Journal of Agriculture and Food Research 19 (2025) 101594

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Analysis of genetically modified foods and consumer: 25 years of research indexed in Scopus

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ARTICLE INFO

Keywords:
Genetically modified foods
GM food
GMO
Consumer
TCCM analysis

ABSTRACT

Genetically modified (GM) foods are frequently recognized as an essential source of world food supply, linked to Sustainable Development Goal (SDG) 2: Zero hunger. However, several aspects of the risks and benefits of consuming GM foods have not yet been fully clarified. It is necessary to have the most relevant information to have more accurate legislation that benefits the population. The current research aimed to develop a bibliometric analysis; it also used VOSviewer visualization software to show the evaluation of publications indexed in the Scopus database focused on GM foods and consumers between 1999 and 2023. 979 documents were evaluated. The United States was recognized as the most productive (988 articles); however, Universiteit Gent was the institution with more publications (22), and the European Commission was the funding sponsor with more publications (19). The top institutions originated are from USA, UK, China, Italy and Germany. Nature Biotechnology was the journal with more articles published (28 articles). The study allows for gathering information that helps companies to improve the supply of GM foods and help regulators to generate policies and laws according to scientific evidence.

1. Introduction

Science has developed various technologies to contribute to society's sustainability, specifically in the food industry. Today's technology has made it possible to generate more significant benefits in food [1–6] and impact on consumers [7,8]. Food increasingly demands conditions that allow it to be durable in storage; it also requires technologies that can make it resistant to pests and extreme conditions, such as those caused by climate change, for its normal development in production processes. In that sense, the methods to improve agricultural production have been directed by genetically modified organisms (GMOs). GMOs management technology is a powerful solution to contribute to the resolution of the food crisis since these foods can resist diseases and pests, allowing higher crop yields, and avoiding economic losses in vulnerable populations in charge of agricultural production, increasing the safety of the products for consumers [9–14].

During the production of GM foods, the use of herbicides and insecticides is reduced, thus reducing contamination with chemicals that end up in the final products consumed by people [15–17], thereby reducing contamination with chemicals that end up in the final products consumed by people, thus contributing to sustainability [18]. Although the various benefits of GM foods may be recognized from the scientific point of view, from the consumers' preferences and perspectives, the issue is different as there may be various options [19,20]. There are some relevant research that shows a different kind of method as Boccia, Covino [21] who presents a Noumenic approach; also, the dilemma to eat or not the GM foods according the knowledge about them and the potential risk involved [22]. The use of mix method to evaluate consumer perception of GM foods [23]; demystification about GM foods [24,25], new biotechnology options [26], labeling [27,28] and willingness to pay [29].

In the face of challenges such as rising population, climate change,

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https://doi.org/10.1016/j.jafr.2024.101594
Received 15 October 2024; Received in revised form 9 December 2024; Accepted 13 December 2024
Available online 17 December 2024

and diminishing agricultural resources, GMOs offer a solution to safe security and sustainable agriculture. Through genetic engineering, GMOs can create better crop yield, nutritional content, and reduce environmental impact by enhancing resistance to pests and diseases. However, acceptance of GMOs is not only dependent on scientific advancements but also on consumer preferences and perception. Consumer preferences are instrumental in shaping the food industry. Their beliefs and understanding of GMOs influence market demand, regulatory policies, and public discourse surrounding genetically modified foods. In addition, there is no efficient way to communicate the benefits and risks of GMOs to consumers, as existing knowledge is often affected by misinformation. It is, therefore, crucial to understand the complex relationship between consumers and GMOs to comprehend their preferences and perceptions. While some consumers embrace GMOs, others express skepticism due to concerns about safety, environmental risks, and ethical considerations. Understanding consumer views is critical for policymakers, food producers, and scientists to develop effective communication strategies, transparent labeling practices, and regulatory frameworks that align with societal expectations. By bridging the gap between scientific advancements and consumer sentiment, we can foster an informed and inclusive dialogue surrounding the role of GMOs in our food system. This article explores the complexities of consumer relations to GM foods, including the factors that influence decision-making. Trust in scientific research, labeling requirements, the role of media, and societal attitudes towards GMOs are some of the issues examined. Shedding light on these aspects can lead to a more comprehensive understanding of the GMOs debate and the development of strategies that address consumer concerns and encourage sustainable and responsible use of genetically modified foods. In conclusion, as the challenges of food security and sustainability become more pressing, genetically modified foods hold immense potential. However, achieving widespread acceptance and consumer confidence in GMOs requires an in-depth understanding of consumer preferences and perceptions. By recognizing the multifaceted nature of this topic, it can pave the way for an informed dialogue that embraces the benefits and addresses the concerns associated with genetically modified foods, ultimately shaping a more resilient and sustainable food future.

This information on GM foods is not always conclusive; it needs to review the scientific literature constantly to establish effective policies that help to disseminate the most recent and solid scientific information; on the other hand, regulation changes should be based on evidence, so it is expected that more information on GM foods can be made transparent on their packaging and can help consumers to have complete information and make informed decisions for consumption. The aim was to conduct a bibliometric evaluation to analyze the Scopus publications focused on GM foods and consumers from 1999 to 2023.

