BioTechnologia vol. 103 (2) • pp. 185–201 • 2022
Journal of Biotechnology, Computational Biology and Bionanotechnology RESEARCH PAPERS
http://doi.org/10.5114/bta.2022.116212

Public opinion on biotechnology and genetic engineering in the European Union: Polish consumer study

EWA WOŹNIAK-GIENTKA*, AGATA TYCZEWSKA, TOMASZ TWARDOWSKI

[1] Institute of Bioorganic Chemistry, Polish Academy of Sciences, Poznań, Poland

Abstract

The aim of the article is to show the current state of public opinion of Poles on biotechnology and genetic engineering in the context of European Union countries. The authors refer to the results of their own study based on a survey conducted in 2019 in Poland. To introduce the matter of public opinion on biotechnology and genetic engineering in the European Union a short review of research related to the topic is presented, showing discrepancies in perception of biotechnology and genetic engineering. The results of the survey showed that more than half of Poles noticed that products obtained by genetic engineering techniques are available on the market. Despite the fear of the research in the field of biotechnology and genetic engineering, 39 to 69% (depending on the subject of research) of Poles supported them. Moreover, 62% of Poles were opponents of genetically modified feeds as they believed that they can be harmful to human life and health. The findings regarding the current consumer perception, knowledge, and attitude towards genetically modified foods and feeds will help in building strategic approaches to educating society about genetically modified organisms and genetically modified products.

Key words: biotechnology; genetic engineering; agribiotechnology; social attitude; public perception

Introduction

Handling, preparation, and storage of food to avoid potential health hazards in ways that prevent food-borne illnesses at every step of the food chain all fall under food safety. As indicated by the World Health Organisation (WHO) more than 200 diseases (ranging from diarrhoea to cancer) are caused by unsafe food containing bacteria, viruses, parasites, or chemical substances. Importantly, foodborne diseases impede socioeconomic development by impairing healthcare systems as approximately 600 million people fall ill after eating contaminated food, and as a result, 420 000 people die every year (WHO, 2020). This situation influences not only national health services but also economies, tourism, and trade as well. Ensuring global food safety necessitates a good collaboration between governments, producers, and consumers.

The World Food Summit (1996) defines food security as "foods that are sufficient, safe and nutritious to meet dietary needs and food preferences for an active and healthy life to all people at all times". Unfortunately, hunger, food insecurity, and malnutrition remain widespread (Borras and Mohamed, 2020). This situation is worsened by climate change which is among the factors that negatively influence the amount and nutrition of foods. Enormous escalation in fossil fuel production that results in increasing greenhouse gas emissions (GHG) is among the predominant elements limiting agricultural productivity (Tyczewska et al., 2019; Leisner, 2020; McGrath and Lobell, 2013; Loladze, 2014; Myers et al., 2014). Such decline in crop yield and at the same time its nutrition are associated with abiotic and biotic stresses. Extreme temperatures, alterations in precipitation, and increased occurrence of extreme weather events across the globe prevent crops from growing and challenge adequate and nutritious food production (Tyczewska et al., 2019; Leisner, 2020; Teixeira et al., 2013; Yang et al., 2016; Hussain et al., 2018; Nakashima et al., 2014). The situation becomes even more serious when we take into account the increasing global population,

* Corresponding author: Institute of Bioorganic Chemistry, Polish Academy of Sciences, Noskowskiego 12/14, 61-704 Poznań, Poland; e-mail: ewozniak@ibch.poznan.pl

estimated to reach more than 9 billion people by 2050 (Fedoroff et al., 2010; Tyczewska et al., 2019). Moreover, the current food production levels are not enough to feed such a large population and it has been determined that they must be doubled (Ray et al., 2013; Tyczewska et al., 2019).

The recent advances in molecular biology and genetic engineering techniques open new horizons and possibilities for the future of agribiotechnology (see Glossary). Importantly, GM plants can help address some of the challenges that are ahead of the human race like reducing fossil fuel use (as the source of biomass: wood pellets, grasses, microalgae, for heating and energy production), greenhouse gas emissions (by applying no-tillage agricultural practices), production of large amounts of nutritious food and feed (eg. stress-tolerant varieties, fortified with nutrients). Unfortunately, genetically modified (GM) technology is extremely controversial for nowadays global food consumers (Cui and Shoemaker, 2018). The commercial development of GM crops started in 1996 with GM corn and has been developing further every year with the increasing cultivation of GM crops. According to the International Service for the Acquisition of Agri-biotech Applications (ISAAA, 2019) in 2019 global land use for GM crops reached 190.4 million hectares.

New technologies, such as transgenesis and targeted mutagenesis, have the potential to provide sustainable agriculture and food security by expanding agricultural yields, decreasing pesticide usage, and increasing the nutritional value of crops products (Klumper and Qaim, 2014; Barrows et al., 2014; Hansson et al., 2018). According to Woźniak et al. (2020), the strongest limitations happen in the field of agribiotechnology and are associated with "legal obstacles for marketing and further sale of such technologies as effects of genetic engineering". Farmers require the most innovative technologies to be competitive, allowing yields to increase and to export the goods. Prohibiting innovative plant breeding technologies, such as genome editing will cause the dependence of farmers on older, less efficient technologies, resulting in lower yields and decreasing the competitiveness of European farmers compared to those from other parts of the world where the farming of GMOs is less restricted (Smyth and Lassoued, 2019).

The transition towards biotechnology and genetic engineering depends not only on the efforts and interests of experts and policymakers but also on the acceptance and involvement of society. The importance of gaining insight into people's perceptions of new technologies can be described in the case of genetic modification. Even though the experts see many benefits to genetic modification, this technology is not generally accepted and might even be discarded by users (Sijtsema et al., 2016). In fact, worldwide consumers are concerned about the use of GM crops for food purposes (Kim et al., 2018; Kubisz et al., 2021; Woźniak et al., 2021; Sikora and Rzymski, 2021; Lassoued et al., 2019).

Due to the fact that the transition towards a "bio-based society" is still at an early stage, it is important to consider what types of expectations and concerns consumers have. As noted by Aguilar et al. (2019) future bioeconomy requires not only people's involvement and engagement but a new systemic approach. In this article, the results of research on the social attitudes of Poles toward GM food and feed on the background of the opinions of citizens of other European countries are described and discussed.

Materials and methods

Participants

The target population (respondents) constituted residents of Poland over 15 years old. The survey was distributed to all 16 administrative divisions of Poland (so-called voivodeships). The sample was random-quota and was selected from the sampling TERYT address. Layering takes into account the size of the locality and territorial distribution within voivodeships, as well as the gender and age of the selected people. The basis for layering was demographic data contained in the publication of the Central Statistical Office *Population. State and structure in the territorial division* (CSO, 2019).

Questionnaire design

Ten questions were designed to investigate 1) the awareness about products obtained by genetic engineering techniques, 2) the opinion about different applications of biotechnology and genetic engineering, 3) general opinion about GM feeds. Questions were precisely prepared by the authors and were submitted for implementation to the external company in 2019. In addition, the respondents were asked about their socio-demographic characteristics, including sex, age, educational

level[1], income and region of residence. The questionnaire was prepared in Polish (see supplementary material[2]). Due to the incomplete number of people determining their income level, this characteristic was excluded from the analysis.

Data collection

The survey of Poles' opinions on biotechnology and genetic engineering was carried out using the technique of direct interviews – Computer-Assisted Personal Interviewing (CAPI) in the homes of the respondents. The total number of surveys completed was 1008. Interviews were conducted on August 23–28, 2019, as part of a cyclical omnibus study. The questionnaire was in Polish and took about 20 minutes to complete.

Data analysis

All collected data were entered into a multivariate Excel worksheet.

Statistical analyses

Analysis was carried out in R software, version 4.0.5. The relationship between variables was verified using the chi-square test, including Cramer's V effect size measure. All tests were based on $\alpha = 0.05$.

Results

Demographic characteristics

In total, 1008 respondents took part in a survey, including 483 men and 525 women. A detailed presentation of the socio-economic characteristics of Polish respondents is provided in Table 1.

