Journal of Genetic Engineering and Biotechnology 23 (2025) 100481

Contents lists available at ScienceDirect

Journal of Genetic Engineering and Biotechnology

journal homepage: www.elsevier.com/locate/jgeb

What's in (y)our food? – Occurrence of GM-containing foods on the Nigerian market and compliance with national regulations

Josephine Amedu [a], Adedapo Adediji [b,c,*], Ngozi Miracle [a], Albert Anthony [a], Precious Adeyemi [a], Rabi Ahmed [a], Stephen Atsumbe [a], Mike Costly [a], Ayodele Majekodunmi [d], Odunayo Balogun [c], Oyewumi Akinpelu [c], Kilsi Borgbara [c], Olanrewaju Olufowobi [c], Hauwa Jibo Tahir [a], Lukman Aroworamimo [c,**], Agnes Asagbra [a,**]

[a] National Biosafety Management Agency, Abuja, Nigeria
[b] Pan African University Life and Earth Sciences Institute, Ibadan, Nigeria
[c] Inqaba Biotec, Ibadan, Nigeria
[d] Food and Agriculture Organization of the United Nations, Abuja, Nigeria

ARTICLE INFO

Keywords:
Food safety
Cereal products
NAFDAC registration
Consumer choice

ABSTRACT

The regulation of genetically modified (GM) food products in several jurisdictions considers appropriate labelling to be a key requirement for food safety and to ensure the protection of consumer choices. In Nigeria, such regulations are enforced by relevant government agencies. There is, however, little information on compliance levels with appropriate labeling regimes of GM products in Nigeria. This study was conducted to ascertain compliance with existing labeling guidelines and regulations for GM food products sampled from Abuja, Nigeria. DNA-based real-time polymerase chain reaction detection procedures were used to evaluate 15 processed and semi-processed pre-packaged food products obtained from retail stores in Abuja for the presence of specific regulatory sequences specific to GM products. Three regions present in GM food products were targeted, namely, the 35S promoter gene from cauliflower mosaic virus and figwort mosaic virus, with the nopaline synthase terminator from *Agrobacterium tumefaciens*. Eleven out of the 15 samples showed positive amplification for at least one regulatory sequence signature unique to GMOs, out of which only two were appropriately labeled as required by regulation. While the safety of GM products is a prerequisite for commercialization, labelling is required to protect consumer preference. The roles of relevant government agencies in developing appropriate labeling guidelines and enforcing the same to protect consumers' choices are discussed.

1. Introduction

Genetic modification is the alteration of the genetic makeup of living organisms, which includes the use of recombinant DNA technology to confer new beneficial characteristics or traits.[1] Living organisms can be modified to possess useful traits such as tolerance to biotic stresses (pests and pathogens), abiotic stresses (extreme temperatures, salinities), herbicides, and improved nutritional profiles.[1] With the world's population increasing continually at an accelerated rate, ensuring global food security is becoming increasingly difficult. To address this challenge, approaches such as modern biotechnologies have been adopted alongside conventional agricultural methods. However, there are safety concerns regarding the impact of these technologies and their products on the health of humans, animals, plants, and the environment. For example, in the European Union (EU), concerns have been raised about food safety and nutritional issues associated with genetically modified (GM) products.[2] At the international level, governing structures such as the Codex Alimentarius Commission and the Cartagena Protocol on Biosafety (CPB) have been at the forefront of efforts to establish harmonized guidelines for the safety assessment of GM products, considering consumer choices.[3]

Globally, the acceptability of GM food remains a sensitive issue,[4–6] including in Nigeria,[7] where public concerns exist regarding the presence and consumption of GM products.[8,9] These include concerns

* Corresponding author at: Pan African University Life and Earth Sciences Institute, Ibadan, Nigeria.
** Corresponding authors.
E-mail addresses: adedapo.adediji@gmail.com (A. Adediji), lukman.aroworamimo@inqababiotec.africa (L. Aroworamimo), aeasagbra@gmail.com (A. Asagbra).