2. Methods

The current study has a bibliometric approach based on the comprehensive Scopus database [30]. When it comes to research databases, Scopus is the clear choice for several compelling reasons: Firstly, Scopus boasts unparalleled coverage and is multidisciplinary, which makes it the perfect tool for interdisciplinary research. Its extensive indexing of subject areas, journals, and conference proceedings from across the globe ensures a more comprehensive representation of the research landscape. Scopus offers an expansive citation database, including citations from multiple sources such as journals, conference papers, books, and patents. This comprehensive coverage provides a more accurate assessment of the impact and influence of scholarly works. Additionally, Scopus provides a range of citation metrics, such as the h-index, CiteScore, and SJR, which can offer valuable insights into the research performance of authors, institutions, and journals. Moreover, Scopus is recognized for its timeliness, with its faster indexing process making recently published articles available sooner for analysis. This feature is particularly advantageous for bibliometric studies that require up-to-date information and trends.

By using Scopus, researchers can access the most current literature and track the progress of research in real-time, ensuring that their analysis reflects the latest developments in the field. Scopus has a global focus, indexing a higher number of journals from non-English-speaking countries than any other databases. This broader international coverage allows for a more inclusive analysis of research outputs from diverse regions and languages, reducing potential biases towards English-language publications. Lastly, Scopus offers advanced search and analysis features, providing a user-friendly interface and various filters, document types, and indexing terms to customize searches according to specific research interests. Additionally, Scopus provides data export options, allowing researchers to export search results and citation data for further analysis using external tools. With Scopus, researchers can also cover a wider range of open access journals, ensuring a more comprehensive examination of research output, particularly in fields where open access publishing is prevalent. In total, Scopus has more than 85 million records, including research articles, reviews and other types of publications. Considering that more than 2.5 million academic articles are published annually worldwide, it is estimated that only 70–80 % of these are covered by Scopus since many articles from smaller or regional journals are not indexed.

We consider it important to know what the increase in the number of publications is annually; likewise, it will seek to know the leading countries to identify the geographical areas as well as the collaboration between the countries, which helps to know where the knowledge of GM foods is concentrated. The knowledge of the institutions, journals and authors allows us to know the trajectory of the publications, making it feasible to contact said institutions and authors to generate more research on the subject of GM foods.

Terms and Boolean operators were used to build the search: (TITLE-ABS-KEY (consumer) AND TITLE-ABS-KEY ("genetically modified food")) AND PUBYEAR >1999 AND PUBYEAR <2023. The period of evaluation was specified from 1999 to 2023. All data was collected on December 31, 2023. The publications were in journals, reviews, book chapters, and conference papers. In total, 988 documents were evaluated. It used bibliometric analysis software; search outcomes were exported, including information about titles, authors, journals, countries, organizations, funding sponsors, keywords and publication years. Fig. 1 describes the study design. Current research evaluated the publications concerning year, authors, countries, journals, affiliations, highly cited papers, and keywords. VOSviewer was used for the evaluation of the co-authorship and co-occurrence relationship [31,32].

A previous study was conducted by Sendhi R et al. (2022) [33] to evaluate the literature on GM foods and consumers based on the Web of Science; however, the present study provides broader content with direct utility for future studies. The current study uses Scopus as a database, and in this way, TCCM (theory development, context, characteristics, and methodology) analysis was included to evaluate theory development, context, characteristics, and methodology). Finally, it describes variables and items proposed based on previous studies on consumers regarding GM foods.

3. Results

3.1. Trend of publications

Fig. 2 shows publications on GM foods and consumer indexed in Scopus showed a little elevating trend. It is shown that the relationship between the quantity of each published article and the year was fitted with an exponential regression model (1999–2023). The equation allows us to predict future publications. The exponential model has a relative predictive power by R^2. A decrease in the publications on GM foods and consumer has been recognized from 1999 to 2023. It can be predicted that research on GM foods and consumers needs to ensure that the outcomes can help to regulate sales better, and companies may have

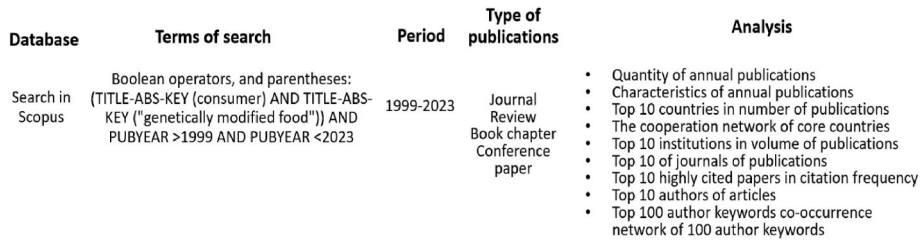

Fig. 1. Research design.

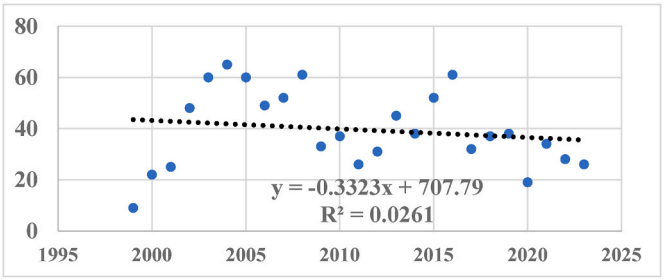

Fig. 2. Publications on GM foods and consumer between 1999 and 2023.

more information to consume them confidently.

Table 1 shows the main characteristics of the annual publications. A slight decrease in publications and citations was reported. The references by article were 14.11 in 1999, 29.80 in 2005, 24.78 in 2010, 28.36 in 2015, 12.31 in 2020, and 3.16 in 2023.

3.2. Publication by countries

The 988 Scopus publications showed that 72 countries participated. Table 2 details the top ten countries, mentioning the articles, citations and the h-index of each country (Song et al., 2021).