Table 1. Socio-economic characteristics of respondents

Feature	Number of respondents
Poland	*n* = 1008
Gender *n* [%]	
man	483 (48)
woman	525 (52)
Age *n* [%]	
15–29	231 (23)
30–39	195 (19)
40–49	153 (15)
50–59	167 (17)
60+	262 (26)
Education *n* [%]	
basic	203 (20)
vocational	249 (25)
upper-secondary	335 (33)
tertiary	221 (22)
Income*	
to 1000 PLN	42
1001–2000 PLN	170
2001–3000 PLN	189
more than 3000 PLN	142
Region of residence *n* [%]	
North	100 (10)
East	191 (19)
West	174 (17)
Central	243 (24)
South	300 (30)

* excluded from the analysis due to not sufficient data

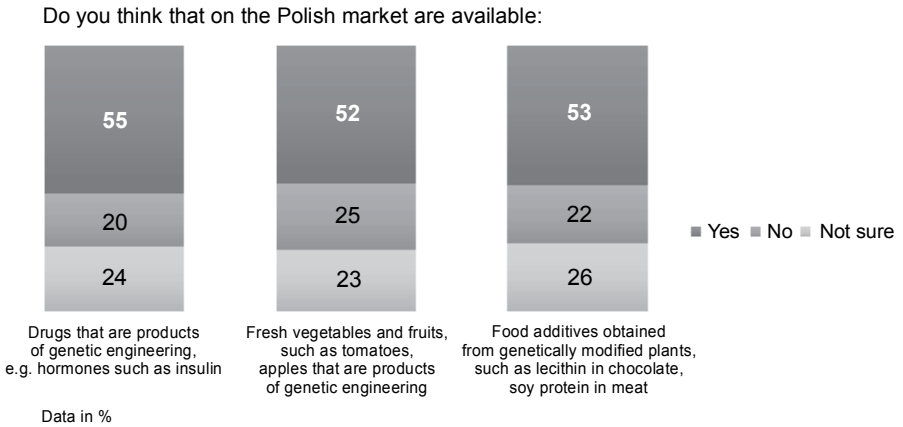

Fig. 1. Public opinion about availability of products of genetic engineering on the Polish market

Consumers' knowledge and attitudes towards GM food

In Poland in 2019, more than 50% of Poles believed that on their market products obtained by genetic engineering techniques (drugs, vegetables, fruits and food) were available (Fig. 1).

Polish women were slightly more aware of the availability of drugs (F58%, M53%) [3] and food additives (F54%, M52%) that are the products of genetic engineering on the Polish market than men. In the 30–39 age group – about 60% of respondents believed that drugs that are genetic engineering products are available on the Polish market. When it comes to the presence of vegetables and fruits obtained by genetic engineering techniques greater awareness was among people from the older age group (40–49 years old – 57%, 50–59 years old – 56% of respondents). In terms of awareness of the availability of food additives obtained from GM plants on the Polish market similar results were obtained in three age groups: 30–39 (57%); 40–49 (57%) and 50–59 (58%).

There was a significant relationship between knowledge on the availability of products of genetic engineering on the Polish market and education ($P < 0.001$ for the availability of drugs, $P = 0.002$ for the availability of fruits/vegetables and $P = 0.018$ for the availability of food additives). For all areas of knowledge verification (availability of drugs, fruits/vegetables and food additives), the higher the education level, the greater was the percentage of responses confirming availability. The effect size of the dependency between education and knowledge on the availability of products of genetic engineering was weak (for the area of food additives, $V = 0.087$) to moderate (for the areas of drugs, $V = 0.112$ and fruits/vegetables, $V = 0.102$) (Table 2).

Importantly, only one in four (24%) Poles said that the production and sale of transgenic food should be allowed (Fig. 2). Over half of the respondents (52%) wanted it to be banned, and 24% of respondents did not have an opinion on this subject. Interestingly, people with basic education slightly more often (28%) than those with higher education (24%) believed that producing and selling transgenic food should be allowed. Respondents living in the central and southern parts of Poland were more likely to advocate a ban on the production and sale of GM food.

There was a statistically significant relationship between knowledge of the availability of products of genetic engineering on the Polish market and the opinion that GM plants should be cultivated in Poland to ensure food and feed security ($P < 0.001$ for all 3 areas of knowledge verification) – with very strong effect size.

Table 2. Knowledge of the availability of products of genetic engineering in the Polish market against education

Do you think that on the Polish market are available:	Education				Test statistics	*P*
	basic	vocational	upper-secondary	tertiary		
	$N = 203$	$N = 249$	$N = 335$	$N = 221$		
drugs that are products of genetic engineering, e.g. hormones such as insulin?						
Yes	93 (45.7)	124 (49.8)	200 (59.6)	142 (64.4)	$\chi^2 = 25.28$ $df = 6$ $V = 0.112$	< 0.001
No	46 (22.8)	50 (20.0)	64 (19.0)	43 (19.7)		
Difficult to say	64 (31.6)	75 (30.2)	72 (21.4)	35 (15.9)		
fresh vegetables and fruits, such as tomatoes, apples						
Yes	101 (49.9)	112 (45.0)	174 (51.8)	134 (60.4)	$\chi^2 = 21.15$ $df = 6$ $V = 0.102$	0.002
No	42 (20.6)	68 (27.1)	91 (27.1)	55 (24.8)		
Difficult to say	60 (29.5)	69 (27.9)	71 (21.1)	33 (14.8)		
food additives obtained from genetically modified plants, such as lecithin in chocolate, soy protein in meat?						
Yes	95 (46.9)	121 (48.7)	184 (54.9)	132 (59.6)	$\chi^2 = 15.37$ $df = 6$ $V = 0.087$	0.018
No	42 (20.8)	56 (22.6)	69 (20.5)	51 (23.0)		
Difficult to say	66 (32.4)	72 (28.7)	83 (24.6)	39 (17.5)		

Data presented as *n* (% of education group); analysis with chi-square test; χ^2 – chi-square statistics, *df* – degrees of freedom, *V*-Cramer's – *V* effect size

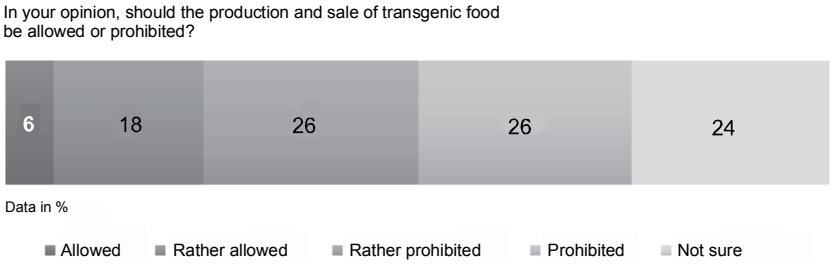

Fig. 2. Public opinion about production and sale of transgenic food

Table 3. Opinion about GM plants vs. knowledge on the availability of products of genetic engineering on the Polish market

Q5: Do you think that genetically modified plants should be cultivated in Poland to ensure food and feed security?	Do you think that on the Polish market are available: drugs that are products of genetic engineering, e.g. hormones such as insulin?			Test statistics	*P*
	yes	no	difficult to say		
	N = 559	*N* = 203	*N* = 246		
Yes	73 (13.1)	23 (11.3)	8 (3.3)	χ^2 = 138.17 *df* = 8 *V* = 0.262	< 0.001
Rather yes	142 (25.4)	44 (21.7)	24 (9.8)		
Rather no	128 (22.9)	53 (26.1)	51 (20.7)		
No	136 (24.3)	67 (33.0)	55 (22.4)		
Not sure	80 (14.3)	16 (7.9)	109 (44.3)		
	Do you think that on the Polish market are available: fresh vegetables and fruits, such as tomatoes, apples			Test statistics	*P*
	yes	no	difficult to say		
	N = 521	*N* = 255	*N* = 233		
Yes	73 (14.0)	20 (7.8)	11 (4.7)	χ^2 = 119.98 *df* = 8 *V* = 0.244	< 0.001
Rather yes	143 (27.4)	44 (17.3)	22 (9.4)		
Rather no	110 (21.1)	66 (25.9)	56 (24.0)		
No	122 (23.4)	88 (34.5)	48 (20.6)		
Not sure	72 (13.8)	36 (14.1)	95 (40.8)		
	Do you think that on the Polish market are available: food additives obtained from genetically modified plants, such as lecithin in chocolate, soy protein in meat?			Test statistics	*P*
	yes	no	difficult to say		
	N = 532	*N* = 218	*N* = 258		
Yes	43 (8.3)	11 (4.3)	4 (1.7)	χ^2 = 108.08 *df* = 8 *V* = 0.231	< 0.001
Rather yes	104 (20.0)	51 (20.0)	22 (9.4)		
Rather no	137 (26.3)	69 (27.1)	56 (24.0)		
No	142 (27.3)	71 (27.8)	51 (21.9)		
Not sure	95 (18.2)	52 (20.4)	99 (42.5)		

