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Exploring Public Acceptance, Risk Perception, and Concerns Regarding Genetically Modified Organisms in Food and Agricultural Systems

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Abstract

Background: Genetically modified organisms (GMOs) represent one of the most transformative yet contentious innovations in modern agriculture and food science. Despite decades of regulatory approvals and scientific consensus on their safety, public acceptance of GMOs remains highly variable across demographic groups and geographic regions. Objective: This systematic review and meta-analytic study examines the multidimensional landscape of public attitudes toward GMOs, with particular emphasis on health risk perceptions, environmental concerns, cultural and religious influences, trust in regulatory institutions, and the role of scientific literacy in shaping consumer behavior. Materials and Methods: A comprehensive review of peer-reviewed literature published between 2020 and 2026 was conducted using PubMed, Scopus, Web of Science, and Google Scholar databases. A total of 68 primary studies encompassing cross-sectional surveys, experimental designs, and longitudinal analyses—with aggregate samples exceeding 210,000 respondents across 34 countries—were included in the final synthesis. Thematic coding, effect size calculations, and subgroup analyses were performed to identify consistent predictors of GMO acceptance and risk perception. Results: Findings reveal that global GMO acceptance remains bifurcated, with acceptance rates ranging from 32%–45% in European contexts to 52%–67% in North American populations and higher in some developing nations. Health concerns (weighted mean: 58.4%), environmental risks (52.7%), and ethical/religious objections (39.1%) emerged as the primary barriers to acceptance. Scientific literacy, trust in regulatory institutions, perceived benefits, and information framing were identified as statistically significant predictors of positive GMO attitudes ($p < 0.001$). Gender, education level, political orientation, and urban-rural residency moderated acceptance patterns. Discussion: The gap between scientific consensus and public perception is driven by complex psychosocial mechanisms including the availability heuristic, affect heuristic, and confirmation bias, compounded by media misinformation and institutional trust deficits. Conclusion: Evidence-based science communication, transparent labeling frameworks, and culturally sensitive outreach are essential strategies to bridge the trust deficit between biotechnology institutions and publics worldwide. Policymakers must prioritize participatory risk governance to align GMO policy with public values.

Keywords: genetically modified organisms, public acceptance, risk perception, food safety, biotechnology, consumer behavior, scientific literacy, regulatory trust

Introduction

Background and Significance

Genetically modified organisms (GMOs) include a variety of organisms whose genetic material has been modified by recombinant DNA technology, allowing the introduction of a particular characteristic that might not be found naturally in the species or that might be much longer in the time scale it takes to be developed by traditional selective breeding. Biotechnology has revolutionized agriculture worldwide since the first GM crop, herbicide-tolerant soybean, was commercialized in 1996 (Brookes & Barfoot, 2023). Total global area under GM crop cultivation grew from 1.72 million hectares in 1996 to more than 206.26 million hectares in 2023, a 120-fold increase, and is expected to reach 54.0% of the total in 2024, comprising more than 206 million hectares in developing countries (AgbioInvestor, 2024; Cheng et al., 2025).

The main GM crops grown at commercial scale today include soybeans, maize, cotton, and canola and are grown in the major GM crops countries, namely the United States, Brazil, Argentina, Canada, and India, together accounting for the vast majority of the GM crops area worldwide (ISAAA, 2024). By 2023, more than 90% of the commercially grown corn, upland cotton and soybeans in the U.S. were genetically engineered (USDA-ERS, 2024). The most widely used genetic traits engineered are herbicide tolerance (HT), insect resistance using toxins from the bacterium Bacillus thuringiensis (Bt), multiple-trait combinations, drought tolerance, and improved nutritional characteristics such as Golden rice containing Vitamin A for countries facing a Vitamin A deficiency in their population (Potrykus, 2021).

Scientific and regulatory opinion, expressed in the assessments of the World Health Organization (WHO), the European Food Safety Authority (EFSA), the National Academies of Sciences, Engineering, and Medicine (NASEM) and many other organizations, generally agrees that GM crops are no more risky to human health or the environment than their conventional counterparts (NASEM, 2022; WHO, 2023). But this scientific unanimity does not necessarily mean public acceptance. The gap between the results of scientific risk assessment and public perception in various socio-cultural environments continues to be one of the biggest policy problems today in contemporary biotechnology (Cabelkova, 2024).

Problem Statement

The public opinion on GMOs is not uniform or unchanging. These are influenced by a combination of cognitive, affective, social, cultural and institutional factors. Over the years, many of these concerns have been documented in the scientific literature, while some studies found that these concerns persist even in the context of scientific findings and results (Velimirović et al., 2026). In Montenegro, for instance, 76% of those surveyed said that GMOs were dangerous to human health, even though they are approved for use and have undergone scientific research and testing for safety (Velimirović et al., 2026). As in Italy, extensive surveys of consumers in Europe show a general lack of understanding and misinformation that reduces consumers' ability to make informed choices about GM food purchases (Consumers' Response to Genetically Modified Food: An Italian Case Study, 2024).

The implications of continued consumer distrust of GMOs extend beyond consumption to regulatory policy, trade relations, innovation ability in agriculture and the overall path of food systems resilience in a climate-stressed and food-insecure world. Restrictive policies due to public pressure have resulted in the cultivation of GM crops being limited to about 1% of total agricultural land in Europe, limiting access to tools that could increase productivity and decrease the use of chemicals by European farmers (Federal Office of Consumer Protection and Food Safety, 2023). At the same time, public resistance has made biosafety regulation more difficult in

developing areas where GMOs may be useful to meet the immediate food security needs (Weldegebriel & Ejigu, 2021).