It used VOSviewer software to visualize the academic collaboration among researchers from different countries from 1999 to 2023 (Fig. 3). The distance between countries (circles) represents the degree of cooperation. Each circle means a country, and the size explains the number of articles published. Lines that are connected mean collaboration between both countries. Fig. 3 shows that there was close cooperation among many countries. The USA showed the most relations with collaboration with 26 countries. The USA and the United Kingdom were the most significant academic collaborators.

Table 1
Publications by year during 1999–2023.

PY	NA	CC	CC/NA
1999	9	127	14.11
2000	22	675	30.68
2001	25	1259	50.36
2002	48	1218	23.38
2003	60	2090	34.26
2004	65	2717	42.45
2005	60	1788	29.80
2006	49	1587	32.38
2007	52	1761	33.86
2008	61	2632	43.14
2009	33	919	27.84
2010	37	917	24.78
2011	26	521	20.84
2012	31	474	15.29
2013	45	996	22.13
2014	38	693	18.23
2015	52	1475	28.36
2016	61	1244	20.39
2017	32	379	11.84
2018	37	478	12.91
2019	38	606	16.37
2020	19	234	12.31
2021	34	180	5.80
2022	28	41	1.70
2023	36	114	3.16
Total	**988**	**25,125**	**Mean= 23.05**

PY: publication year; NA: Number of articles; CC: cited count; and CC/NA: average cited count per publication.

Table 2
Top countries in GM foods and consumer during 1999–2023.

No.	Country	A	Percentage (%)
1	United States	288	36.55
2	United Kingdom	105	13.32
3	China	85	10.79
4	Italy	64	8.12
5	Germany	54	6.85
6	Canada	49	6.22
7	Spain	44	5.58
8	Netherlands	35	4.44
9	Belgium	35	4.44
10	India	31	3.93

A: Articles.

3.3. Distribution of publications by institutions

The top 10 institutions with more articles published are 14.98 % (Table 3). Belgium, the Netherlands, the United States and Italy were the top countries with articles published on GM foods and consumer products.

3.4. Collaboration between authors

Fig. 4 shows the map of collaboration among authors. It can be recognized that there was a first cluster (yellow) led Jose M. Gil from Centro de Investigación en Economía y Desarrollo Agroalimentario, Castelldefels, Spain (3 publications about the current topic evaluated). W. Bruce Traill leads the second cluster (red) from the University of Reading, Reading, United Kingdom (7 publications). The third cluster (sky blue) is led by Wallace E. Huffman from Iowa State University, Ames, United States (11 publications). Finally, the fourth cluster is led by Jayson L. Lusk from Purdue University, West Lafayette, United States (19 publications).

3.5. Journals with more articles published

Table 4 details the journals with more articles published about GM foods and consumer. From 1999 to 2023, 196 documents were published in the top 10 journals, representing 19.84 % of the articles. Nature Biotechnology was the journal with the most articles [28], accounting for 2.83 % of the total of publications; it was followed by British Food Journal and Agbioforum with 26 and 25 publications, respectively. Nature was the journal with the highest CiteScore 2022 (83.4). Nature Biotechnology has the highest SJR in 2021 22.781). Then, Nature has