Data presented as *n* (% of group from column); analysis with chi-square test; χ^2 – chi-square statistics, *df* – degrees of freedom, *V*-Cramer's – *V* effect size

Table 4. Q6 against knowledge on the availability of products of genetic engineering on the Polish market

Q6: Do you think that using genetically modified feeds should be banned in Poland, even if this would lead to an increase in production costs for milk, eggs, poultry?	Do you think that on the Polish market are available: drugs that are products of genetic engineering, e.g. hormones such as insulin?			Test statistics	*P*
	yes	no	difficult to say		
	N = 559	*N* = 203	*N* = 246		
Yes	167 (29.9)	47 (23.2)	49 (19.9)	χ^2 = 114.37 *df* = 8 *V* = 0.238	< 0.001
Rather yes	190 (34.0)	60 (29.6)	70 (28.5)		
Rather no	80 (14.3)	44 (21.7)	24 (9.8)		
No	29 (5.2)	34 (16.7)	7 (2.8)		
Not sure	92 (16.5)	19 (9.4)	96 (39.0)		
	Do you think that on the Polish market are available: fresh vegetables and fruits, such as tomatoes, apples			Test statistics	*P*
	yes	no	difficult to say		
	N = 521	*N* = 255	*N* = 233		
Yes	151 (29.0)	67 (26.3)	46 (19.7)	χ^2 = 56.80 *df* = 8 *V* = 0.168	< 0.001
Rather yes	164 (31.5)	85 (33.3)	71 (30.5)		
Rather no	89 (17.1)	37 (14.5)	21 (9.0)		
No	33 (6.3)	27 (10.6)	10 (4.3)		
Not sure	84 (16.1)	38 (14.9)	84 (36.1)		
	Do you think that on the Polish market are available: food additives obtained from genetically modified plants, such as lecithin in chocolate, soy protein in meat?			Test statistics	*P*
	yes	no	difficult to say		
	N = 532	*N* = 218	*N* = 258		
Yes	165 (31.0)	53 (24.3)	45 (17.4)	χ^2 = 82.33 *df* = 8 *V* = 0.202	< 0.001
Rather yes	168 (31.6)	76 (34.9)	77 (29.8)		
Rather no	78 (14.7)	43 (19.7)	26 (10.1)		
No	37 (7.0)	22 (10.1)	11 (4.3)		
Not sure	84 (15.8)	24 (11.0)	99 (38.4)		

Data presented as *n* (% of group from column); analysis with chi-square test; χ^2 – chi-square statistics, *df* – degrees of freedom, *V*-Cramer's – *V* effect size

Responders who were giving confirming responses on the availability of GM drugs, fruits/vegetables and food additives were more frequently presenting a positive opinion (responses 'Yes' or 'Rather yes') in the area that GM plants should be cultivated in Poland to ensure food and feed security. Additionally, responders, who had difficulty in answering questions verifying their knowledge of GM products in all 3 areas were also more often not sure about their opinion on the production and sales of this type of product (Table 3).

There was a statistically significant relationship between knowledge of the availability of products of genetic engineering on the Polish market and the opinion that using GM feeds should be banned in Poland, even if this would lead to an increase in production costs for milk, eggs, poultry ($P < 0.001$ for all 3 areas of knowledge verification) – with strong or very strong effect size. Responders who were giving confirming responses on the availability of GM drugs, fruits/vegetables, and food additives were more frequently presenting the con-

Table 5. Q8 against knowledge on the availability of products of genetic engineering on the Polish market

Q8: In your opinion, should the production and sale of transgenic food be allowed or prohibited?	Do you think that on the Polish market are available: drugs that are products of genetic engineering, e.g. hormones such as insulin?			Test statistics	*P*
	yes	no	difficult to say		
	N = 559	*N* = 203	*N* = 246		
Allow	38 (6.8)	17 (8.4)	4 (1.6)	$\chi^2 = 99.55$ *df* = 8 *V* = 0.222	< 0.001
Rather allow	110 (19.7)	46 (22.7)	20 (8.1)		
Rather prohibit	145 (25.9)	57 (28.1)	60 (24.4)		
Prohibit	162 (29.0)	54 (26.6)	48 (19.5)		
Not sure	104 (18.6)	28 (13.8)	114 (46.3)		
	Do you think that on the Polish market are available: fresh vegetables and fruits, such as tomatoes, apples			Test statistics	*P*
	yes	no	difficult to say		
	N = 521	*N* = 255	*N* = 233		
Allow	43 (8.3)	11 (4.3)	4 (1.7)	$\chi^2 = 68.30$ *df* = 8 *V* = 0.184	< 0.001
Rather allow	104 (20.0)	51 (20.0)	22 (9.4)		
Rather prohibit	137 (26.3)	69 (27.1)	56 (24.0)		
Prohibit	142 (27.3)	71 (27.8)	51 (21.9)		
Not sure	95 (18.2)	52 (20.4)	99 (42.5)		
	Do you think that on the Polish market are available: food additives obtained from genetically modified plants, such as lecithin in chocolate, soy protein in meat?			Test statistics	*P*
	yes	no	difficult to say		
	N = 532	*N* = 218	*N* = 258		
Allow	38 (7.1)	17 (7.8)	4 (1.6)	$\chi^2 = 79.33$ *df* = 8 *V* = 0.199	< 0.001
Rather allow	106 (19.9)	46 (21.1)	25 (9.7)		
Rather prohibit	136 (25.6)	55 (25.2)	71 (27.5)		
Prohibit	155 (29.1)	61 (28.0)	48 (18.6)		
Not sure	96 (18.0)	39 (17.9)	110 (42.6)		

Data presented as *n* (% of group from column); analysis with chi-square test; χ^2 – chi-square statistics, *df* – degrees of freedom, *V*-Cramer's – *V* effect size

firming opinion (responses 'Yes' or 'Rather yes') on banning sales of GM feeds.

Additionally, responders, who had difficulty in answering questions verifying their knowledge of GM products in all 3 areas were also more often not sure about their opinion on the sales ban of this type of product (Table 4). There was a statistically significant relationship between knowledge of the availability of products of genetic engineering on the Polish market and the opinion that the production and sale of transgenic food should be allowed or prohibited ($P < 0.001$ for all 3 areas of knowledge verification) – with strong or very strong effect size. Responders, who had difficulty in answering questions verifying their knowledge of GM products in all 3 areas were also more often not sure about their opinion on the production and sales of transgenic food (Table 5).