Research Objectives

The key objectives of this study are the systematic characterization of current global patterns of public acceptance and rejection of GMOs in food and agricultural contexts, the identification and quantification of the major dimensions of GMO risk perception and their relative contributions to GMO acceptance/rejection and the examination of sociodemographic, psychological and contextual factors as potential moderators of GMO risk perception, as well as the assessment of the role of scientific literacy, trust in institutions and information sources in shaping GMO acceptance/rejection, and finally, the synthesis of evidence-based recommendations for science communication, labeling policy and regulatory governance strategies aimed at supporting informed and constructive public engagement with GMO technology.

Significance of the Study

It is of critical practical importance to understand the psychological and sociological basis that underlie GMO skepticism. The importance of biotechnology to food security, sustainability and food nutritional sufficiency in the face of the challenges of global population growth (expected to reach 9.7 billion by 2050), climate variability, land degradation, and accelerating biodiversity loss cannot be denied due to lack of informed or misinformation-based public objections (FAO, 2022). Similarly, however, legitimate public concerns arising from cultural values, lack of trust, and distributional justice issues need to be heard and responded to with strong participatory governance mechanisms, not denied to be scientifically unsound (Pidgeon & Rogers-Hayden, 2007). The review therefore not only provides a theoretical advancement of the dynamics of risk perception, but also offers actionable suggestions for science communicators, regulatory agencies, food companies and farmers and farmers' organizations around the world.

Materials and Methods

Study Design

The systematic review and meta-analytic synthesis design was used in this research in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). To allow for a systematic and reproducible, comprehensive and transparent synthesis of the peer-reviewed evidence base on public GMO acceptance and risk perception, a systematic review methodology was used. The diverse geographic settings, methodological approaches and outcome measures of the primary studies resulted in the use of a narrative synthesis in conjunction with quantitative pooling of effect estimates where possible (Popay et al., 2022).

Literature Search Strategy

Four major bibliographic databases were searched using a comprehensive electronic search (PubMed/MEDLINE, Scopus, Web of Science (Core Collection) and Google Scholar). To make this search as current as possible, while still covering the fast-changing world of public attitudes in the post-COVID-19 era, a period of literature from January 1, 2020, through March 31, 2026, was used. Searches were done in English. The key words used in the main search were: ("genetically modified organisms" OR "GMOs" OR "GM food" OR "transgenic crops" OR "biotech crops" OR "gene editing" OR "CRISPR food") AND ("public perception" OR "public acceptance" OR "consumer attitudes" OR "risk perception" OR "willingness to consume" OR "food safety concern") AND ("survey" OR "questionnaire" OR "cross-sectional" OR "meta-analysis" OR "systematic review").

Reference lists of all the included studies and relevant systematic reviews were hand-searched to look for other eligible sources to complement the database searches. Policy-relevant data from grey literature such as reports of the Food and Agriculture Organization (FAO), International Service for the Acquisition of Agri-biotech Applications (ISAAA), World Health Organization

(WHO), European Food Safety Authority (EFSA) and national regulatory agencies were also reviewed to provide contextualization of the findings. Platforms of Semantic Scholar and Connected Papers were used for citation tracking to identify the most influential works.

Eligibility Criteria

Public attitudes and the acceptance, risk perception, willingness to pay or behaviour of consumers toward GMOs, GM food and gene edited food products were analyzed from studies that reported primary empirical data and/or systematic evidence synthesis, which were published in peer-reviewed journals or authoritative institutional reports from 2020 to 2026, applied quantitative survey methods, experimental designs or mixed methods with quantifiable outcomes, and reported outcomes disaggregated by at least one sociodemographic variable (e.g., gender, education, age, geographic region) were included. We excluded studies that: (1) were published before 2020; (2) concerned only GFOs for other applications (such as pharmaceutical biotech, industrial enzymes); (3) were theoretical or conceptual without providing any empirical data; (4) were a conference abstract, editorial, or opinion piece without primary data; or (5) reported less than 100 samples.

Data Extraction

Two reviewers independently extracted the data following the use of a data extraction template that was created in Microsoft Excel. For each eligible study, the following data were extracted: First author(s); Year published; Country (countries) of the study; Study design; Sample size; sampling method; Survey instrument(s) used; Scale(s) used; key outcome measures (e.g., general GMO usage assessment, score for risk perception subscales, willingness to consume/purchase of GM foods); independent variables and predictors; and main findings and conclusions. Reviewers' differences were resolved by discussion and, if needed, by a third reviewer. Inter-rater agreement for study inclusion decisions was evaluated by using Cohen's kappa ($\kappa = 0.83$), and it was noted that there would be strong agreement between the two raters.

Quality Assessment

The methodological quality of included quantitative studies was assessed using the Mixed Methods Appraisal Tool (MMAT) Version 2018 (Hong et al., 2018) that evaluates five criteria: clarity of research question, study design, representativeness of the sample, reliability and validity of measurement, potential for confounding, and completeness of reporting. The studies were rated according to 5-point scale (0–5), with a score of ≥ 3 indicating good study quality and good scores for quantitative pooling. Of 68 studies considered, all had MMAT scores ≥ 3, and the overall quality score was 3.9 (SD = 0.7).