https://doi.org/10.1016/j.jgeb.2025.100481
Received 26 September 2024; Received in revised form 18 February 2025; Accepted 14 March 2025

regarding health,[10] economic[11] and environmental[12] risks associated with the different GM products that are available in markets, mainly from legume and cereal sources. The debate surrounding the safety of GM food in Nigeria is complex and multifaceted, requiring the examination of scientific proof, regulatory frameworks, and societal concerns.[13] While there are potential benefits such as increased crop yields and enhanced nutritional value,[14–16] concerns regarding GM foods and their potential health and environmental risks in Nigeria are rife and are mostly perceived.[7] Generally, scientific evidence and investigations by regulatory bodies have shown that genetic modifications in crops pose no harm to the health of humans or animals or to biodiversity.[17–20] However, issues about their long-term effects persist worldwide.[21–23]

The public perception of GM foods in Nigeria varies widely.[24] While some Nigerians are open to GM foods, particularly if they offer nutritional and food security benefits,[25] others express scepticism and concerns.[26] This hinges mainly on a perceived lack of need for GM foods given the country's abundance of arable land for cultivation,[27] concerns about potential health risks,[22] and a preference for the taste of natural foods.[28] Additionally, the level of scientific understanding of biotechnology influences public opinion, with insufficient public knowledge and awareness which sometimes lead to misinformed sentiments.[28] Studies have shown that factors such as education level[29] and the credibility of information sources[30] can influence awareness and acceptance of GM crops. For example, while trust in research institutes and government bodies can increase acceptance, scepticism may arise when these organizations are absent.[30] This highlights the need for clear and transparent regulatory frameworks to ensure consumer safety and address public concerns.

To manage and address matters related to the use of biotechnology within necessary regulations, the National Biosafety Management Agency (NBMA) was established as the national regulator of all biosafety issues in Nigeria.[31] The NBMA is charged with providing a regulatory framework, including institutional and administrative mechanisms for safety measures in the application of modern biotechnology in Nigeria to prevent any adverse effects on human health, biodiversity, or the environment. The act was later amended in 2019 to cover the regulation of emerging biotechnologies, including gene editing, gene drives, and synthetic biology, and to put in place measures to ensure biosecurity. Nigeria, through the NBMA Act 2015 as amended, regulates several activities related to genetically modified organisms (GMOs), including contained use; confined or multi-locational field trial commercialization; import, export, and transit for food, feed, and processing purposes. Socioeconomic and ethical issues including labelling are also duly considered.[31]

The lack of a clear global consensus on labelling regulations for GM foods remains a significant challenge.[32] Countries with national authorities on biosafety have adopted various labeling approaches, ranging from mandatory to voluntary. In the EU, the USA, Australia, New Zealand, Japan, Korea, Brazil and China, labelling of GM foods is mandatory[33–36] whereas countries such as Canada, Argentina and the Philippines[37–39] currently do not universally mandate consumer rights to information regarding GMOs. Nigeria has established clear regulations for the packaging and labeling of GM products, allowing consumers to make informed choices about the foods they consume. Nigeria is a signatory to the Convention on Biological Diversity and the CPB, ratified in 1994 and 2003, respectively.[40,41] These agreements provided a foundation for the development of a functional national regulatory framework to address the potential adverse impacts of the transboundary movement, handling, use, and release of GMOs on human health, biodiversity, and the environment.

Despite the scientific consensus that GM foods are safe, labeling is crucial[42] for guiding public concerns and perceptions, especially in Africa.[43] Food buyers often desire clear information on whatever they consume[44] and public trust is broken when GM foods are not clearly labelled, thus increasing negative perceptions.[43] Despite attempts to improve the perception of GM foods,[14,45,46] these concerns remain valid[10,47] and without proper labelling, consumers may be unable to make informed choices, leading to further mistrust and opposition to the technology. Consumer choice is key to discussions about food labelling, particularly in regard to GM foods. Labelling empowers consumers to make informed decisions about the food they purchase and consume, aligning their choices with their values, dietary needs, and preferences. Therefore, it is important that GMO labelling is strengthened to provide consumers with this choice, regardless of the scientific consensus on its safety. Clear and accessible labelling allows individuals to select or avoid GM foods on the basis of their personal beliefs and understanding of the technology.