Over half of Poles (60%) would not be convinced by such features of transgenic food as lower price, better nutrition value, better taste and appearance, and longer durability (Fig. 3). Increased nutritional value was the most encouraging and would convince 31% of respondents. Longer durability of food (28% of respondents),

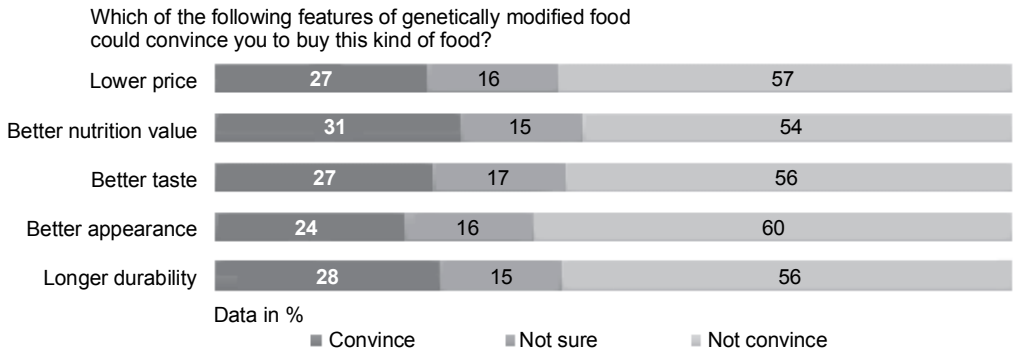

Fig. 3. Public opinion about features of GM food

lower price (27%) and better taste (27%) were the remaining important factors. A better look, indicated by 24% of respondents, was the least encouraging.

Features of GM food that could convince people to buy this kind of food were significantly related to education level ($P < 0.001$ for each feature with moderate effect size): For each feature, the percentage of responses 'Would convince' was declining with growth in education level. At the same time for each feature analysis the percentage of responses 'Would not convince' was increasing with the growing education level. Additionally, the percentage of unsure responders was declining with growth in education level (Table 6). There were no significant differences in the features of GM food that could convince to buy this kind of food against sex and age ($P > 0.05$).

Opinion on different applications of biotechnology and genetic engineering

In question 2 respondents were asked to indicate if they agreed or disagreed with different sentences related to biotechnology and genetic engineering. The first sentence referred to using new methods of biotechnology and genetic engineering in the **production and processing of food**. As a result, almost half of the respondents (47%) answered that this research should be conducted and supported. However, 61% of respondents said that new methods of biotechnology and genetic engineering may involve a risk to human health or the environment. Almost 74% of respondents thought that such research must be controlled by the government and regulated by law. Relationship between age and opinion: 'Regardless of the type of research, it (using new methods of biotechnology and genetic engineering in the production and processing of food) must be controlled by the government and regulated by law' was statistically significant ($P = 0.047$), but with a very weak strength ($V = 0.081$). The percentage of responders who strongly agreed with this statement was higher in groups 50–59 years and above 60 years (47% and 37% respectively) vs. 29% and 30% in age groups of 15–29 years and 30–39 years. Younger responders more often gave the response "Agree" than older age groups. Relationship between education and opinion: 'This research (using new methods of biotechnology and genetic engineering in the production and processing of food) may involve a risk to human health or the environment was statistically significant ($P = 0.012$) with weak effect size ($V = 0.092$). The percentage of positive responses was growing with education (52% in the basic education group for responses 'Agree' or 'Strongly agree' to 70% in the tertiary education group).

Approximately every third Pole believed that the use of modern biotechnology in **food production**, e.g. to increase the protein content, extend the shelf life, or change the taste, is useful (33%), should be supported (31%) and can be accepted (32%). At the same time, there were more people who considered it harmful (45%), believed that it should be banned (46%) and could not be accepted (46%). Forty seven percent of women and 44% of men believed that the use of modern biotechnology in food production was harmful. This opinion was expressed by 46% of Poles aged 40–49 and 47% aged 50–59, 56% of respondents agreeing with this statement had a tertiary level of education. Using modern biotechnology in food production should be banned according to almost 50% of women and 43% of men. Interestingly, 46% of respondents supporting this narration were aged between 50 and 60+, 52% had higher education. Research related to GM food production was not acceptable to 49% of women and 44% of men.

Table 6. Features of genetically modified food that could convince to buy this kind of food against education

Which of the following features of genetically modified food could convince you to buy this kind of food?	Education				Test statistics	*P*
	basic	vocational	upper-secondary	tertiary		
	N = 203	*N* = 249	*N* = 335	*N* = 221		
Lower price						
convince	67 (33.1)	65 (25.9)	91 (27.3)	45 (20.4)	$\chi^2 = 31.08$ *df* = 6 *V* = 0.110	< 0.001
not convince	90 (44.6)	132 (53.2)	200 (59.7)	151 (68.1)		
not sure	45 (22.3)	52 (20.9)	44 (13.0)	25 (11.4)		
Better nutrition value						
convince	67 (33.0)	64 (25.9)	117 (34.9)	62 (28.1)	$\chi^2 = 28.83$ *df* = 6 *V* = 0.113	< 0.001
not convince	94 (46.1)	131 (52.6)	181 (54.1)	137 (62.0)		
not sure	43 (21.0)	54 (21.5)	37 (11.0)	22 (10.0)		
Better taste						
convince	66 (32.4)	64 (25.6)	94 (28.2)	51 (23.1)	$\chi^2 = 27.27$ *df* = 6 *V* = 0.102	< 0.001
not convince	90 (44.2)	134 (53.6)	194 (58.0)	146 (66.2)		
not sure	48 (23.4)	52 (20.7)	47 (13.9)	24 (10.7)		
Better appearance						
convince	57 (27.9)	52 (21.1)	83 (24.8)	49 (22.0)	$\chi^2 = 24.49$ *df* = 6 *V* = 0.101	< 0.001
not convince	98 (48.1)	149 (59.8)	211 (63.0)	146 (66.1)		
not sure	49 (24.1)	48 (19.2)	41 (12.2)	26 (11.9)		
Longer durability						
convince	70 (34.4)	65 (26.2)	93 (27.8)	56 (25.4)	$\chi^2 = 37.84$ *df* = 6 *V* = 0.127	< 0.001
not convince	86 (42.2)	133 (53.5)	207 (61.9)	143 (64.5)		
not sure	48 (23.5)	50 (20.3)	35 (10.3)	22 (10.1)		

Data presented as *n* (% of education group); analysis with chi-square test; χ^2 – chi-square statistics, *df* – degrees of freedom, *V*-Cramer's – *V* effect size

More than half of Poles (59%) said that using microorganisms during the production of food products such as bread, beer and yoghurt should be conducted and supported. Moreover, 55% of respondents thought that this kind of research may involve a risk to human health or the environment. The percentage of positive responses was growing with education (45% in the basic education group and 46% in the vocational education group for responses 'Agree' or 'Strongly agree' to 60% in the tertiary education group). The percentage of undecided responders was declining with a growing level of education (from 22% in the basic education group to 13% in the tertiary education group). Seventy two percent of respondents answered that the research of using microorganisms during the production of food products must be controlled by the government and regulated by law.

Interestingly, even if Poles supported research in the field of biotechnology and genetic engineering, they were afraid of them. Forty eight percent of respondents said that research related to using biotechnology and genetic engineering in **breeding livestock** (so that animals are immune to diseases, grow better, give more meat or milk) should be conducted and supported. However, 62% of Poles believed that they have an impact on health and the environment. Such an opinion belonged to 65% of Poles aged 15–29 years, 68% of those with a tertiary level of education. Seventy three percent of Poles thought that this research must be controlled by the government and regulated by law.

Sixty four percent of Poles were positive about using biotechnology and genetic engineering in the production of **new vaccines and drugs** and believed that they

should be conducted and supported. Slightly less, 58% of respondents were afraid that such research may pose a threat to human health and the environment. On the other hand, 75% of respondents believed that they must be controlled by the government and regulated by law (claimed by 83% of respondents with a tertiary level of education). Sixty six percent of men and sixty two percent of women said that research related to the production of new vaccines and drugs should be supported. This was the opinion of 71% of Poles aged 15–29 years, on a tertiary level of education (66%).

About 69% of Poles said that **using microorganisms to treat sewage** and other wastes should be carried out and supported. Fifty four percent of respondents believed that they may pose a threat to human health and the environment, and 74% thought that such research must be controlled by the government and regulated by law. Seventy one percent of women and 67% of men said that such research should be supported. Such an opinion was expressed by 73% of Poles aged 15–29 years, on a tertiary level of education (73%).