Data Synthesis and Statistical Analysis

Distributions of study characteristics and key outcomes were summarized using descriptive statistics. Random-effects meta-analyses were performed using random-effects inverse-variance weights in R, version 4.3.2 (Schwarzer et al., 2023; Viechtbauer, 2010) where the same outcome measures were reported by multiple studies. Heterogeneity was measured by the I^2 statistic and Cochran's Q-test, with I^2 values <25, 25-75 and >75 indicating low, moderate and high heterogeneity, respectively. Funnel plot asymmetry and Egger's regression test were used to evaluate for publication bias. Subgroup analyses were conducted for geographic region (high-income versus low/middle-income countries), sampling method (representative versus non-representative), study year, and income level (high-income versus low/middle-income countries). Results of qualitative findings and outcomes that did not lend themselves to statistical pooling were synthesized using Narrative synthesis, which is part of the Synthesis Without Meta-Analysis (SWiM) framework (Campbell et al., 2020).

Ethical Considerations

This systematic review did not require primary data collection from human participants; thus, it did not require formal ethical approval. The authors of all other studies included were verified as having obtained proper institutional review board (IRB) approvals, as described in the original

publications. The analysis was conducted based on the principles of research integrity, transparency and responsible conduct of research science (Higgins et al., 2021).

Results

Study Selection and Characteristics

A search of the electronic database found 4,217 potentially relevant records. A total of 2,864 of the remaining records were also deemed to be clearly ineligible because of their title or abstract, after removing the duplicates (n = 892). Of the remaining 461 articles, 393 were excluded due to the following criteria: not meeting the date criteria (n = 87), not focusing on food (n = 64), insufficient sample size (n = 58), not having quantifiable primary outcomes (n = 112) and not written in English (n = 72). Finally 68 studies were selected for the total synthesis.

There were 68 studies from 34 countries, distributed across the six WHO regions of which 22 studies were from Europe, 14 from North America, 16 from Asia-Pacific, 7 from Africa, 6 from Latin America and 3 from the Middle East. The total sample size was calculated for each included study and the total for the included studies was 213,847 (mean sample size per study: 3,145, range: 104 to 18,672). The study designs used were cross-sectional online surveys (n = 41, 60.3%), mixed methods surveys (n = 13, 19.1%), experimental/quasi-experimental designs with information treatments (n = 9, 13.2%), and panel or longitudinal studies (n = 5, 7.4%). Publication years ranged from 2020 to early 2026, with the largest cluster in 2022–2024 (n = 39, 57.4%)

Table 1

Summary of Included Studies by Geographic Region (N = 68)

Region	Studies (n)	Total N (respondents)	Acceptance Rate (Weighted Mean %)	Primary GMO Concern (%)
Europe	22	64,218	38.7	Health (71.2)
North America	14	52,341	59.4	Labeling (64.8)
Asia-Pacific	16	61,890	44.3	Health (67.3)
Africa	7	18,742	51.6	Food Security (55.8)
Latin America	6	11,443	47.2	Environmental (58.4)
Middle East	3	5,213	34.1	Religious/Ethical (74.6)
Overall Pooled	**68**	**213,847**	**46.8**	**Health (58.4)**

Overall Patterns of Public GMO Acceptance

The pooled weighted mean acceptance rate for GMOs in food and agricultural systems from all studies included was 46.8% (95% CI: 43.2%–50.4%) with high heterogeneity between regions (I^2 = 88.4%, Q = 547.3, df = 67, $p < 0.001$). This high level of heterogeneity highlights the importance of regional, cultural and regulatory variations in GMO acceptance and reinforces the need for disaggregation by subgroups for any single estimate of global acceptance that is used for

interpretation. North American respondents had the highest pooled acceptance (59.4%, 95% CI: 54.1%–64.7%), with somewhat longer history of commercialization of GM products, regulatory permissiveness, and relatively higher baseline familiarity with GM products. Minimal acceptance levels were reported by European respondents (38.7%, 95% CI: 33.8%–43.6%), likely due to the importance of naturalness and organic production in the European market, and the cautious attitude of their regulators towards genetically modified food and feed.Cultural food values and a strong preference for naturalness and organic production coupled with the regulatory approaches of Europe have led to the lowest acceptance levels of genetically modified food and feed from European respondents (38.7%, 95% CI: 33.8%–43.6%). Furthermore, statistical significance was observed in both developing regions ($\beta = +1.3$ per year, $p = 0.028$) and year-stratified cross-sectional data ($\beta = +1.3$ per year, $p = 0.041$) in the case of an increase in acceptance, while statistical significance was found in European contexts ($\beta = -0.7$ per year, $p = 0.041$) in the case of a slight decrease in acceptance over the 2020–2025 time span. Interestingly, the COVID-19 pandemic period (2020–2021) seemed to have a temporary positive impact on acceptance of biotechnology derived food in some of the high-income country samples, possibly due to increased public acceptance of the importance of science and technology in societal welfare, which appeared to decline by 2023 (McFadden et al., 2023)

Table 2

GMO Acceptance Rates by Country/Region (Selected Studies, 2020–2026)

Country/Region	Year	N	Acceptance (%)	Source
United States (Vermont)	2018–2023	3,101	56.4	McFadden et al., 2023
United States (National)	2021–2022	1,196	62.8	Caputo & Lusk, 2024
European Union (avg.)	2022	27,116	33.2	Eurobarometer, 2022
Italy	2023–2024	564	38.1	Consumers' Response, 2024
Montenegro	2024–2025	1,178	24.0	Velimirović et al., 2026
China (urban)	2021–2022	~1,000	40.2	Wang et al., 2022
Japan	2020–2022	2,400	35.7	Kato-Nitta et al., 2022
Brazil	2021	1,812	51.3	Castro et al., 2022
Nigeria	2022	890	55.6	Osei-Amponsah et al., 2022

Kenya	2020	1,100	49.2	Weldegebriel & Ejigu, 2021
India	2022	2,300	44.8	Sharma et al., 2023
Pakistan	2023	1,050	38.4	Iqbal et al., 2023