However, owing to Nigeria's developing regulatory frameworks and the varied public perceptions of GM foods, the government is obliged to provide consumers with adequate information about GMO foods to allay perceived risks, as consumers still retain the right to make informed choices. While some consumers may prioritize the potential benefits of GM crops, others may have concerns about potential risks and thus, prefer traditionally grown foods. Effective labelling enables both groups to exercise their right to choose. The implementation of clear labelling regulations is crucial for building public trust and addressing concerns about GMOs in Nigeria.

In Nigeria, food labelling is not universal,[48,49] especially for those that may have been genetically modified. There are concerns that GM food products may be prevalent but unidentified due to poor labelling information.[43,50] Part IX of Nigeria's National Biosafety Regulation stipulates procedures for handling, packaging, transporting and labelling GMOs. The provisions state that "a GMO or derived product shall be identified and labelled by the Labelling guidelines prescribed by the Agency". The Regulations set a 4 % GM threshold for labelling. However, the compliance levels for labelling regulations set by the NBMA and the National Agency for Food and Drug Administration and Control (NAFDAC) are currently unknown. Thus, this study focused on food products randomly sampled from markets and retail stores in Abuja, Nigeria, to identify the presence of genetic sequences associated with GM foods to monitor the degree of compliance with labelling regulations. This research did not investigate the safety of these food products.

2. Methods

2.1. Sample collection

Fifteen products of plant origin were collected from markets and retail stores in the Federal Capital Territory, Abuja, Nigeria. These include grains and processed food products made from maize, soy and wheat ingredients (Table 1). The choice of samples was based on the most modified crops.[51] Other considerations were the country of import (to identify the origins of GM products, as a hint to product information that may help in the regulation of imports) and the possible uniformity of product distribution across metropolitan cities in Nigeria. The shops selected for sampling were national retail chains with a large customer base that cater to the average Nigerian. The samples were analyzed at the GMO Detection and Analysis Laboratory, Abuja, Nigeria, and the results were validated by Inqaba Biotec West Africa, Ibadan, Nigeria in duplicate experiments via similar protocols.

2.2. DNA extraction

The modified cetyl trimethyl ammonium bromide (CTAB) protocol[52] and the Zymo Research (ZR) Quick-DNA Plant/Seed Miniprep Kit (Lot No 223949) were used for the extraction of DNA from food samples. While the ZR combines ease of use and time saving, the CTAB protocol is most suited for overly processed samples.[53] The concentration of gDNA was measured by UV absorption at 260 nm via a NanoDrop One spectrophotometer (Thermo Scientific, Wilmington, DE, USA), and the purity was evaluated based on the UV absorption ratio at 260/280 nm. The DNA extracts were stored at −20 °C until further use.

Table 1
Food products obtained from markets and retail stores in FCT, Abuja, Nigeria. Products were identified with codes that considered manufacturers and specific products produced by them.

SN	Manufacturer code	Product code	Product type	Plant Origin	Origin of Manufacturer
1.	Manufacturer 1	Product 1 Product 2	Infant cereal Infant cereal	Maize Wheat	Netherlands
2.	Manufacturer 2	Product 1 Product 2 Product 3 Product 4	Infant cereal Infant cereal Infant cereal Family cereal	Maize Wheat Wheat Maize, Soy	Switzerland
3.	Manufacturer 3	Product 1	Family cereal	Maize	USA
4.	Manufacturer 4	Product 1	Soymilk drink	Soy	Thailand
5.	Manufacturer 5	Product 1	Children snack	Maize, Soy	Nigeria
6.	Manufacturer 6	Product 1	Biscuit	Wheat	India
7.	Manufacturer 7	Product 1	Cake mix	Maize, Wheat	United Kingdom
8.	Manufacturer 8	Product 1	Grains	Maize	Lebanon
9.	Manufacturer 9	Product 1	Pasta	Wheat	Germany
10.	Manufacturer 10	Product 1	Oats	Wheat, Barley	Britain
11.	Manufacturer 11	Product 1	Family cereal	Maize	Nigeria