According to 44% of Poles, using biotechnology by isolating genes responsible for **plant resistance to insects** and their use in the production of other plants, so that they are also resistant to insects was useful, the same percentage of respondents thought that it should be supported, and 45% that it is acceptable. Twenty six percent of respondents were convinced of the harmfulness of such use of biotechnology, 26% wanted to prohibit it, and for every fourth (25%) it was unacceptable.

Almost half (47%) of Poles assessed the usefulness of **introduction of human genes** into bacteria to obtain medicines or vaccines valuable in human treatment. Forty eight percent of respondents believed that such use of genetic engineering should be supported, and for 49% it was acceptable. Every fourth (25%) respondent considered them harmful and the same percentage would like to ban such practices. Moreover, for 22% of Poles, they were unacceptable.

Forty one percent of Poles found it useful to **breed GM animals** used for laboratory tests. For 39% of respondents, it should be supported and for 41% it was acceptable. According to 24% of respondents, such use of genetic engineering was harmful, 25% would like to ban it, and for 22% it was unacceptable. It is worth mentioning that more than 1/3 of people did not know how to assess this specific application of genetic engineering.

Genetic alteration of microorganisms in order to use them to purify the environment was useful for over half (55%) of Poles. Men more often than women pointed out the utility of such research (M58%; F53%). Fifty four percent said that such research should be supported, and for 55% they were acceptable. Respectively, 20%, 21% and 19% of respondents considered them harmful, wanted to ban them and assess them as unacceptable. Sixty percent and 59% of respondents supporting the use of microorganisms were Poles aged 30–39 and 40–49, respectively, on upper-secondary (57%) and tertiary (63%) levels of education. Fifty seven percent of men and 52% of women said that research related to using microorganisms to purify the environment should be supported. The main groups of the supporters constituted people aged 40–49 (58%) and 50–59 (59%), on upper-secondary (56%) and tertiary (60%) levels of education. Moreover, this application of biotechnology could be accepted for moral reasons by almost 60% of men and 51% of women.

The most controversial application of biotechnology and genetic engineering was **introducing human genes to animals** to produce transplant organs for humans. It was useful in the opinion of 39% of respondents. Such practices were supported by 37%, and 38% believed that this was acceptable. Every fourth (24%) of Poles saw such technologies as harmful, 23% would like to ban them, and for 21% they were unacceptable. A significant part of the population (between 37% and 40%) did not know what to think about this issue. Better educated people were more often willing to accept the use of genetic engineering to help clean the environment, but when modifications related to animals or food were involved, such issues were slightly easier acceptable to less educated people. Interestingly, 42% of Poles who supported such application of biotechnology were between 15 and 29 years of age, and 40% had upper-secondary education. Contrarily, 41% of those who wanted to ban it were between 50 and 59 years of age, and 44% with higher education. Younger respondents (age 15–29 (43%)) claimed that this application could be accepted, whereas older Poles indicated that this application could not be accepted (age 40–49 (42%)) for moral reasons.

Opinion about GM feeds

In 2019, 62% of Poles believed that products derived from animals fed with GM feed can be harmful to human

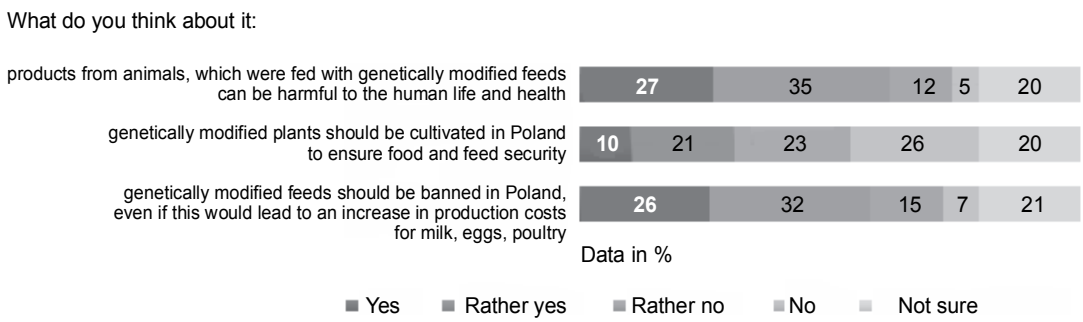

Fig. 4. Public opinion about GM plants

life and health (Fig. 4). Only 17% of respondents had the opposite opinion. Moreover, 58% of respondents were in favour of a ban on the use of GM feed, even if this would involve an increase in the cost of producing milk, eggs and poultry. Only 22% of respondents were against the ban. Interestingly, the older the respondents were, the more they indicated the harmfulness of products derived from animals fed with GM feeds (for instance, for 62% of respondents in the age group 60+ it was the most harmful). Sixty eight percent of respondents with higher education thought that these products can be harmful. Respondents living in the central (68%) and southern (61%) parts of Poland more often pointed to the harmfulness of products derived from animals fed with GM feeds to people. Every third Pole (31%) said that GM plants should be grown in Poland to ensure food and feed safety.

On the other hand, 49% of respondents did not agree with this opinion. Among people with higher education, support for the ban on the use of GM feed reached 62%, whereas in a group of people with basic education it was 52%. The majority of respondents aged between 40 and 49 (54%) and 50 and 59 (53%) believed that GM crops should not be grown in Poland. The largest group of people who opposed the cultivation of GM plants in Poland were people with basic education (53%) and people with upper-secondary and higher education (50% each). More often, people from the southern region of Poland (53% of respondents) objected to the cultivation of GM plants in Poland. Moreover, the higher the respondents' education, the more often they said that using GM feed should be banned in Poland (62% of respondents with a tertiary level of education were against using GM feed in Poland). There was no significant correlation between opinion on the usage of GM feeds and education ($P > 0.05$). Feeds derived from rapeseed were just as valuable as those derived from soybeans according to 47% of Poles, and those derived from GM soybeans, according to 51%. A significant share of respondents (28% and 29%, respectively) were unable to answer this question.

Discussion

As a result of climate change, population and livestock growth, soil pollution and erosion, we are forced to find new ways to ensure the safety and security of food. As noted by Carzoli et al. (2019) one of the solutions to increase food security is to improve agricultural productivity and the quality of food. Due to the fact that standard production procedures for the generation of new plant varieties are long and laborious, genetic engineering techniques, in particular, new breeding techniques (NBTs) (see Glossary) developed recently (Hartung and Schiemann, 2014; Sauer et al., 2016; Bortesi and Fischer, 2015; McNutt, 2015; Zimny et al., 2019; Lassoued et al., 2019), are a great alternative to achieve advances in various fields of bioeconomy. Such methods can be used to introduce new plant varieties (more nutritious, stress-tolerant, herbicide-tolerant, etc.) into the environment, as well as preserve the natural environment and human health (Carzoli et al., 2019).

In Europe, in 2020, MON 810 (Bt-resistant) maize was planted on approximately 102 367 hectares in only two countries – Spain and Portugal (Report MON 810, 2021). In August 2021, the European Commission announced the authorization (valid for 10 years) of seven GM crops (3 maize, 2 soybeans, 1 oilseed rape, and 1 cotton) and renewal of the authorizations for two maize and one oilseed rape used for food and animal feed. Importantly, the authorization decisions do not cover cultivation, besides any product produced from these GMOs

will be subject to the EU's strict labeling and traceability rules (ISAAA, 2021). Soybean, maize, and rapeseed are the most important crops used as feed for livestock. EU import dependency is particularly high for soybeans used in feed, with EU soya production covering less than 3% of its needs (EU 2020–2021). The Polish study showed that almost 60% of respondents were in favour of a ban on the use of GM feed, even if it would involve an increase in the costs of milk, egg and poultry production. However, in Poland the ban on using GM components in animal feed was postponed by the government several times – finally until January 1, 2023 (The National Legal Act on Feed, 2006; Tygodnik Rolniczy, 2020).