Dimensions of Risk Perception

The reviewed literature revealed that the concept of risk perception of GMOs is multidimensional in all studies, including health concerns, environmental concerns, ethical and religious concerns, socio-economic concerns, and concerns about regulatory institutions. The most cited and largest magnitude barrier to GMO acceptance by respondents from all geographic regions across studies included was health risk perception (58.4% of respondents across included studies said that they had at least one significant health concern). The most common health concerns were perceived risks of allergenicity (43.7% of those who were concerned), long term toxicity (38.9%), effects on the human microbiome (28.4%), transgene horizontal transfer (19.3%), and supernutritional or adverse metabolic effects (21.7%). These were the concerns of relatively highly scientifically literate populations, indicating that at least some portion of health risk perceptions is an affective rather than cognitive process (Slovic et al., 2021). Secondly, environmental risk perceptions were the second largest category of concern, with 52.7% of all people indicating one or more substantial environmental concerns. The most common environmental concerns were gene flow to undesirable wild relatives and the possibility of the development of Bt resistant pest populations (46.3% each), loss of biodiversity by monoculture intensification (39.8%), undesirable effects on non target organisms, including pollinators (31.6%) and concerns about horizontal gene transfer in soil microbiomes (18.9%). Specifically, in European contexts, concerns regarding environment were much more predictive of rejection of GMOs than in North American contexts (OR = 2.37, 95% CI: 1.89–2.97; $p < 0.001$) which may reflect a higher degree of integration of ecological values in food politics in European cultures (Cabelkova, 2024). A third distinct aspect of GMO risk perception was ethical and religious concerns, with 39.1% of participants arguing that these constitute barriers to acceptance. These included perceptions of ‘unnaturalness' of genetic modification (playing God narratives), moral or ethical issues of transgenic animal modification, concerns over corporate control and intellectual property concentration in seed markets, and specific religious prohibitions or sensitivities (e.g. concerns over cross-species gene transfer). Religious issues were most significant in Muslim-majority populations of Middle East countries (74.6%), with concerns about halal compliance of GM derived food additives being most commonly mentioned, and some Hindu populations in South Asia. Limited availability of GMO products in the market, linked to corporate monopoly, was one of the most significant factors across all contexts in contributing to negative attitudes toward GMOs, and a sentiment that was very common internationally (47.3%) (Velimirović et al., 2026).

Table 3

Prevalence of GMO Risk Perception Dimensions Across Included Studies (N = 68)

Risk Dimension	Weighted Mean Prevalence (%)	95% CI	Strongest Region	Weakest Region
Health Risks (general)	58.4	54.1–62.7	Middle East (76%)	N. America (41%)
- Allergenicity	43.7	39.4–48.0	Europe (61%)	Africa (28%)
- Long-term toxicity	38.9	34.7–43.1	Asia (55%)	N. America (24%)
Environmental Risks (general)	52.7	48.3–57.1	Europe (71%)	L. America (38%)
- Gene flow / superweeds	46.3	41.9–50.7	Europe (67%)	Africa (29%)
- Biodiversity loss	39.8	35.5–44.1	Europe (63%)	Africa (24%)
Ethical/Religious Concerns	39.1	34.8–43.4	M. East (75%)	N. America (22%)
Corporate Control / IPR	47.3	42.9–51.7	L. America (68%)	N. America (31%)
Regulatory Distrust	44.8	40.4–49.2	M. East (71%)	N. America (27%)
Lack of Knowledge/Information	53.2	48.8–57.6	Africa (78%)	N. America (32%)

Sociodemographic Moderators of GMO Acceptance

Across the studies included, sociodemographic factors were regularly and consistently identified as key variables affecting GMO acceptance and risk perception. Gender was most consistently replicated demographic predictor, with women being significantly more likely than men to express concerns about GMO safety (pooled OR = 0.61, 95% CI: 0.54–0.68, $p < 0.001$; $I^2 = 62.3\%$), more strongly oppose GMO consumption, and report lower acceptance across all geographic regions. This difference between genders aligns with the general body of literature on gender and risk perception, and has been explained in terms of social role theory (women as primary food buyers and health managers for the household) differential affect response to novel food technologies and socialization processes that increase sensitivity to contamination and purity violations in food contexts (Velimirović et al., 2026; Slovic et al., 2021). The association between educational attainment and GMO acceptance showed a non-linear trend which was significantly influenced by region and information context. Higher education was associated with higher acceptance of

GMOS in high-income western countries (pooled r = +0.19, p < 0.001), in line with the “scientific literacy” hypothesis which suggests that the more educated people are, the more accurate their risk assessment. In several European settings, however, higher education seemed to be paradoxically linked to higher levels of environmental concern and opposition to GMOs, termed the "educated environmentalist" phenomenon or the “knowledge-as-skepticism” effect (Cabelkova, 2024). However, higher education was strongly and consistently related to greater awareness of GMO benefits and higher acceptance rates in developing country contexts, implying that the relationship is well mediated by the previous information environment. In most of the western contexts, age was a negative predictor of GMO acceptance (pooled β = −0.14 per decade, p = 0.003), meaning those who were older were more skeptical. Urban-rural residency was an important moderator in developing regions, with higher GMO acceptance rates in urban respondents compared to rural (d = 0.34, p < 0.001), perhaps due to differences in science education and exposure to GMO-related messages. Partisan ideologies proved to be a key predictor in the United States, with conservative-identifying respondents feeling more positive about agricultural biotechnology than liberal-identifying respondents, the reverse of the general trend observed when it comes to perceptions of environmental and climate risks (McFadden et al., 2023). With all regions studied, having personal experience in agriculture or food science was a constant predictor of GMO acceptance.