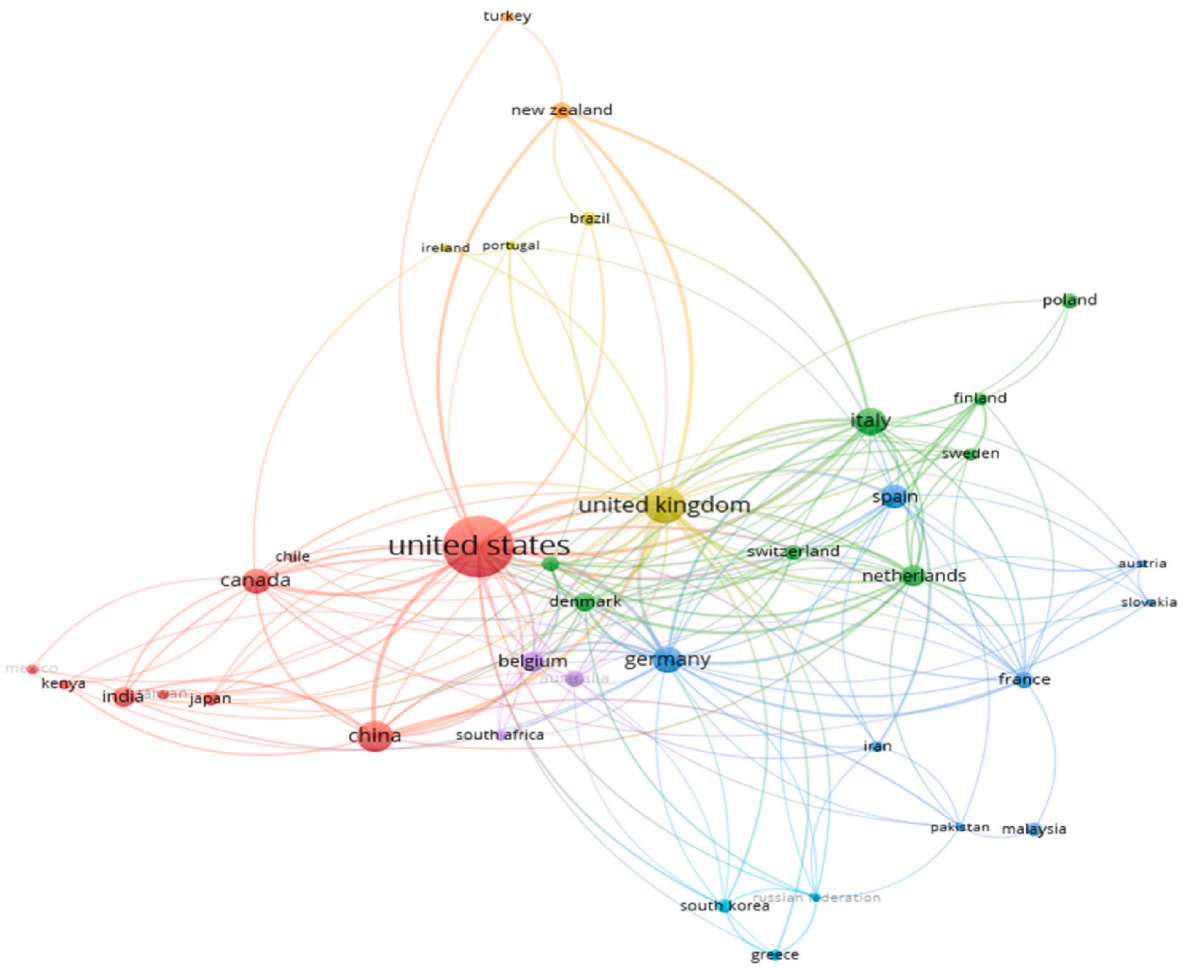

Fig. 3. Cooperation network between countries on GM foods and consumer during 1999–2023.

Table 3
Top institutions in the articles on GM foods and consumer during 1999–2023.

No.	Institution	Country	A	Percentage (%)
1	Universiteit Gent	Belgium	22	2.23
2	Wageningen University & Research	Netherlands	20	2.02
3	Iowa State University	USA	16	1.62
4	Rutgers University–New Brunswick	USA	16	1.62
5	University of Florida	USA	15	1.52
6	Parthenope University of Naples	Italy	13	1.32
7	Purdue University	USA	12	1.21
8	Washington State University Pullman	USA	12	1.21
9	The Ohio State University	USA	11	1.11
10	Oklahoma State University	USA	11	1.11

A: Articles.

the highest Impact Factor (64.8). Finally, Nature was the journal with the highest H-index (1331).

3.6. Articles most cited

The citations and affiliations evaluated the top cited articles on GM foods and consumer from 1999 to 2023 (Table 5). The top articles were from developing countries (UK, Denmark, Spain, Netherlands, United States and Italy). The most highly cited publication was “Applications and implications of nanotechnologies for the food sector” published in Food Additives and Contaminants - Part A in 2008, with 1018 citations [34]. The second was “Determinants of consumer attitudes and purchase intentions with regard to genetically modified foods - results of a cross-national survey” published in Journal of Consumer Policy in 2001 with 434 citations [35]. One aspect that is relevant among the results is that there are geographic areas where publications on these topics are

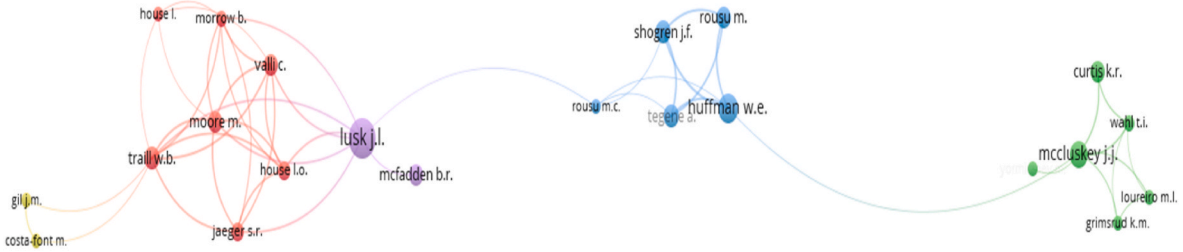

Fig. 4. The academic collaboration among authors of publications on GM foods consumer during 1999–2023.

Table 4
Top journals of publications on GM foods and consumer during 1999–2023.

Rank	Journals	A	(%)	CiteScore 2022	SJR 2022	Impact Factor (2022)	H-index	Country
1	Nature Biotechnology	28	2.83	71.9	22.781	68.164	491	United Kingdom
2	British Food Journal	26	2.63	3.5	0.645	3.224	94	United Kingdom
3	Agbioforum	25	2.53	3.2	0.395	0.345	42	United States
4	Appetite	25	2.53	8.1	1.187	5.016	168	United States
5	Food and Chemical Toxicology	23	2.33	11.2	0.817	4.3	192	United Kingdom
6	Food Quality and Preference	17	1.72	10.7	1.161	5.3	144	United Kingdom
7	Food Policy	14	1.42	9.9	1.896	6.5	126	United Kingdom
8	Trends in Biotechnology	13	1.32	31.3	2.721	21.942	242	United Kingdom
9	Nature	13	1.32	83.4	20.957	64.8	1331	United States
10	Regulatory Toxicology and Pharmacology	12	1.21	6.1	0.718	3.4	119	United States

A: Articles.

Table 5
Top 10 highly cited publications during 1999–2023 about GM foods and consumer.

