friendly than conventional technologies. Thus, as shown in the ASAS Communiqué, the use of transgenic plants in agriculture has a positive impact on the environment; globally, in the period 1996-2006, the use of these plants determined the reduction of pesticide consumption by 286 million kg, equivalent to the total amount of pesticide active ingredients used during one year on the arable surface of the EU [13].

While in Romania the uncultivated agricultural areas are increasing, in many countries of the world, both developed and developing, the areas cultivated with transgenic plants are expanding and the number and incomes of farmers which adopt new technologies constantly increase. At the same time, the ban without any scientific basis on the use of transgenic plants delays progress in agriculture, deprives farmers of the right to choose what they want to grow and reduces Romania's competitiveness on the global market.

According to ISAAA Report (2021), from 1996 to 2019, genetically modified agricultural crops contributed to food security, sustainability and environmental protection by:

- An increase in agricultural production valued at $150 billion;
- Avoiding the application of approx. 500 million kg of pesticides (in active substance);
- Reduction of CO_2 emissions, by reducing the number of pesticide treatments; for example, in 2016 alone, CO_2 emissions into the atmosphere were reduced by 28 billion kg, an amount equal to the amount of carbon dioxide that would no longer reach the atmosphere if 12.4 million automobiles were withdrawn from circulation; etc. [12].

CONCLUSIONS

With a rapidly growing population, humanity is increasingly dependent on the ability of biotechnology to develop and maintain a sustainable agriculture and a healthy environment. The innovative thinking of the specialists in the laboratories is doubled by concrete actions to create new GM plants with production and quality characteristics improved, safe for consumers and for environment.

Transgenic commercial crops have improved traits that give to the plant herbicide tolerance, disease and pest resistance, drought tolerance, health or nutritional benefits, a longer shelf life, or a industrial use more efficient, etc. Also, the GM crops contribute to sustainable ensuring of food security and environmental protection by agricultural production increase, reduction of the pesticides application amount and reduction of CO_2 emissions.

The main transgenic plant growing countries globally are: USA, Brazil, Argentina, Canada, India, Paraguay and China. The largest GM areas are occupied by soybean, maize, cotton, canola and alfalfa. Other transgenic plants authorized and grown worldwide are: sugar beet, potato, rice, papaya, tomatoes, sweet pepper, and various flower species.

GM foods production reduces the need for pesticides and increasing investment in the field of biotechnology research and development are fueling pace to growth of GM food market. The global agricultural biotechnology market for transgenic crops was 5.23 billion USD in 2021 and is expected to reach 12.07 billion USD in 2026, growing by 18.2%

The immense diversity of theoretical and practical implications that the field of genetic transformation in agriculture entails, as well as its future evolution, are not yet fully predictable, but the current information explosion creates the theoretical and practical framework necessary for continued research and, at the same time, opens new horizons.

REFERENCES

[1]Agerpres, 2022, https://www.agerpres.ro/economic-extern/, Accessed on January 10, 2023.

[2]Agrointeligența, 2020, Vaduva, I., Trei tipuri de soia modificata genetic, autorizate de Comisia Euroapeana pentru utilizare alimentara si productia de nutret (Three types of genetically modified soybean, authorized by The European Commission for food use and forage use), https://agrointel.ro/159914, Accessed on January 10, 2023.

[3]Bonciu, E., 2019, The climate change mitigation through agricultural biotechnologies, Annals of the University of Craiova-Agriculture, Montanology, Cadastre Series, 49(1):36-43.

[4]Cai, Q., Qiao, L., Wang. M., He, B., Lin, F.M., Palmquist, J., Huang, S.D., Jin, H., 2018, Plants send small RNAs in extracellular vesicles to fungal pathogen to silence virulence genes, Science, 360:1126-1129.

[5]Catanzariti, A.M., Lim, G.T., Jones, D.A., 2015. The tomato I-3 gene: a novel gene for resistance to *Fusarium wilt* disease, New Phytologist, 207:106-118.

[6]Cotuna, O., Paraschivu, M., Sărățeanu, V., 2022a, Charcoal rot of the sunflower roots and stems (*Macrophomina phaseolina* (Tassi) Goid.) - an overview, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 22(1):107-116.