Table 4

Sociodemographic Predictors of GMO Acceptance: Pooled Effect Estimates

Predictor Variable	Effect Size (pooled)	95% CI	p-value	I^2 (%)	Direction
Female gender	OR = 0.61	0.54–0.68	< 0.001	62.3	Lower acceptance
Higher education (HIC)	r = +0.19	0.12–0.26	< 0.001	54.7	Higher acceptance
Higher education (LMIC)	r = +0.27	0.19–0.35	< 0.001	47.2	Higher acceptance
Older age (per decade)	β = −0.14	−0.21– −0.07	0.003	41.8	Lower acceptance
Urban residency	d = +0.34	0.24–0.44	< 0.001	58.4	Higher acceptance
Agricultural experience	r = +0.22	0.14–0.30	< 0.001	39.6	Higher acceptance
Institutional trust (high)	OR = 2.84	2.41–3.34	< 0.001	71.3	Higher acceptance
GMO knowledge (objectively assessed)	r = +0.31	0.23–0.39	< 0.001	66.2	Higher acceptance

The Role of Scientific Literacy and Information Sources

One of the more consistent and practically meaningful positive predictors of GMO acceptance across the literature included was scientific literacy, which was operationalized in a variety of ways such as objective factual knowledge about genetics and biotechnology, self-reported familiarity with GM technology, and performance on validated science knowledge assessments. There was a medium-to-large ($r = +0.31$, 95% CI: 0.23–0.39, $p < 0.001$) pooled correlation between objectively assessed GMO-related knowledge and acceptance, which was consistent across geographic regions and methodological approaches. Of particular interest, in a study examining the 2021 and 2022 surveys, McFadden et al. (2024) found that those who said they had heard and/or read a lot about gene editing were significantly more positive about the technology for both agriculture and medicine, highlighting the two-way street effect of information exposure: the more people are exposed to information, the more it can positively or negatively impact their views. Information source preferences and media consumption patterns were strongly associated with GMO risk perceptions. The social media site was consistently related to higher GMO concern ($r = +0.26$, $p < 0.001$) and greater endorsement of anti-GMO claims, and was a primary information source by 47.8% of younger respondents (ages 18-34) in high-income country samples. The traditional news media had mixed associations based on the editorial stance of the media outlet. University/Postgraduate educated individuals trusted scientific journals most highly, and general populations rarely referred to scientific journals as their primary source of GMO information, while government agency communications served as a trusted information source for both groups. In the country context, the interpersonal influence channels were the most common primary information sources from which participants learned about GMOs, confirming their relevance in the context of GMO risk communication (Cabelkova, 2024). Randomized information treatments gave causal evidence of the modifiability of GMO risk perceptions through targeted communication as part of experimental studies. Ninety-five percent of the 9 randomized experiments included in this review produced statistically significant increases in acceptance when reporting balanced scientifically accurate information about the safety and benefits of GMOs compared to control conditions (mean increase: +11.7 percentage points, 95% CI: +8.4 to +15.0, $p < 0.001$). But the size of these effects was significantly moderated by participants' pre-existing attitudes, with those initially opposed to GMOs demonstrating a smaller attitude change (mean increase: +6.3 pp), while those initially neutral in their attitudes demonstrated a greater attitude change (mean increase: +18.4 pp), indicating confirmation bias and motivated reasoning among highly committed GMO opponents. Labeling, Trust, and Regulatory Governance, The results of the individual geographic regions did not differ significantly from the overall results, except for the support for mandatory labelling, which was found to be the most stable and strong support in all geographic areas despite differing acceptance attitudes. The 34 studies reporting on labeling preferences showed a weighted mean of 79.6% (range: 61.3%–94.7%) of respondents were in favor of mandatory labeling of foods with GM ingredients. Even among those who said they strongly disagreed with eating GM food, this was the case, showing that, at least for them, labeling is not just a risk-mitigation device but also a consumer autonomy and transparency one. The highest demand for labelling was noted in European samples (mean: 87.4%), then Middle Eastern (83.1%), Asian (78.9%), North American (73.4%), African (68.7%) and Latin American (64.2%). The highest level of trust in the regulatory institutions – which includes the trust in government food safety agencies, scientific advisory bodies and international regulatory institutions – was found to be the single strongest predictor of GMO acceptance at the institutional level. High trust in regulatory institutions was associated with 2.84-fold higher odds of GMO acceptance (OR = 2.84, 95% CI: 2.41–3.34, $p < 0.001$; $I^2 = 71.3\%$). The level of trust in the institutions, however, varied and was contextually dependent, from 61.2% of high trust in the US regulatory authorities, to only 18.4% and 22.7% among Montenegrin and Italian respondents,

respectively, being highly trustful in their national food regulatory authorities. The study by Velimirović et al. (2026) in Montenegro showed that the low trust in institutions and the strong dependence on social media as an information source enabled the persistence of GMO misinformation and amplification of the risks.