Rank	Title	Country Corresponding Author	Publication Year	Journal	QC
1	Applications and implications of nanotechnologies for the food sector	UK	2008	Food Additives and Contaminants - Part A	1018
2	Determinants of consumer attitudes and purchase intentions with regard to genetically modified foods - results of a cross-national survey	Denmark	2001	Journal of Consumer Policy	434
3	Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy	Spain	2008	Food Policy	417
4	Effects of cheap talk on consumer willingness-to-pay for golden rice	USA	2003	American Journal of Agricultural Economics	356
5	Genetically modified foods: Safety, risks and public concerns - A review	India	2013	Journal of Food Science and Technology	313
6	A meta-analysis of genetically modified food valuation studies	USA	2005	Journal of Agricultural and Resource Economics	300
7	Communicating about the Risks and Benefits of Genetically Modified Foods: The Mediating Role of Trust	Netherlands	2003	Risk Analysis	298
8	Effect of information about benefits of biotechnology on consumer acceptance of genetically modified food: Evidence from experimental auctions in the United States, England, and France	USA	2004	European Review of Agricultural Economics	279
9	Detection and traceability of genetically modified organisms in the food production chain	Italy	2004	Food and Chemical Toxicology	271
10	Societal aspects of genetically modified foods	Netherlands	2004	Food and Chemical Toxicology	264

QC: Quantity of citations.

tiny in Asia with Philippines [1], Indonesia [2], Singapore [2]; in Africa with Ghana [1], Ethiopia [2], Uganda [2], Zimbabwe [2]; in Latin America with Colombia [1], Costa Rica [1], Venezuela [1].

3.7. Relevant authors of publications on GM foods and consumer

Table 6 presents the more relevant authors of publications on GM foods and consumer, showing their filiations, countries, and total H-index.

3.8. TCCM analysis

We will review the literature using the TCCM framework. We will identify knowledge gaps from previous studies and make proposals for future research.

3.9. Theory development

Food Cognition Dissonance [36] in relation to GMOs refers to the psychological tension experienced by consumers when their beliefs and attitudes regarding these foods conflict with their dietary behaviors or the information they receive. Many consumers associate GM foods with potential health and environmental risks, which generates a negative perception despite scientific evidence supporting their safety and benefits, such as increased agricultural productivity and pest resistance.

Table 6
Top authors of publications on GM foods and consumer.

Rank	Authors	A	Institution	H-index	Country
1	Jayson L. Lusk	19	Oklahoma State University	56	United States
2	Wallace E. Huffman	11	Iowa State University	94	United States
3	Rodolfo M. Nayga	10	Korea University	48	South Korea
4	Flavio Boccia	9	Parthenope University of Naples	22	Italy
5	Hans de Steur	9	Universiteit Gent	33	Belgium
6	Jill J. McCluskey	9	Washington State University Pullman	32	United States
7	Xavier Gellynck	8	Universiteit Gent	45	Belgium
8	W. Bruce Traill	7	University of Reading	28	United Kingdom
9	Jason F. Shogren	7	University of Wyoming College of Business	53	United States
10	Benjamin Moranga Onyango	7	Missouri State University	10	United States

The values of H-Index were considered from December 31st, 2023.

This phenomenon of dissonance occurs when people, despite their concerns, choose to consume GMOs, which may be driven by factors such as accessibility, price and limited availability of alternatives. In addition, dissonance is intensified in the context of conflicting information from experts and media presenting both the perceived benefits and risks of GMOs. To reduce this dissonance, some consumers tend to justify their choice by ignoring the risks or adopting a critical stance toward information sources that favor GM foods. This process of resolving cognitive dissonance profoundly influences decision-making and attitudes toward GM foods, affecting their acceptance and consumption.

Social Judgment Theory (SJT) [37] focuses on how people evaluate messages about controversial topics, such as GM foods, based on their previous attitudes. The theory holds that, upon receiving a message, people do not judge it objectively but rather compare it to their already established beliefs, placing it in zones of acceptance, rejection or indifference. In the GMOs context, those in favor might accept information about its benefits, such as crop improvement or pesticide reduction, while those against might reject the same information by associating it with perceived health and environmental risks. SJT explains that the more extreme the message is with respect to prior beliefs, the more likely it is to be rejected, reinforcing existing attitudes. This phenomenon underscores the challenge of communicating the benefits and risks of GMOs, as recipients tend to process information according to their predispositions.

The Theory of Cultural Values [38] explores how a culture's shared values influence attitudes and behaviors toward various issues, including GMOs. This theory, developed initially by Schwartz [39], defines dimensions such as collectivism, openness to change, and conservatism, which affect risk perception and acceptance of GMOs. In cultures with high values of conservatism and protection, GMO foods are often viewed with suspicion, as these societies prioritize safety and stability, fearing potential environmental or health impacts. On the contrary, in cultures that value openness to change and autonomy, GMOs may be received with greater acceptance, as they are considered a technological innovation and a potential resource in the face of food and climate challenges. Thus, the Theory of Cultural Values helps to explain why the acceptance of GM foods varies between countries and cultures, and how cultural values condition the regulation and consumption of these foods.

The Commitment-Trust Theory, developed by Morgan and Hunt [40], argues that the two key factors in the successful relationship between consumers and companies are trust and commitment. Applied to GM foods, this theory suggests that consumers' acceptance and adoption of GMOs depends largely on their trust in biotech companies and in the regulators that endorse these products. Trust, in this context, is built through transparency in the processes of development, safety testing and proper labeling of GMOs. The commitment of companies to ensure the safety and quality of their products can foster consumer loyalty and acceptance, and consumers perceive a higher value in this relationship. Without trust and commitment, consumers are more likely to reject GMOs for fear of potential unknown risks, limiting their adoption and expansion in the marketplace.