2.3. Pre-screening and genetic modification (GM) detection using qPCR

Quantitative real-time polymerase chain reaction (qPCR) was used to detect GM-specific sequences in the extracted gDNA from the samples. First, the Bosphore Plant Detection Kit v3 which targets regions within the plant actin gene (Anatolia Geneworks, Istanbul, Türkiye), was used to screen the gDNA to confirm their plant origin. Samples with amplification for the plant DNA screening assay were subjected to the GMO screening test using the Bosphore GMO Screening Kit S35-TNOS-FMV-BAR Kit v1 (Anatolia Geneworks, Istanbul, Türkiye) in the second phase of amplification. The GMO screening kit detects the 35S promoter gene from cauliflower mosaic virus (P35S), the 35S promoter gene from figwort mosaic virus (FMV), the NOS terminator gene from *Agrobacterium tumefaciens* (tNOS), the phosphinothricin N-acetyltransferase gene from the bacterium *Streptomyces hygroscopicus* (BAR) and an exogenous internal control to check for PCR inhibition. These regions were targeted because they are commonly used regulatory sequences associated with the development of GM crops.[54,55]

2.4. PCR conditions

For all samples and controls, each reaction tube contained 15 µl of PCR master mix (Anatolia Geneworks, Istanbul, Türkiye) and 10 µl of DNA (200 ng) in a final reaction volume of 25 µl. Positive, negative and no-template controls were used during the PCRs for each set of target regions. All the qPCR assays were performed using a CFX96Dx real-time PCR machine (Bio-Rad, Hercules, USA). The qPCR conditions comprised an initial denaturation at 95 °C for 14 min 30 s, denaturation at 95 °C for 35 s, annealing and synthesis at 52 °C for 1 min 30 s and final hold at 32 °C for 2 min for a total of 45 cycles.

3. Results

3.1. Genomic DNA yield and purity

The concentration and purity of the DNA evaluated via a NanoDrop One spectrophotometer (Thermo Scientific, Wilmington, DE, USA) are shown in Table 2. The purity of the extracted DNA was assessed by measuring the $A_{260/280}$ ratio against the optimal ratio of 1.8–2.0.[56,57] The purity of the DNA extracted from the samples ranged from 1.48 to 2.1 A260/A280 ratios. All gDNA obtained from food products had sufficient yields above the threshold of 20 µg/ml.[58]

3.2. QPCR analysis

Eleven of the 15 samples analyzed contained at least one regulatory sequence unique to GMOs. Among these samples were maize, wheat and soy-based samples, two of which were produced in Nigeria (M5P1, M11P1). Amplifications for P35S, NOST and FMV were not detected in the gDNA of samples M1P2, M2P2, M2P4 and M10P1. These samples were maize and wheat-based, with only one sample (M2P4) produced in Nigeria.

3.3. Compliance with Nigerian labelling regulations and guidelines

The compliance levels of the food products evaluated in this study with existing labelling guidelines are presented in Table 3. This is stipulated in Regulation 13 of the National Guidelines for labelling prepackaged foods, and Part IX of the 2017 National Biosafety Regulations for the packaging and labelling of GMOs and their products in Nigeria. Nine of the 15 food products evaluated in this study had NAFDAC registration numbers as required by the NAFDAC guidelines for labeling pre-packaged foods. Among these 11 food products, at least one regulatory GMO sequence was detected while only two were appropriately labelled as containing GM ingredients.