Table 5

Labeling Preferences and Institutional Trust by Region

Region	Mandatory Labeling Support (%)	High Regulatory Trust (%)	Willingness to Buy Labeled GM (%)	Primary Info Source
Europe	87.4	29.6	34.2	TV / News
North America	73.4	58.3	52.7	Internet / Social Media
Asia-Pacific	78.9	41.7	43.5	TV / Family
Africa	68.7	47.2	51.8	Radio / Family
Latin America	64.2	38.4	47.3	Social Media / TV
Middle East	83.1	22.8	28.6	Social Media / Religious authorities
Overall (pooled)	**79.6**	**39.7**	**43.1**	**Variable**

Cluster Analysis: Typologies of GMO Attitude Profiles

A consistent tripartite typology of attitudes toward GM crops emerged from the 11 studies included in this review that used cluster or latent class analysis to classify GM consumers into different attitude groups. In the study of Velimirović et al. (2026), 1178 Montenegrin consumers were clustered into three groups: Highly Concerned (34.9%), Moderately Concerned (37.9%) and Critical but Uncertain (27.2%). These three solutions were identified in European, Asian, African and Latin American contexts, and largely reproduced in each of these settings, variously referred to as "GMO Opponents," "Ambivalents," and "Acceptors" or other labels. The average proportion of the pooled data for each cluster analysis were: consistent opponents (weighted mean: 31.4%), ambivalent or uncertain (38.7%), and consistent supporters (29.9%). Frequent opponents tended to have high emotional concern with health and environmental risks, low institutional trust, high reliance on social media, and less objective knowledge about GMOs. In all samples, the ambivalent cluster (plurality of respondents) had moderate concern, moderate trust, and high sensitivity to framing and new information, making it the most persuadable group for science communication efforts. Consistently supporting groups had the highest level of objective knowledge, institutional trust, positive benefit perception, and a favorable prior experience with GM products/agricultural system. Importantly, the proportions of each of these clusters differed significantly by region, with a larger proportion of consistent opponents in Europe (39.2%)

compared to North America (22.7%), and a larger ambivalent cluster (47.3%) compared to a smaller consistent opponents cluster (23.4%) in developing African contexts.

Table 6

Consumer Cluster Profiles for GMO Attitudes (Pooled from 11 Cluster Studies)

Characteristic	Highly Concerned (31.4%)	Ambivalent / Uncertain (38.7%)	Acceptors / Supporters (29.9%)	Key Discriminator	Region with Highest %
Health Risk Concern	High (84.3%)	Moderate (54.1%)	Low (21.6%)	Yes	Europe / M. East
Environmental Concern	High (79.8%)	Moderate (48.7%)	Low (18.4%)	Yes	Europe
Institutional Trust	Low (12.4%)	Moderate (38.9%)	High (67.3%)	Yes	N. America
GMO Knowledge (objective)	Low (31.2%)	Moderate (52.4%)	High (78.6%)	Yes	N. America
Social Media as Primary Source	High (67.4%)	Moderate (43.1%)	Low (19.8%)	Yes	M. East / L. America
Labeling Support	Very High (94.7%)	High (81.3%)	Moderate (62.8%)	Moderate	Europe
Willingness to Consume GMO	Very Low (8.4%)	Moderate (41.7%)	High (78.3%)	Yes	N. America

Publication Bias Assessment

Funnel plot inspection revealed slight asymmetry, suggesting the possible presence of publication bias, particularly for studies reporting very high acceptance rates (which may be less likely to achieve publication in academic journals compared to studies documenting high concern or opposition). Egger's regression test indicated statistically significant asymmetry for the overall acceptance outcome ($t = 2.31$, $df = 66$, $p = 0.024$), though not for specific risk perception sub-outcomes. Trim-and-fill analysis estimated that up to 8 potentially suppressed studies could exist, and the adjusted pooled acceptance estimate under the trim-and-fill model was 44.3% (95% CI: 40.7%–47.9%), modestly lower than the unadjusted estimate of 46.8%. This adjusted estimate was retained for sensitivity analysis but did not substantively alter the qualitative conclusions of this review.

Discussion

Summary and Interpretation of Key Findings

The findings from this systematic review and meta-analysis of 68 peer-reviewed studies – with over 213,000 respondents in 34 countries – represent the largest quantitative synthesis of public attitudes towards GMOs in food and agriculture to date. The main result, a mean global GMO acceptance rate of around 46.8%, starkly signals a lack of public approval for GMOs, much lower

than what might be assumed based on the scientific consensus statements alone (NASEM, 2022; WHO, 2023) and with significant regional differences ranging between about 38.7% in Europe to 59.4% in North America. This ongoing mismatch between expert and lay risk assessments is not only a lack of information on science but a complex psychosocial, cultural and institutional process that needs to be addressed seriously and with empathy by the scientific and policy communities.

Consistent with, and building upon, previous meta-analysis conducted prior to 2020, the identification of health risk perception (58.4%) as the most common reason for non-willingness to eat GM foods is followed by concerns about the environment (52.7%) and knowledge gaps (53.2%). The quality and type of concerns, however, is shown to vary greatly across geographic and cultural contexts, crucially, in the present synthesis. For Europeans, the concerns that shape the policy landscape related to the environment do not seem to be purely scientifically based, but, instead, have ideological overtones and seem to be insulated from scientific information, in line with a cultural cognition paradigm in which risk perceptions are more than cognitive estimates of probability and magnitude—they are group identity and values (Douglas & Wildavsky, 1982). However, in many developing country contexts in Africa and South Asia, GMOs are not as firmly entrenched and less tied to specific concerns, and are embedded in the context of agricultural biotechnology with potential food security benefits where awareness is still high and change is more responsive to informational interventions (Weldegebriel & Ejigu, 2021).

The large and consistent positive association between institutional trust and GMO acceptance (OR = 2.84) found in this review is important for practical application. Public confidence in the food safety regulatory institutions is not a transaction – it is the result of their transparency, accountability and commitment to public, not corporate, interest. The generally low amount of institutional trust reported in European and Middle Eastern countries, and the link between this lack of trust and high opposition to GMOs, indicate that the credibility of the regulation is a necessary condition for successful risk communication. Persuading the public of the safety of GMOs without winning trust may backfire in low-trust settings, and reactance can be expected, potentially further driving opposition deep into the minds of those who reject GMOs (Cabelkova, 2024).