Consumers' attitudes to GM food are complex and directly linked with people's awareness and knowledge, lifestyles and current worldwide trends. According to the Food Safety report (2019), Europeans have a high level of awareness of **food safety issues** as 72% of them said that they have heard about the food and drink additives like colours, preservatives or flavourings. Moreover, 98% of respondents from Sweden, 95% from the Netherlands and 87% from Estonia "most likely" heard about these compounds. Interestingly, 60% of Europeans heard about **GM ingredients in foods or drinks**, whereas only 21% heard about **genome editing,** while in Poland it was 58% and 16%, respectively. Respondents from Sweden were most likely to have heard about GM ingredients in food and drinks (83%), whereas respondents from Finland (62%) and Estonia (57%) were most aware of genome editing. When it comes to socio-economic relations, it is worth mentioning that people who have heard about GM ingredients in food and drinks were adults (20+), self-employed or managers (Food Safety Report, 2019).

Importantly, as much as 43% of Europeans believed that **food products** were full of harmful substances. The highest level of compliance with this statement was recorded in Cyprus (66%), France (63%) and Croatia (61%), in Poland it was 52%. The lowest level of agreement with that statement was in Finland (17%), Sweden (24%) and Germany (29%) (Food Safety Report, 2019). Interestingly, in a Polish study, a large group of respondents had false beliefs (e.g. that there are fresh GM products available on the Polish market) and this group tended to oppose the technology. To a large degree, the ignorance of the society in the aspect of genetic engineering results from a lack of honest and reliable information on GM food diffused by the opponents of GMO. Sadly, until recently the scientific community lacked the interest in sharing the results of thousands of studies showing no GMO harm to humans or the environment. In order to achieve food security the newest biotechnology achievements must be thoughtfully and sustainably incorporated into agricultural practice. They also must be continuously explained to the public. It is extremely important to engage the scientific community in the discourse on biotechnologies and to prevent discussions based on inaccurate or false information.

In 2019, Europeans were most likely to be **concerned** about antibiotic, hormone or steroid residues in meat (44%), pesticide residues in food (39%), environmental pollutants in fish, meat and dairy (37%) and additives like colours, preservatives or flavourings used in food or drinks (36%). Twenty seven percent of Europeans were concerned about **GM ingredients in food or drinks**, whereas only 4% were about **genome editing**, while in Poland it was 39% and 5%, respectively. The highest concerns about GM ingredients in food or drinks were in Lithuania (45%), Bulgaria and Greece (both 42%) and Latvia (41%), whereas the lowest level of concerns was in Malta (12%) and Finland (13%). Such attitudes could be explained by lesser familiarity with the field of biotechnology, as well as knowledge among people from Eastern European countries, an observation confirmed also by our research. Respondents from Finland were less likely to be concerned about genome editing (11%), while in Portugal only 1% of residents showed concerns. It is worth mentioning that the longer the respondents stayed in education, the more likely they were concerned about most of the topics (Food Safety Report, 2019).

This trend is similar to the results of the surveys conducted in Poland and described herein. It can be seen, also from our analyses, that the way the technology is used and for what purpose has a great influence on people's acceptance. In Poland, the highest **support** (69%) was given to the research on the use of microorganisms for the treatment of wastewater and other wastes. The use of biotechnology in improving plant resistance to pests gained 44% of support. The contrast in the level of support for different ways of using genetic engineering and biotechnology was also seen among other European nations in a recent study (Lakomy et al., 2018). The biggest support was given to the prevention

or cure of diseases (from 86% to 96%, depending on the country), prevention of disabilities (75% to 93%), and organ transplantation (70% to 90%) (Lakomy et al., 2018). Surprisingly, as shown herein, research aimed at introducing human genes to animals to produce transplant organs for humans was useful in the opinion of only 39% of Poles. In the EU, the least supported research was changing non-life limiting characteristics of human embryos (29% to 49%), and improvement of livestock production (34% to 57%). Importantly, one of the least supported uses of the technology was an improvement of plant production for which the acceptance varied from 49% in Germany and Sweden to 67% in Spain. The biggest support for the usage of genetic engineering and biotechnology was reported in Spain, while the least supportive nation was Czechia (Lakomy et al., 2018). Nevertheless, the most surprising results of the conducted survey are that only about one third of Poles thought that the use of modern biotechnology in food production, e.g. to increase the protein content, extend the shelf life, or change the taste, is useful and should be supported, while as much as 45% considered it harmful and believed that it should be banned (46%).

According to EC F2F strategy, innovations in plant breeding and crop production can contribute to a more sustainable food system (F2F strategy 2020). However, in the case of the EU, the continued uncertainty about the regulatory status of new breeding techniques (such as genome editing) may be the key obstacle to reaching this goal. On 29 April 2021, in light of the Court of Justice's judgement in Case C-528/16 on mutagenesis, the EC submitted a study regarding the status of novel genomic techniques (NGTs) under EU law. The study described the limitations of the capacity of EU legislation to keep pace with scientific and technological progress, which cause implementation challenges and legal uncertainties. In addition, it may not be justified to apply different levels of regulatory oversight to similar products with similar levels of risk, as is the case for plants conventionally bred and obtained from certain NGTs. What is more important, it was highlighted that more effort should be made to inform and engage with the public on NGTs and to assess their views (EC Study, 2021). Despite the above, the preservative/conservative attitude of the EU officials/politicians manifested in the EU GM regulations gives contradictory messages to society. How is the public supposed to trust that the advances in biotechnology and the genome editing fields are desirable if the authorities demonstrate negative attitudes and lack of confidence? This is sort of a feedback loop where the negative public opinion shapes the approach of decision-makers, whose decisions further influence the public. This is why it is of utmost importance to educate society, the challenges and solutions of modern and sustainable food production systems must be presented clearly and understandably.

One of the essential products of biotechnology are vaccines, which are especially important during the current pandemic crisis. Between 21 and 26 May 2021, 26.106 interviews were conducted in the EU countries to analyse the attitudes of Europeans on **vaccination against COVID-19**. As noted in the EU report (Flash Eurobarometer 2021) the vaccine acceptance among the respondents was high and accounted for 69%. Only 9% would have never gotten vaccinated against COVID-19. The combined proportion of those who have already been vaccinated, or would like to get vaccinated as soon as possible, or had a high vaccine acceptance varied between 31% in Bulgaria and 86% in Malta. The high vaccine acceptance was observed also in Spain (78%), Germany (77%) and Ireland (76%). In the Central and Eastern European countries the acceptance ranged from 61% in Lithuania to 45% in Latvia, in Poland, it accounted for 58%. Interestingly, the percentage of respondents who were negative to vaccination and said that they would never have gotten vaccinated against COVID-19 was the highest in Central and Eastern European countries (from 14% in Poland to 23% in Bulgaria).

Communication between scientists and the public is essential, especially regarding the use of genetic engineering technology in the industry. The use of biotechnology in medicine or food production is controversial among today's consumers. In the past two years, the **COVID-19 pandemic** has shown that acceptance of the vaccine - as one of the products of biotechnology – is the only way out of the crisis. However, false and not scientifically confirmed information that appeared in the media and social media influenced the public opinion on the use of vaccines, and hence during the pandemic, we are observing the growing movement of anti-vaccines. On the other hand, public views on GMOs in the EU may change considering the positive experience of approving vaccines against COVID-19. The COVID-19 pandemic may be a trigger for a long-needed shift in the UE regu-

latory of GMOs. Scientists and the public can be inspired by the opportunities offered by the new developments in biotechnology. Research related to public opinion on biotechnology in Poland described herein was conducted just before the pandemic, so an important issue is to analyse the changes in the opinion of Poles after the pandemic crisis. The comparison of results can indicate the most important changes in people's views in times when biotechnological advances showed their immense potential.

The positive attitude of the public towards different technologies was noted in recent studies. According to Special Eurobarometer (2021), Europeans (N= 26 827) were most likely to think that solar energy (92%), wind energy (87%), vaccines and combating infectious diseases (86%), and information and communication technology (82%) will have a **positive effect on our way of life in the next 20 years**. Interestingly, about 70% said this about **biotechnology and genetic engineering**. In EU countries, the proportion of respondents who think the effect will be positive ranged from 93–82% in Portugal, Estonia, Finland and Sweden to 55–60% in Romania, Austria and Croatia. Men were more likely to be positive about biotechnology and genetic engineering than women (73% vs 67%). In Poland, 69% of respondents saw a positive effect of biotechnology and genetic engineering on our life (Special Eurobarometer, 2021). In 2020 in the EU countries, 42% of respondents indicated that food safety is one of the main factors influencing Europeans' **food purchases**, (together with taste – 45% and cost – 40%); with the largest proportions observed in Italy (58%), Greece (55%) and Cyprus (51%) (Special Eurobarometer, 2020).