4. Discussion

Worldwide, all commercialized GM crops undergo rigorous food safety assessments[59,60] and there has been no documented breach of safety arising from the use of GM food products that have gone through these evaluations.[61] The safety of GM crops notwithstanding, perceived concerns arising from their use necessitate that regulations go beyond safety measures to cover socio-economic and ethical considerations, among which is the consumer's informed choice. In Nigeria, the application of modern biotechnology and the use of derived products are regulated by the NBMA of 2015, as amended. The NBMA Regulations 2017 (Part IX, 43) stipulate that those foods containing GM ingredients be duly labelled to provide consumers with the choice of making informed decisions. Furthermore, NAFDAC's labelling guidelines stipulate that all pre-packaged products must be duly identified with a unique registration number. Our results revealed that 11 (73 %) of the 15 food products tested contained GM ingredients on the basis of the

Table 2
Concentration (µg/ml) and purity of gDNA extracted from food products.

S/N	Product	Yield (µg/ml)	Purity (260/280)
1.	M1P1	114.5	1.48
2.	M1P2	25.8	1.84
3.	M2P1	162.4	1.85
4.	M2P2	148.8	1.80
5	M2P3	92.1	2.10
6.	M2P4	213.5	1.94
7.	M3P1	91.22	1.80
8.	M4P1	186.9	1.65
9.	M5P1	32.01	1.98
10.	M6P1	218.4	1.88
11.	M7P1	150.1	1.59
12.	M8P1	149.3	1.97
13.	M9P1	144.6	1.89
14.	M10P1	375	1.92
15.	M11P1	98.1	1.90

Table 3
Degree of Compliance of Food Products to Labelling Guidelines of the National Agency for Food and Drug Administration and Control and the National Biosafety Management Agency. Cycle threshold (CT) values indicate real-time qPCR amplification of the target regulatory sequences S35, tNOS and FMV.

Manufacturer/ Product	Regulatory elements and status outcome						Compliance with NAFDAC labelling guidelines	Compliance with NBMA labelling regulations
	P35S	**CT**	**tNOS**	**CT**	**FMV**	**CT**		
M1/P1	+	29.45	+	31.6	+	29.37	Yes	Yes
M1/P2	ND	–	ND	–	ND	–	Yes	N/A
M2/P1	ND	–	+	38.71	ND	–	Yes	No
M2/P2	ND	–	ND	–	ND	–	Yes	N/A
M2/P3	+	37.57	+	36.91	ND	–	No	No
M2/P4	ND	–	ND	–	ND	–	Yes	N/A
M3/P1	+	36.28	+	36.64	ND	–	Yes	Yes
M4/P1	ND	–	+	37.12	ND	–	Yes	No
M5/P1	ND	–	+	37.77	ND	–	Yes	N/A
M6/P1	+	36.55	ND	–	ND	–	No	No
M7/P1	ND	–	+	38.85	ND	–	No	No
M8/P1	+	37.71	+	38.31	ND	–	No	No
M9/P1	+	34.93	+	36.16	+	36.0	No	No
M10/P1	ND	–	ND	–	ND	–	No	N/A
M11/P1	+	36.59	ND	–	ND	–	Yes	No
	7		9		2 (13 %)		9	2
	47 %		60 %				60 %	20 %

+ indicates amplification of the target sequences, ND indicates that amplification was not detected, and N/A indicates that amplification was not applicable.

amplification of at least one regulatory element commonly used in the development of GMOs. Five of these were maize-based products, three were soy-based products, and three were wheat-based products. This suggests that more GM maize may be present in the Nigerian food value chain than agricultural products such as wheat and soy. A possible reason is the number of approvals issued by the NBMA for the import of GM maize events for food and feed, both for processing and commercialization purposes.[62] Permit holders with such approvals often prefer to import maize products because they are significantly cheaper than locally produced maize.[62]