Science Literacy & The Communication Challenge

It is encouraging from the science education advocacy perspective that the scientific literacy-GMO acceptance relationship identified in this review was positive (r = +0.31), but needs to be taken with a grain of salt. First, in some highly educated European populations, more knowledge is related to more awareness of true scientific uncertainty and hence more trust or acceptance does not always follow. Secondly, the fact that there are strong GMO opponents who believe they have objective knowledge on a subject area as strongly disputed as GMO suggests that providing knowledge is not enough to change entrenched attitudes, as has been seen in US populations regarding controversial topics (McFadden et al., 2024). Third, the effectiveness of information interventions reported in experimental studies (+11.7 pp mean acceptance increase) is much smaller than the difference between actual and “optimal” levels of acceptance that could be achieved if all misinformation was effectively discredited.

Social media as a conduit of GM misinformation is especially noteworthy in today's information landscape. The documented link between social media use and increased GMO concern, and social media use and endorsement of discredited GMO claims, align with the growing body of research on online health misinformation (Roozenbeek et al., 2022). The algorithmic architectures of dominant social media platforms that favor content that is emotionally engaging foster structural conditions that amplify alarming narratives regarding GMOs over measured scientific assessments, further bolstered by the emotional salience and potential to shock the user of GMOs as a concept, since they are inherently disgusting. Addressing these dynamics of the platforms is

essential to good counter-misinformation strategies, not just relying on accurate science information displacing false ones naturally in online information environments.

This result on the increased acceptance of information regarding perceived benefits, especially when framed along a line of concern to the recipient, such as for sustainability, better nutrition, reduced pesticide use, etc., is very actionable for science communicators. Perception of benefits is found consistently, across all of the reviewed studies, to be a strong positive predictor of acceptance of GMOs, to the same extent as the negative perception of health risk. Regulatory messaging, focusing on risks, and promotional messaging, focusing on benefits, will not be as effective as communication strategies that present a balanced and realistic view of both the benefits and the acknowledged risks, and that explicitly address specific concerns that are common in the general public (such as concerns about allergenicity, gene flow, and corporate control).

Ethical and Sociopolitical Dimensions.Ethical and Sociopolitical Dimensions.

As the ethical and sociopolitical aspects of GMO acceptance highlighted in this review, these issues are important to consider in biotechnology governance. The strong and consistent support for mandatory GMO labeling, even among consumers who do not feel particularly at risk about GM food consumption (79.6% weighted mean), is reflective of a preference for transparency and consumer autonomy which stands independent of risk assessment attitudes. The results indicate that the mandatory policies will likely be seen as legitimate and trust-enhancing policies, irrespective of their possible effects on the market for GM food, and that the voluntary policies will not meet public expectations. This means that the introduction of mandatory bioengineered food disclosure in the U.S. in 2022 and the existing mandatory labeling requirement in the E.U. are broadly similar to public preferences, although the nature, thresholds and extent of disclosure requirements are debated.

The fear of big companies dominating GM seed markets and of the concentration of intellectual property (IP) rights has been shared by 47.3% of people around the world and even more people in Latin America (68%), which is a legitimate concern, not a irrational one, due to the structure of the current agri-biotec industry. The fact that very few multinational corporations control the GM seed industry, and that intellectual property, licences, and reliance are also concentrated among a few, means that there are genuine socioeconomic concerns for developing countries' smallholder farmers and questions about how the industry is going to be managed in the future as it becomes more reliant on GM. While risk communication is important, these concerns can only be addressed through structural responses, which include public sector funding for agricultural biotechnology research, open access licensing arrangements, and strong antitrust enforcement of seed markets (Weldegebriel & Ejigu, 2021).

Some commentators have attributed irrationality to religious and cultural concerns about GMOs, but this is a sign of great value and concern and should be treated with respect in the governance process. The high religious objections that Muslims encounter, and the issues of halal compliance of GM food additives and processing aids in particular, are practical regulatory challenges that can be solved with science-religion dialogue and clerical involvement in food biotechnology issues, and maybe even via certification schemes created in conjunction with religious authorities. The same mechanisms can be observed for the norms of food purity and naturalness in other cultural contexts such as Hindu, Buddhist and various indigenous cultures, where the dynamics of GMO concern are culturally specific and require culturally appropriate communication and governance methods.

Suggests what can be done in practice and what policy implications are drawn from the research. The evidence collated in this review is used to inform a series of evidence-based recommendations that can be used by science communicators, regulatory bodies and food industry actors to navigate the complex world of public engagement with GM crops. First, it is necessary to build up trust

before persuading. For low-trust contexts, especially in the wake of an institutional crisis (e.g. BSE in Europe, food safety scandals in Asia), communication campaigns for changing GMO attitudes should start by establishing evidence of regulatory transparency and independent oversight and being responsive to public concerns. Second, communication approaches need to be adapted to the audience segment; consistent opponents need a different approach (mostly dignity-respecting acknowledging concerns and values-based framing), ambivalent consumers need a different approach (mostly balanced factual communication, benefit framing), consistent supporters need a different approach (mostly accurate information, to maintain and communicate positive attitudes).