Conclusions

Based on the analysis of the results of various public opinion surveys (including the one described herein) it becomes obvious that the general public has a reasonably optimistic view of the contribution of science and technology to humanity. In the EU, society has noticed the benefits of using biotechnology and genetic engineering in medicine to prevent or cure diseases and prevent disabilities. However, GM products (especially GM plants) are being accepted to a lesser degree. Similarly, in Poland, the support for research in the field of biotechnology and genetic engineering varied depending on the subject of research. Research related to environmental protection (the use of microorganisms for wastewater and other waste treatment) enjoyed the greatest public support. On the other hand, research aimed at using biotechnology and genetic engineering in breeding and changing the properties (improvement) of produced food met higher resistance of the Poles. An interesting result of the Polish study showed that the public had a positive approach to biotechnology when it limited the currently harmful effects of conventional agriculture (e.g. effects of pesticide use).

The need to provide higher amounts of improved (resistant to various stresses, more nutritious, with higher yields) crops we face now necessitates higher public acceptance of using novel genetic engineering techniques such as NBTs. Engaging society, communicating and explaining biotechnology and genome editing advances to society is more critical now than ever as current global challenges such as climate change, ecosystem degradation, and growing human population have necessitated seeking new methods of production and consumption. To achieve the goal we must explain the basic concepts of such methods to society in a way similar to the efforts that are being made to demonstrate the detrimental effects of human activities on the environment. Since most consumers lack basic knowledge of GMOs there is an urgent need to develop excellent educational programs that will improve their familiarity and perception of the plant improvement via genetic modifications. However, to do that the first step has to be the determination and understanding of consumers' knowledge, attitudes, and needs in the fields of GM plants and GM food. Future research will examine the respondents' current knowledge of biotechnology against to their beliefs.

Acknowledgments

This publication is based upon work from COST Action PlantEd (CA18111), supported by COST (European Cooperation in Science and Technology).

Author contributions

All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by EWG, AT and TT. The first draft of the manuscript was written by EWG and AT and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Statements and declarations

Funding: This work was supported by the COST Association (European Cooperation in Science and Technology) through the COST Action PlantEd (CA18111).

Conflict of interest: the authors declare no competing interests

Ethics approval: not applicable

Consent to participate: not applicable

Consent for publication: not applicable

Glossary

Agribiotechnology: (also named green biotechnology or agricultural biotechnology) is an area of agricultural science that uses technology based on molecular biology in the agriculture, forestry and food industries. The most common and at the same time controversial form of biotechnology in agriculture is the cultivation of new plant varieties, called genetically modified (GM) plants.

Gene/genome editing (GE): the International Organization for Standardization (ISO) defines "genome editing" as "techniques for genome engineering that involve DNA repair mechanisms and/or replication incorporating site-specific modification into a genomic DNA". ISO states that gene editing is a subclass of GE, without further indicating whether other subclasses are identified. Similarly, the use of the term "genome engineering" is considered here to relate to "genetic engineering" (see below) in the same way (ISO/DIS 5058-1).

Genetic engineering: term commonly used in the United States. The United States Department of Agriculture (USDA) defines genetic engineering as the "manipulation of an organism's genes by introducing, eliminating or rearranging specific genes using the methods of modern molecular biology, particularly those techniques referred to as recombinant DNA techniques".

Genetically modified organism (GMO): any organism, with the exception of humans, whose genetic material has been changed in a way that does not occur naturally by mating and/or natural recombination.

New breeding techniques (NBTs): methods for developing new varieties in a manner that is faster and more precise than conventional breeding techniques by modifying the DNA of seeds and cells. Using NBTs a number of limitations of conventional breeding can be overcome. Some of these methods include the zinc-finger nucleases (ZFNs), TALENs, and the meganuclease and CRISPR systems.

Notes

[1] Primary education. Secondary education: 1) high school, 2) vocational school and technical college. Tertiary education – post-secondary, higher education (Bachelor, Engineering, Master, Doctoral).

[2] Survey questions have been translated into English for the purposes of the article.

[3] Separately in the group of women and men.

References

Aguilar A., Twardowski T., Wohlgemuth R. (2019) *Bioeconomy for sustainable development*. Biotechnol. J. 14(8): e1800638. https://doi.org/10.1002/biot.201800638

Barrows G., Sexton S., Zilberman D. (2014) *The impact of agricultural biotechnology on supply and land-use*. Environ. Dev. Econ. 19: 676–703. https://doi.org/10.1017/S1355770X14000400

Borras A.M., Mohamed F.A. (2020) *Health inequities and the shifting paradigms of food security, food insecurity and food sovereignty.* Int. J. Health Serv. 50(3): 299–313. https://doi.org/10.1177/0020731420913184

Bortesi L., Fischer R. (2015) *The CRISPR/Cas9 system for plant genome editing and beyond*. Biotechnol Adv. 33: 41–52. https://doi.org/10.1016/j.biotechadv.2014.12.006

Brosig S., Bavorova M. (2019) *Association of attitudes towards genetically modified food among young adults and their referent persons.* PLoS One 14(2): e0211879. https://doi. org/10.1371/journal.pone.0211879

Carzoli A.K., Aboobucker S.I., Sandall L.L., Lubberstedt T.T., Suza W.P. (2019) *Risk and opportunities of GM crops: Bt maize example.* Global Food Security 19: 84–91. https://doi.org/10.1016/j.gfs.2018.10.004

CSO (2019) *Central Statistical Office, Science and Technology.* Retrieved January 7, 2022, from, https://stat.gov.pl/en/

Cui K., Shoemaker S.P. (2018) *Public perception of genetically-modified (GM) food: a Nationwide Chinese Consumer Study.* NPJ Sci. Food 2: 10. https://doi.org/10.1038/s41538-018-0018-4

Deng H., Hu R., Pray C., Jin Y. (2019) *Perception and attitude toward GM technology among agribusiness managers in China as producers and as consumers*. Sustainability 11: 1342. https://doi.org/10.3390/su11051342

EC study (2021) *EC study on new genomic techniques*. Retrieved January 4, 2022, from https://ec.europa.eu/food/plants/genetically-modified-organisms/new-techniques-biotechnology/ec-study-new-genomic-techniques_en

EU (2020–2021) *EU Feed Protein Balance Sheet (forecast)*. Retrieved January 4, 2022, form https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/eu-feed-protein-balance-sheet_2020-2021_en.pdf

Fedoroff N.V., Battisti D.S., Beachy R.N., Cooper P.J.M., Fischhoff D.A., Hodges C.N., Knauf V.C., Lobel D., Mazur B.J., Molden D. et al. (2010) *Radically rethinking agriculture for the 21st century.* Science 327: 833–834. https://doi.org/10.1126/science.1186834

Flash Eurobarometer (2021) *Attitudes on vaccination against COVID-19. Report 494.* Retrieved January 20, 2022, from https://europa.eu/eurobarometer/surveys/detail/2512

Food Safety in the EU – *Report (2020) Special Eurobarometer. Wave EB91.3.* Retrieved January 10, 2022, from https://www.efsa.europa.eu/en/corporate/pub/eurobarometer19

F2F strategy (2020) *A farm to fork strategy for a fair, healthy and environmentally-friendly food system. Document 52020DC0381.* COM(2020) 381 final. Brussels.