[7]Cotuna, O., Paraschivu, M., Sărăţeanu, V., Horablaga, M.N., Durău, C.C., 2022b, Research regarding the contamination with *Fusarium spp*. of the wheat grains from the variety *Triticum aestivum ssp. spelta* before and after the treatment with bio-fungicide - case study, Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1:266-273.

[8]Cotuna, O., Paraschivu, M., Bulai, A., Toma, I., Sărăţeanu, V., Horablaga, N.M. Buzna, C., 2021, Behaviour of some oat lines to the attack of the fungus *Blumeria graminis* (D.C.) *f.* sp. *avenae* EM. Marchal, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 21(4):161-170.

[9]De Souza, C.P., Bonciu, E., 2022a, Progress in genomics and biotechnology, the key to ensuring food security. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 22(1), 149-157.

[10]De Souza, C.P., Bonciu, E., 2022b, Use of molecular markers in plant bioengineering. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 22(1), 159-166.

[11]European Biotechnology, 2021, Industria biotech 2023, https://european-biotechnology.com, Accessed on January 10, 2023.

[12]ISAAA, 2021, Biotec Information Resources, https://www.isaaa.org/resources/, Accessed on January 10, 2023.

[13]MADR, Genetically Modified Organisms, 2022, http://www.madr.ro/, Accessed on January 10, 2023.

[14]Market Watch, 2021, Gene Editing Market: Future Scope, Revenue, Top Trends, Growth Opportunity, Regional Outlook, https://www.marketwatch.com, Accessed on January 12, 2023.

[15]Michno, J.M., Virdi, K., Stec, A.O., et al., 2020, Integration, abundance, and transmission of mutations and transgenes in a series of CRISPR/Cas9 soybean lines. BMC Biotechnol., Vol. 20(10):1-13.

[16]Moshelion, M., Altman, A., 2015, Current challenges and future perspectives of plant and agricultural biotechnology, Trends in Biotechnology, 33(6):337-342.

[17]Nemudryi, A.A., Valetdinova, K.R., Medvedev, S.P., Zakian, S.M., 2014, TALEN and CRISPR/Cas Genome Editing Systems: Tools of Discovery, Acta naturae, Vol. 6(3):19-40.

[18]Paraschivu, M., Matei, G., Cotuna, O., Paraschivu, M., Drăghici, R., 2021, Reaction of rye cultivars to leaf rust (*P. recondita f.* sp. *secalis*) in the context of climate change in dry area in southern Romania, Scientific Papers. Series A. Agronomy, Vol. LXIV, No. 1: 500-507.

[19]Park, D., Park, S.H., Ban, Y.W. et al., 2017, A bioinformatics approach for identifying transgene insertion sites using whole genome sequencing data, BMC Biotechnol., Vol. 17(67):1-8.

[20]Research and markets, 2022, https://www.researchandmarkets.com/reports, Accessed on January 16, 2023.

[21]USDA Report, 2020, https://apps.fas.usda.gov/, Accessed on January 14, 2023.

[22]Velea, L., Bojariu, R., Burada, C., Udristioiu, M.T., Paraschivu, M., Burce, R.D., 2021, Characteristics of extreme temperatures relevant for agriculture in the near future (2021-2040) in Romania, Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, Vol. X:70-75.

[23]What are TALENs? Infographics, 2021, https://www.isaaa.org/resources/, Accessed on January 10, 2023.

[24]World Declaration and Plan of Action for Nutrition, 1992, https://www.fao.org/, accessed on January 16, 2023.

[25]Woźniak-Gientka, E., Tyczewska, A., Perisic, M., Beniermann, A., Eriksson, D., Vangheluwe, N., Gheysen, G., Cetiner, S., Abiri, N., Twardowski, T., 2022, Public perception of plant gene technologies worldwide in the light of food security, GM Crops & Food, 13(1):218-241.

[26]Zheng, Q., Wang, H.H.. 2021, Do consumers view the genetically modified food labeling systems differently? "Contains GMO" versus "Non-GMO" labels, China Econ., Vol. 54(6):376-388.

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