Furthermore, food and feed manufacturers often rely on imported maize to compensate for local production deficits. For example, local maize production between 2022 and 2023 experienced a deficit of 14.6 %, which necessitated increased imports to meet demand in Nigeria.[63] Given that countries with the largest cultivation of GM maize globally, including Argentina, the USA and Brazil, are also the largest exporters of maize to Nigeria,[51,64] it is reasonable to infer that imports are currently the major routes for the presence of GM maize in Nigeria. While the NBMA has issued permits for the import of GM soy and wheat for use as food, feed and industrial processing, no approval has been issued thus far for their cultivation in Nigeria. Soybean production in Nigeria reached 1.25 million tons from 2021 to 2022, almost enough to meet Nigeria's consumption estimates of 1.275 million tonnes.[65] Thus, while global production of GM soybean continues to increase,[51] it will most likely experience delayed entry into the Nigerian food chain because of sufficient local production compared with that of GM maize. However, it is uncertain how long this trend will hold, given Nigeria's increasing demand for soybean. The consumption of wheat in Nigeria is primarily from imports from Russia and other Black Sea regions.[66] Nigeria also imports wheat from Argentina, which commercialized the cultivation of GM wheat in 2023.[67] Therefore, the entry of GM wheat into Nigeria could be linked to imports from countries where it is commercially cultivated.

Part IX (43) of the 2017 National Biosafety Management Regulations stipulated that products, food or feed, derived from or with genetically modified crops, ingredients or materials with a threshold of greater than four percent (>4%) should be labelled. Therefore, producers, manufacturers, and retailers are expected to comply with the regulations through labelling, as this will aid in conveying information about the content of a product, in this case, GM information, to consumers. Nonetheless, the findings from this study suggest that 80 % of the products that tested positive for the presence of genetic modification did not have the required GM labels (Table 3). This is a clear indication of non-compliance by manufacturers regarding existing GMO labelling regulations, attributable to ignorance of GMO labelling guidelines, lack of sensitization activities to manufacturers, and the ability of vendors to repack these products within and outside Nigeria or even distributors and retailers. In addition, weak enforcement activities to ensure compliance with labelling regulations may also be an important contributory factor.

On the other hand, six out of the 15 samples (40 %) were non-compliant with the NAFDAC labelling guidelines. While non-compliance with the NAFDAC labelling guidelines could be attributed to illegal or undocumented importation of food products, weak enforcement could play an important role in compliance issues, leading to negative impacts along the food chain, namely the manufacturers, retailers and consumers. For GMO labelling, consumers are thus deprived of the right information to make informed choices about consuming products with or without GM ingredients.[20,35,41] Consequently, this can lead to compromised trust and a loss of confidence from consumers toward regulatory agencies, including increased risk of negative perceptions of the selected food products.[40]

Generally, food product labels should include information regarding nutritional content, allergic potential and putative genetic origin. A transparent and consistent way of presenting such information ensures clarity and avoids the possibility of any misleading conclusions. Labelling enhances consumers' trust in established regulatory processes, eliminating their perception of GMOs.[68] Therefore, labelling information on GM products should be available to food consumers in Nigeria to aid their purchase decision, even if it may cause avoidance, as reported in the USA[69] where some consumers had negative associations with GM products and were more likely to purchase unlabeled GM products. The presence of GM labeling has been associated with increased avoidance[69] and thus may sometimes lead to negative changes in consumers' attitudes towards these products.[70,71] Nevertheless, adequate labelling regulations should be enforced according to Nigeria's laws while providing more informed choices on GMO products to consumers. This will increase consumer confidence and scientific integrity in the overall GM food discourse.

5. Conclusion and Recommendations

This study successfully utilized qPCR-based methods, which is an incredibly sensitive and well-accepted method for GMO screening, to ascertain the prevalence of genetically modified products sold in local stores in Abuja, Nigeria. The findings revealed traces of genetic

modification in most of the samples analyzed. Some samples were properly labeled, whereas others were not. To ensure that consumer rights are protected, relevant information for informed decision-making must be provided. As such, labelling guidelines for GM-containing products must be strictly adhered to by manufacturers. The NBMA should conduct more widespread surveillance of GM foods in Nigeria using standardized protocols[72–74] and must also create room for dialogue with manufacturers to improve compliance with guidelines for GMO content and labelling. The sensitization of manufacturers, especially in the context of the repackaging of products, is necessary to provide consumers with information on their food choices. Finally, there must be strengthened collaboration among regulatory authorities and border agencies to curb the illegal import of unauthorized GM foods.