3.9.1. Context

The introduction of GM foods into the global marketplace has provoked significant debate among researchers, regulators, consumers and food companies [41,42]. As GM foods have become more accessible, consumer attitudes towards them have varied widely due to cultural, economic and social factors. Understanding this context is essential for analyzing consumer perceptions and behavior in relation to GMOs [43] and their implications for the global food industry [44]. The sociocultural context plays a significant role in shaping attitudes and acceptance or rejection of GM foods [45]. In many societies, risk perceptions and cultural values impact consumers' willingness to adopt or reject GMOs products [46]. For example, in the European Union, attitudes toward GMOs tend to be more negative due to a combination of historical and sociopolitical factors, as well as active awareness campaigns. In contrast, in regions such as North America, acceptance has been relatively higher, driven in part by less restrictive government policies and a perception of economic benefits in agricultural production. Another relevant aspect of the context is access to information and education [47]. The perception of the risks and benefits of GMOs often depends on the level of knowledge and information available to the consumer [48]. In this regard, media and digital platforms have had a considerable impact, as they can amplify both scientific information and erroneous beliefs or myths about GMOs. For example, informed consumers tend to value safety and regulatory control, which can temper their skepticism [27]. However, when access to reliable information is limited, consumers may develop rejectionist attitudes based on poorly substantiated risk perceptions or misinformation.

In addition, the economic context also influences consumer behavior towards GMOs [49]. Low-income or developing countries often see GMOs as an opportunity to improve food security through more resilient and higher-yielding crops [50]. In contrast, in high-income countries, consumer concern often focuses on potential health and environmental risks, where there is a greater willingness to pay for foods labeled "GMO-free." Labeling regulations and policies are another important dimension in the context of GMO foods [51]. In some countries, legislation requires GMO-derived products to be labeled, which gives consumers a choice, but may also reinforce the rejection of GMO products in certain population groups. Labeling, therefore, functions as a mediator between acceptance and rejection, as it impacts on consumer confidence and perceived transparency.

3.9.2. Chracteristics

The study of GM foods has different research models where several variables have been taken into account as predictors of the intention to consume GM foods. In this analysis, we can identify variables and their effects on each other. Some of them include

Perceived benefits → Purchase intention [52–54]

Perceived risks → Purchase intention [52–54]

Trust in industrial organizations → Perceived benefits [52]

Trust in industrial organizations → Perceived risks [52]

Trust in governmental regulator → Perceived benefits [52–54]

Trust in governmental regulator → Perceived risks [52–54]

Knowledge → Consumer preference [21]

Fear → Consumer preference [21]

Fear → Attitude toward genetically modified food [55]

Attitude towards GM foods → Purchase intention [54,56]

Attitude towards GM foods → Willingness to consume GM foods [57]

Attitude towards GM foods → Purchase intention [58–60]

Hedonism values → Purchase intention [58]

Hedonism values → Attitude towards GM foods [58]

Perceived benefits → Attitude towards GM foods [54,60]

Perceived risks → Attitude towards GM foods [54,60]

Subjective norms → Purchase intention [54,60]

Perceived behavior control → Purchase intention [54,60]

3.9.3. Methodology

The methodology used in the current study includes correlational design [61], meta-analysis [62], case study [63], mix papers [64], review paper [65], longitudinal [66] and theoretical articles [56]. However, the other methods remain pending for new studies. Future research can use experimental studies to test the modification of variables, such as the increase in purchase intention. It is also important to measure purchase intention among customers of different generations and regions.

4. Discussion

It has been recognized that the number of papers from a country or an author is not related to the number of citations that those papers may have. Thus, 288 articles were generated from the USA, which represents 36.55 % of the total number of articles published in that time range; however, the United Kingdom (105) and China [85] are the countries with the most publications, followed by Italy [64] and Germany [54]. This shows that the more outstanding production per country is not reflected in the greater institutional production.

On the other hand, there is no coincidence between the countries of the institutions most prolific in papers and the country of affiliation of the corresponding author of the most cited articles. Also, the most cited articles are not always in quartile 1 journals, as in the case of Food Additives and Contaminants - Part A and Journal of Consumer Policy which are Q2. Likewise, the authors with the most publications on the subject of GM foods and consumer do not have articles as the most cited, nor do they have articles in the journals with the highest impact. However, it is important to note here that the authors with the most publications have some innovative articles that allow a better understanding of consumer behaviors and may lead to new research. Among these articles are “Do consumers care how a genetically engineered food was created or who created it?” by Jayson L. Lusk, published in Food Policy (Q1), “Consumers’ willingness to pay for genetically modified foods with product-enhancing nutritional attributes” by Wallace E. Huffman published in American Journal of Agricultural Economics (Q1), “Consumer attitudes to genetically modified food in Norway” by Jill J. McCluskey published in Journal of Agricultural Economics (Q1), “Investigating the Effect of Nudges on Consumers’ Willingness to Pay for Genetically Modified Corn Oil” by Flavio Boccia published in Sustainability (Q1) and the innovative research “Genetically modified food versus knowledge and fear: A Noumenic approach for consumer behaviour” published in Food Research International (Q1).