Hansson S.O., Aman P., Becker W., De Koning D.J., Lagerkvist C.J., Larsson I., Lehrman A., Riserus U., Stymne S. (2018) *Breeding for public health: a strategy*. Trends Food Sci. Tech. 80: 131–140. https://doi.org/10.1016/j.tifs.2018.07.023

Hartung F., Schiemann J. (2014) *Precise plant breeding using new genome editing techniques: opportunities, safety and regulation in the EU.* Plant J. 78: 742–52. https://doi.org/10.1111/tpj.12413

Hussain H.A., Hussain S., Khaliq A., Ashraf U., Anjum S.A., Men S., Wang L. (2018) *Chilling and drought stresses in crop plants-implications, cross talk and potential management opportunities*. Front. Plant Sci. 9: 393. https://doi.org/10.3389/fpls.2018.00393

ISAAA (2019) *Global Status of Commercialized Biotech/GM Crops in 2019.* ISAAA Brief No. 55. ISAAA, Ithaca, NY, USA.

ISAAA (2021) *European Commission Authorizes 10 GM Crops for Food and Feed*. Retrieved January 4, 2022, from https://www.isaaa.org/kc/cropbiotechupdate/article/default.asp?ID=18969

Kim N.H., Hwang J.Y., Lee H.G., Song M.K., Kang Y.S. (2018) *Strategic approaches to communicating with food consumers about genetically modified food*. Food Control 92: 523–531. Advance online publication. https://doi.org/10.1016/j.foodcont.2018.05.016

Klumper W., Qaim M. (2014) *A metaanalysis of the impacts of genetically modified crops*. PLoS One 9: e111629. https://doi.org/10.1371/journal.pone.0111629

Kubisz P., Dalton G., Majewski E., Pogodzińska K. (2021) *Facts and myths about GM food – the case of Poland*. Agriculture 11(8): 791. https://doi.org/10.3390/agriculture 11080791

Lakomy M., Bohlin G., Hlavová R., Macháčková H., Bergman M., Lindholm M. (2018) *Public attitudes to life sciences research in six European countries. ORION Project Deliverable No. 2.3.* Retrieved January 11, 2022, from https://www.orion-openscience.eu/node/221

Lassoued R., Macall D.M., Hesseln H., Phillips P.W.B., Smyth S.J. (2019) *Benefits of genome-edited crops: expert opinion.* Transgenic Res. 28: 247–256. https://doi.org/10.1007/s11248-019-00118-5

Leisner C.P. (2020) *Review: climate change impacts on food security- focus on perennial cropping systems and nutritional value*. Plant Sci. 293: 110412. https://doi.org/10.1016/j.plantsci.2020.110412

Loladze I. (2014) *Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition.* ELife 3: e02245. https://doi.org/10.7554/eLife.02245

McCluskey J.J., Wesseler J., Winfree J.A. (2018) *The economics and politics GM food labeling: An introduction to the special issue*. Food Policy 78: 1–5. https://doi.org/10.1016/j.foodpol.2018.02.012

McGrath J.M., Lobell D.B. (2013) *Reduction of transpiration and altered nutrient allocation contribute to nutrient decline of crops grown in elevated CO_2 concentrations: nutrient decline mechanisms in CO_2*. Plant Cell Environ. 36: 697–705. https://doi.org/10.1111/pce.12007

McNutt M. (2015) *Breakthrough to genome editing*. Science 350(6267): 1445. https://doi.org/10.1126/science.aae0479

Myers S.S., Zanobetti A., Kloog I., Huybers P., Leakey A.D.B., Bloom A.J., Carlisle E., Dietterich L.H., Fitzgerald G., Hasegawa T. et al. (2014) *Increasing CO_2 threatens human nutrition.* Nature 510: 139–142. https://doi.org/10.1038/nature13179

Nakashima K., Yamaguchi-Shinozaki K., Shinozaki K. (2014) *The transcriptional regulatory network in the drought response and its crosstalk in abiotic stress responses including drought, cold, and heat*. Front. Plant Sci. 5: 170. https://doi.org/10.3389/fpls.2014.00170

Ray D.K., Mueller N.D., West P.C., Foley J.A. (2013) *Yield trends are insufficient to double global crop production by 2050.* PLoS One 8: e66428. https://doi.org/10.1371/journal.pone.0066428

Report MON 810 (2021) *Annual monitoring report on the cultivation of MON 810 in 2020. Portugal and Spain Submitted by Bayer Agriculture BV.* Retrieved January 4, 2022, from: https://ec.europa.eu/food/system/files/2021-10/gmo_rep-stud_mon-810_report-2020.pdf

Sauer N.J., Mozoruk J., Miller R.B., Warburg Z.J., Walker K.A., Beetham P.R., Schöpke C.R., Gocal G.F. (2016) *Oligonucleotide-directed mutagenesis for precision gene editing*. Plant Biotechnol. J. 14(2): 496–502. https:/ doi.org/10.1111/ pbi.12496

Sijtsema S.J., Onwezen M.C., Reinders M.J., Dagevos H., Partanen A., Meeusen M. (2016) *Consumer perception of bio-based products – an exploratory study in 5 European countries*. NJAS-Wagen. J. Life Sci. 77: 61–69. http://dx.doi.org/10.1016/j.njas.2016.03.007.

Sikora D., Rzymski P. (2021) *Public acceptance of GM foods: a global perspective (1999–2019).* [in:] *Policy issues in genetically modified crops: global policies and perspectives.* Ed. Singh P., Borthakur A., Singh A.A., Kumar A., Singh K., Elsevier, Academic Press: 293–315.

Smyth S.J., Lassoued R. (2019) *Agriculture R&D implications of the CJEU's Gene-specific mutagenesis ruling*. Trends Biotechnol. 37(4): 337–340. https://doi.org/10.1016/j.tibtech.2018. 09.004

Special Eurobarometer 516 (2021) *European citizens' knowledge and attitudes towards science and technology*. Retrieved January 4, 2022, from https://europa.eu/ eurobarometer/surveys/detail/2237

Special Eurobarometer 505 (2020) *Making our food fit for the future – Citizens' expectations.* Retrieved January 4, 2022, from https://europa.eu/eurobarometer/surveys/ detail/2241

Teixeira E.I., Fischer G., van Velthuizen H., Walter C., Ewert F. (2013) *Global hot-spots of heat stress on agricultural crops due to climate change*. Agric. Meteorol. 170: 206–215. https://doi.org/10.1016/j.agrformet.2011.09.002

The National Legal Act on Feed (2006). Retrieved March 4, 2022, from https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20061441045

Tygodnik Rolniczy (2020) *Zakaz stosowania GMO przesunięty na 2023 rok*. Retrived March 4, 2022, from https://www.tygodnik-rolniczy.pl/articles/hodowla-zwierzat/zakaz-stosowania-gmo-przesuniety-na-2023-rok/

Tyczewska A., Wozniak E., Gracz J., Kuczynski J., Twardowski T. (2018) *Towards food security: current state and future prospects of agrobiotechnology*. Trends Biotechnol. 36(12): 1219–1229. https://doi.org/10.1016/j.tibtech. 2018.07.008

WHO (2020) *Food safety*. Retrieved January 20, 2022, from https://www.who.int/news-room/fact-sheets/detail/food-safety

Woźniak E., Zimny T., Twardowski T. (2020) *Agri-biotechnology: legal and economic aspects of using GMOs in EU.* [In:] *Bioeconomy for sustainable development*. Ed. Chetan K., Springer, Singapore: 21–41. https://doi.org/10.1007/978-981-13-9431-7

Woźniak E., Tyczewska A., Twardowski T. (2021) *A shift towards biotechnology: social opinion in the EU.* Trends Biotechnol. 39: 214–218. https://doi.org/10.1016/j.tibtech. 2020.08.001

Yang Y., Sornaraj P., Borisjuk N., Kovalchuk N., Haefele S. M. (2016) *Transcriptional network involved in drought response and adaptation in cereals*. [in:] *Abiotic and biotic stress in plants – recent advances and future perspectives*. Ed. Shanker A.K., Shanker C., India: InTech: 3–29.

Zimny T., Sowa S., Tyczewska A., Twardowski T. (2019) *Certain new plant breeding techniques and their marketability in the context of EU GMO legislation – recent developments*. New Biotech. 51: 49–56. https://doi.org/10.1016/j.nbt. 2019.02.003