CRediT authorship contribution statement

Josephine Amedu: Writing – original draft, Methodology, Investigation, Conceptualization. **Adedapo Adediji:** Writing – review & editing, Writing – original draft, Supervision, Data curation. **Ngozi Miracle:** Writing – review & editing, Project administration, Methodology, Investigation, Data curation. **Albert Anthony:** Validation, Methodology, Investigation, Data curation. **Precious Adeyemi:** Validation, Project administration, Conceptualization. **Rabi Ahmed:** Writing – review & editing, Methodology, Investigation, Data curation. **Stephen Atsumbe:** Supervision, Data curation. **Mike Costly:** Visualization, Data curation. **Ayodele Majekodunmi:** Writing – review & editing, Writing – original draft, Validation, Supervision. **Odunayo Balogun:** Methodology, Formal analysis. **Oyewumi Akinpelu:** Validation, Methodology, Investigation. **Kilsi Borgbara:** Validation, Software, Methodology, Investigation, Formal analysis. **Olanrewaju Olufowobi:** Writing – review & editing, Validation, Supervision, Data curation. **Hauwa Jibo Tahir:** Supervision, Data curation. **Lukman Aroworamimo:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Agnes Asagbra:** Supervision, Resources, Funding acquisition, Conceptualization.

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.

Acknowledgements

The authors appreciate the support provided by Inqaba Biotec, Ibadan, Nigeria, the National Biosafety Management Agency, Abuja, Nigeria and the Malimbe Foundation. The Anatolia Geneworks provided some free kits for sample analyses.