Recent studies show diverse evidence on consumer and GM foods. For example, Siddiqui, Asif [67] identified the social and psychological factors that affect consumers’ perceptions of GM foods. GM foods are artificial, affecting the general acceptance for their consumption; consumers also expect an assessment of potential or actual hazards. Finally, they recognize that supplying adequate information on GM foods through a mandatory labeling policy may be an appropriate way to elevate public awareness and acceptance of GM foods. van Stekelenburg, Schaap [68] detailed that consensus communication produced very similar effects for climate change and genetically modified foods, while the small number of experiments on vaccination prevented conclusions on this topic. Although these effects are minor, scientific consensus communication appears to be an effective way to change factual beliefs about controversial scientific topics in consumers. Bearth, Kaptan [69] showed that participants from the United Kingdom and Switzerland expressed higher acceptance of foods based on genome editing compared to foods based on transgenic genetic modification.

As is known, transgenic genetic modification is the incorporation of DNA from another species to incorporate a trait into the food. At the same time, genome editing involves deleting genes that express a particular trait, such as susceptibility to a disease or pest. Huo and Liu [70] have researched rice, a staple food for consumers in China, where there is a profound food safety problem, and the government is pushing the application of biotechnology for agriculture. Despite these efforts, consumers have different perceptions and preferences regarding the consumption of genetically modified rice; on the one hand, there is the perception of the risks, and on the other hand, there is the confidence that the government, scientists and the media can stimulate consumers to buy. The tested model analyzed by structural equation modeling found that health risks, moral risks and purchase intention were negatively correlated, while trust and purchase intention had a significant positive correlation. Yang, Yu [71] assessed the effects of perceived control on the acceptance of GM foods in China by relying on compensatory control theory, which states that the lower an individual’s perceived control, the greater their need for structure, order, and certainty to perform a particular action such as the case of the intention to purchase GM foods. First, it was found that individuals’ sense of control negatively predicted their perception of GM foods risk, with the need for structure mediating. Likewise, an experimental model (higher or lower risk exposure) showed that under conditions of lower control, individuals recognize higher risks, which, in turn, decreases their willingness to purchase GM foods.

Anyshchenko [72] said that the achievements that can be made to improve food through genetic engineering involve improving nutrition, increasing yields, and improving crop resistance. While GM foods have a place in the market and their use is increasing, new genome editing techniques can help overcome the limitations inherent in the usual plant breeding. However, there are still barriers to their wide application, such as the regulatory environment, decision making and public perception. Different studies described the different factors that have an effect on the intention to purchase GM foods as Sleboda and Lagerkvist [73] in Sweden, Wang [74] in Hong Kong, Tadich and Escobar-Aguirre [75] in Chile, Akbari, Maleksaeidi [76] in Iran, Boccia and Punzo [77] in Italy, Lehberger and Becker [78] et al. in Germany, Chinn and Hasell [79] in USA. Other studies describe the importance of communication between the government and companies to explain in detail the properties of GM foods, as Chon, Xu [80], Woźniak-Gientka, Tyczewska [81] and Kubisz, Dalton [82] in Poland, Marques, Kerr [83] in Australia and New Zealand, Batalha, Foroni [84] in Australia, Tallapragada, Hardy [85] and Besley, Lee [86] in USA.

Although, indeed, the countries with the most significant areas of cultivation of GM foods remain the same (USA, Brazil, Argentina, India and Canada), the consumption of these products varies in these countries and, as we have been able to review, is influenced by different factors, which means that consumers, on the one hand, need detailed information to increase their consumption and, at the same time, better regulations are needed so that information on the use of GM foods in the products that are launched on the market is transparent. To make it easier for consumers to know if their food contains genetically modified ingredients, the U.S. Department of Agriculture has a list of bioengineered foods. In January 2022, the "bioengineered" label on some foods was made mandatory, as mentioned in the National Bioengineered Food Disclosure Rule. It should be noted that this standardization has taken place in the USA, but several countries have not yet committed to transparency in the ingredients of various types of products.

Policymakers should take into account these articles and the evaluation made in this study to formulate new proposals for implementation with specific funding and research agencies to expand their related priority topics and to ensure that consumers have complete information based on scientific evidence and can make informed decisions; on the other hand, this information allows the reporting of adverse reactions to the consumption of GM foods, as has been established with the use of drugs (pharmacovigilance) or cosmetics (cosmetic surveillance). There has been a growth in GM foods research. However, it is not very large, and there is an urgent need for more research in various regions of the world, especially in countries that are more exposed to food insecurity, with the USA, Europe and Australia being the areas where a large percentage of GM foods and preferences by consumers research is conducted; there are limited studies in Africa and Latin America. It has also

been possible to recognize that the USA and UK are the countries that lead the investigative cooperation networks, having collaborations with more than 20 countries; Once again, the need for research on consumers in countries with little evidence, such as those found in Africa, Latin America and some in Asia is stressed. It is striking to see that universities like Universiti Kebangsaan Malaysia (Malaysia), Universiteit Gent (Belgium) and University of Otago (New Zealand), even though their countries do not lead the list of most publications, have a share in research in this field, allowing to obtain evidence for local decision-making.

The results obtained through bibliometric analysis show the trends in research on genetically modified foods. The information from this study can help to recognize the authors leading research on genetically modified foods and to evaluate which trends should be followed in the research and development of new technologies. Also, the present study has some limitations, since it uses Scopus database to get information. Articles and citations in other databases were not included. Therefore, future studies should use different databases to obtain articles and employ innovative tools to filter the outcomes, which would help improve the evaluation's accuracy.