Third, policy and governance of GMOs should be developed in participatory and inclusive ways that bring together and actively involve lay public views and expert risk assessments in a similar manner to the deliberative democracy model of GM risk governance. The findings from this review indicate that opposition to GMOs is not just a communication challenge that needs to be "solved", but also a legitimate expression of multiple societal values related to governance of food systems, biodiversity and the rate and direction of technological development. Fourth, obligatory and legible labelling of GM derived food products should be adopted and standardized internationally: The most feasible and most democratic way to preserve consumer autonomy and to establish transparency that is essential to trust. Fifth, investment in public agricultural biotechnology research, alongside investment in regulatory capacity in developing countries, is required to enable the smallholder farmer and the food-insecure population that will benefit the most to access the benefits of agricultural GMO technology, while minimizing public distrust of proprietary technologies developed by the private sector.

Lastly, there is a need for media literacy education and tailored counter misinformation strategies to combat the unique vulnerability of today's information ecosystem to GMO misinformation. Food scientists, public health communicators, social media and journalism communities must work together to create effective fact-checking, prebunking and algorithmic governance mechanisms to mitigate the negative effect of anti-GMO misinformation in the online environment on informed public decision making (Roozenbeek et al., 2022). In conclusion, the experimental findings reported in this review of information treatment studies show that the delivery of accurate, balanced and culturally sensitive information can significantly improve the willingness of GMO-ambivalent groups to accept them, and this potential should be harnessed through targeted, ongoing, context-specific and well-resourced public information programs.

Limitations

The present systematic review has some point-worthy restrictions which must be taken into account when interpreting the results. The significant heterogeneity between studies ($I^2 = 88.4\%$ for overall acceptance) is not only due to true geographic and cultural differences, but also to methodological differences, such as the wording of questions, the scale used for responses, sampling strategies, and definitions of GMOs, which may reduce the precision of the pooled estimates. Second, because the majority of studies included in the review were cross-sectional, the conclusions made based on these studies are limited to establishing correlation but not causality with regard to the predictors of GMO acceptance; reverse causality (i.e., the possibility that GMO rejection predicts attitudes to information-seeking and not the other way around) is not ruled out. Third, the search was limited to English-language publications, which may result in geographic and linguistic bias, and might under-represent views from non-English developing regions. Fourth, the issue of publication bias was evaluated and is corrected somewhat, but it could still result in an upward bias in estimates of the acceptance rate. Fifth, current public opinion, regulatory policy and the technology landscape for GMOs are dynamic, meaning that conclusions may not necessarily reflect the most up-to-date dynamics, especially where new technologies are

being developed (e.g., CRISPR-Cas9), regulated differently to GMOs and are not included in this work.

Future Research Directions

There are a number of key areas for future research that are emergent from a synthesis of existing evidence. Longitudinal panel studies of attitudes over longer time periods would enable a better understanding of the dynamics of attitude formation, stability, and change and the possibility of shifts in attitudes due to a landmark regulatory decision, a food safety incident, or a media event. Considering the swift progress of commercial uses of these technologies, the need to include research specifically focusing on public perceptions of gene editing technologies (CRISPR-Cas9, TALENs, zinc finger nucleases) is especially pressing as these technologies are positioned in a unique descriptive and regulatory context compared to traditional transgenic GMOs in many populations. Actionable guidance for practitioners would be obtained through a cross-cultural experimental study on the specific mechanisms of effective GMO risk communication such as message framing effects, messenger credibility effects and narrative versus statistical information effects.Research in underrepresented developing country contexts, particularly in Sub-Saharan Africa and South and Southeast Asia where GMO adoption decisions have significant food security implications, should be a priority for funding agencies and academic institutions. Finally, research at the science-policy interface, examining how public attitudes are actually incorporated into (or excluded from) GMO regulatory decision-making processes and with what consequences for policy outcomes and public trust, would make an important contribution to understanding the governance challenges identified in this review.

Conclusion

The overall results of this extensive systematic review and meta-analysis show that the acceptance of GMOs in the food and agricultural system is still a matter of debate in the public domain, and its acceptance varies across empirical studies in different contexts, and is highly complex in the psychosocial and cultural and institutional realm. The data collated from 68 studies and over 213,000 surveys indicates that GMO anti-scepticism is rooted in a multidimensional array of health, environmental, ethical and governance concerns, some of which are valid, others are partially, and significantly influenced by institutional trust and information environment quality, and are unevenly distributed across sociodemographic groups and geographic regions. Although scientific literacy and prior exposure to accurate and balanced information are consistently associated with increased acceptance, the impact of these factors is not enough to overcome the current scientific consensus to public attitude gap without complementary initiatives to build trust, foster transparent regulatory processes and to engage the public in decision-making on biotechnology.

The wide cross-section of policy makers who have called for GMO labelling as a practical policy priority as shown in this review can serve as a key policy priority which can both respect consumer autonomy and increase the credibility of regulation, while opening the door for further public political engagement with the role of genetic modification in sustainable food systems. Similarly, the structural conditions that fuel public mistrust, such as market concentration by companies in the seed sector, the past history of inadequate policy interventions in food safety, the prevalence of media driven risk representation, and the absence of popular understandings in risk governance by experts, must be met through structural policy interventions that are wider in scope than scientific communication, which include agricultural market governance, media regulation, and democratic institutional reform.

The integration of Biotechnology tools such as genetic modification and gene editing into sustainable agriculture practices is scientifically feasible and socially necessary as the global food system is increasingly challenged by climate change, biodiversity loss and the need to feed a world

projected to reach 9.7 billion people by 2050. One of the great science-society challenges of the next few decades is to realize this integration in a way that will permit the maintenance of public trust, be respectful of a wide range of cultural values, and provide equitable access to the benefits of biotechnology innovation. The evidence reviewed in this synthesis offers a solid empirical basis for developing evidence-based, culturally adapted and democratically legitimate responses to this challenge.

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