This article explores the topic of GM foods and their relation to Sustainable Development Goal 2 (zero hunger). It emphasizes that to achieve this objective, providing customers with information about GM foods consumption is crucial. Nonetheless, limited knowledge exists on the factors that affect consumer purchasing behaviors regarding these products. The article acknowledges that the benefits and risks of GM foods are still being studied, and no conclusive evidence is available yet. However, it stresses the importance of proper communication between companies and governments about GM foods. One way to achieve this is by making sure that product labeling includes mandatory information on the use of GM ingredients. Ultimately, the article highlights that the decision to consume GM foods or not lies with the consumer. Nonetheless, it is imperative to make this decision with the most accurate and comprehensive information available from both the food industry and regulatory agencies.

4.1. Variables and items proposed

The articles reviewed established some variables that can be measured, including examples of items for questionnaires with a Likert scale (Table 7).

5. Conclusion

The contribution of information about the consumption of GM foods can generate an impact on contributing to SDG 2 (zero hunger); however, as has been seen in various studies, there is still a gap in understanding the factors that explain consumers' intention to purchase GM foods. It is true that there is still inconclusive evidence and that the analysis of the benefits and risks is still underway. Likewise, it has been possible to recognize that there is a need for companies and governments to communicate information about GM foods correctly. It is necessary to ensure that product packages contain mandatory information related to the use of GM ingredients. Finally, the consumer must decide whether or not to consume the product, but this must be done with the best and most information possible from the food industry and regulatory agencies. This bibliometric study shows that the United States and the United Kingdom lead the generation of research on the use of GM foods, showing great relevance in this scientific field and collaboration with different countries. However, this leadership shows a major limitation: in regions exposed to different international shocks, such as Africa and Latin America, where food insecurity is more latent, there is a great deficit of research on consumer perceptions and behaviors regarding the consumption of GM foods. The research gap in this field generates great uncertainty, as these regions have great opportunities to benefit from the use of new agricultural technologies, but their

Table 7
Variables related to GM Foods and consumer based on current review.

Variable	Items adapted from sources	Source
Perceived benefits	Overall, GM food technology is useful for society. Transgenic technology can increase crop yields and feed more people. GM food creates a higher quality of life; it is a great technological advancement. Genetically modified foods will eventually be accepted by the majority of people	(52)
	In the long run, a successful genetically modified food industry will be good for the economy. Genetically modified food will be useful for the fight against third-world hunger. The consumption of GM food will be good for the society.	(54)
	Transgenic technology can increase crop yields Transgenic technology can solve environmental problems GM food can address food security in developing countries	(60)
Perceived risks	Overall, GMF can be dangerous to people Eating genetically modified food will lead to infertility Eating genetically modified food will change the genes of us or future generations The production of genetically modified food will destroy the diversity of animals and plants Planting genetically modified crops will have a negative impact on the environment.	(52)
	Eating genetically modified food will be harmful to my health and my family's health Growing genetically modified crops will be harmful to the environment Genetically modified food threatens the natural order of things	(54)
	The application of transgenic technology can cause damage to the environment The application of transgenic technology in food production can cause allergies Eating GM food can cause harm to the health of my family	(60)
Purchase intention	I would like to buy genetically modified food I would like to buy this kind of food if the product trademark indicates that it contains genetically modified ingredients Compared with ordinary food, genetically modified food has a longer shelf life. I would choose to buy this afood because of this point	(52)
	I would you buy genetically modified food if it was of better quality than ordinary food I intend to consume GM food in the future I would buy genetically modified food if it was cheaper than ordinary food	(54)
Trust in regulator	I trust the Government in relation to communication on the risks of GM food I trust the Minister of Health in relation to communication on the risks of GM food I trust the World Health Organization in relation to communication on the risks of GM food	(54)
Knowledge	I know a lot about GM food I know a lot about GM food quality labels I know a lot about GM food technology.	(21)
Attitude toward genetically modified food	Overall, I think GM food is hygienic Overall, I think GM food makes me healthy Overall, I think GM food is safe Overall, I think GM food provides good nutrition	(57)
Willingness to consume GM food	I make a special effort to buy GM food products (that are environment friendly) as compared to the conventional food I have switched to conventional food products	(57)

(*continued on next page*)

Table 7 (*continued*)

Variable	Items adapted from sources	Source
	for ecological reasons When I have a choice between two equal food products, I purchase the one that is less harmful to other people and the environment I make a special effort to buy products using fewer chemicals such as pesticides and are environmentally friendly I have avoided buying a product because it had potentially harmful environmental and health effects	
Attitude to GM technology	Application of transgenic technology is ethically unacceptable X2: Application of transgenic technology in the "natural" angle is unacceptable Transgenic technology is worse than traditional technology	(60)
Attitude to GM food	Production of GM food can improve current and future social welfare The production of GM food is a necessary activity for society For the whole society, the benefits of GM food is greater than the risks	(60)
Subjective norms	Those who have a significant impact on me will mind whether I eat GM food Those who have a significant impact on me will affect whether I eat GM food	(60)
Perceived behavioral control	I am confident that I can avoid eating GM food I can self-monitor a good diet, to avoid consumption of GM food	(60)
Intention to consume GM food	If the quality is better than ordinary food, I will buy GM food GM food I will consume GM food in the future If the price is cheaper than traditional foods, I would choose to buy GM food	(60)

implementation faces major obstacles such as lack of adequate information.

CRediT authorship contribution statement

Shyla Del-Aguila-Arcentales: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aldo Alvarez-Risco:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mercedes Rojas-Osorio:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Investigation. **Hugo Meza-Perez:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **John Simbaqueba-Uribe:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Rosa Talavera-Aguirre:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Luis Mayo-Alvarez:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Paul Espinoza-Ipanaque:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Neal M. Davies:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation. **Jaime A. Yáñez:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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