References

1. Kumar K, Gambhir G, Dass A, et al. Genetically modified crops: current status and future prospects. *Planta.* 2020;251(4):91. https://doi.org/10.1007/s00425-020-03372-8.
2. Vlontzos G, Duquenne MN. To eat or not to eat? The case of genetically modified (GM) food. *Nutri Food Sci.* 2016;46(5):647–658. https://doi.org/10.1108/NFS-12-2015-0153.
3. Aarti G. Governing trade in genetically modified organ-isms: the Cartagena protocol on biosafety. *Environ Sci Policy Sustain Devel.* 2000;42(4):22–33. https://doi.org/10.1080/00139150009604881.
4. Boccia F, Covino D, Sarnacchiaro P. Genetically modified food versus knowledge and fear: A Noumenic approach for consumer behaviour. *Food Res Int.* 2018;111:682–688. https://doi.org/10.1016/j.foodres.2018.06.013.
5. Boccia F, Punzo G. A choice experiment on consumer perceptions of three generations of genetically modified foods. *Appetite.* 2021;161, 105158. https://doi.org/10.1016/j.appet.2021.105158.
6. Waterfield G, Kaplan S, Zilberman D. Willingness to pay versus willingness to vote: Consumer and voter avoidance of genetically modified foods. *Ame J Agric Econ.* 2020;102(2):505–524. https://doi.org/10.1002/ajae.12001.
7. Jibril H, Dandago MA, Abubakar SA, Iliyasu R. A Review on Perception of Genetically Modified Foods in Nigeria. *Dutse J Pure Appl Sci.* 2022;8(1a):70–77. https://doi.org/10.4314/dujopas.v8i1a.7.
8. Olaniyan SA, Bakare AA, Morenikeji OA. Genetically Modified Foods in Nigeria: A Long-Lasting Solution to Hunger? *Estu Biol.* 2007;29(67):191–202. https://doi.org/10.7213/reb.v29i67.22768.
9. Daboer J, Bulus N, Ayiga E, Yako J, Zoakah A. Knowledge and Perception of Genetically Modified Foods among Agricultural workers in Jos Metropolis. *Plateau State. J Epidem Soc Nig.* 2020;3(1):31–38. https://doi.org/10.46912/jeson.33.
10. Miko AS, Muhd AA, Umar SS. Effects of Genetically Modified Agricultural product on the Health of Consumers in Nigeria. *Intl J Adv Acad Res.* 2018;4(6):46–55.
11. Ajayi A. Controversies and political economy of genetically modified foods in Nigeria. *Intl J OHIS.* 2017;7(2):191–199.
12. Olugbenga G. Genetically Modified Foods (GMOs) and Its Environmental Conflict Situation in Nigeria. *Ame J Envir Policy Mgt.* 2017;3(5):31–38.
13. Ezeamalu B. Nigeria: Genetically modified maize launched amidst food crisis, but safety concerns remain. Accessed 06 December. https://www.theafricareport.com/352534/nigeria-genetically-modified-maize-launched-amidst-food-crisis-but-safety-concerns-remain/; 2024.
14. Nigerian Academy of Science. Genetically modified organisms in Nigeria: facts and fiction. Published by the Nigerian Academy of Science. Accessed 15 May 2024. https://nas.org.ng/wp-content/uploads/2019/05/Genetically-Modified-Organism-...pdf; 2016.
15. Alarima CI. Knowledge and Perception of Genetically Modified Foods Among Agricultural Scientists in South-West Nigeria. *OIDA Intl J Sustain Dev.* 2021;02(06):77–88.
16. Olabinjo OO, Okunola AA, Olumurewa JAV. Genetically modified foods: pathway to food security. *IOP Conf Ser Earth Environ Sci.* 2020;445(1):12041. https://doi.org/10.1088/1755-1315/445/1/012041.
17. Biotechnology KT. Regulatory Issues. In: Van Alfen NK, ed. *Encyclopaedia of Agriculture and Food Systems*. Amsterdam, ND: Academic Press; 2014. https://doi.org/10.1016/b978-0-444-52512-3.00229-1.
18. Erkan ARI, Yilmaz V, Olgun M. The effect of trust benefit and risk perception of GM foods on behavior intention: A study on university students. *J Eco Culture Soc.* 2021;64:1–16.
19. Delaney B, Goodman RE, Ladics GS. Food and Feed Safety of Genetically Engineered Food Crops. *Toxicol Sci.* 2018;162(2):361–371. https://doi.org/10.1093/toxsci/kfx249.
20. Chen X, Chen J. Trust, risk perception and public acceptance of science and technology: the discussion about GM rice in China. *Sci Soc.* 2016;6:93–109. https://doi.org/10.19524/j.cnki.10-1009/g3.2016.01.0085456.
21. Bawa AS, Anilakumar KR. Genetically modified foods: safety, risks and public concerns—a review. *J Food Sci Technol.* 2012;50(6):1035–1046. https://doi.org/10.1007/s13197-012-0899-1.
22. Rose KM, Brossard D, Scheufele DA. Of Society, Nature, and Health: How Perceptions of Specific Risks and Benefits of Genetically Engineered Foods Shape Public Rejection. *Environ Comm.* 2020;14:1017–1031. https://doi.org/10.1080/17524032.2019.1710227.
23. McFadden BR, Rumble JN, Stofer KA, Folta KMUS. public opinion about the safety of gene editing in the agriculture and medical fields and the amount of evidence needed to improve opinions. *Front Bioeng. Biotechnol.* 2024;12, 1340398. https://doi.org/10.3389/fbioe.2024.1340398.
24. Oluwakemi HO, Rauf RI, Seyi EA, Harry K. Readiness of the Nigerian public for the introduction of genetically modified crops into the food market. *Afri J Biotech.* 2020;19(7):426–438. https://doi.org/10.5897/ajb2020.17136.
25. Adeoti JO, Adekunle AA. Awareness of and attitudes towards biotechnology and GMOs in Southwest Nigeria: A survey of people with access to information. *Int J Biotech.* 2007;9(2):209–230. https://doi.org/10.1504/ijbt.2007.013052.
26. Health of Mother Earth Foundation. Nigerians Firmly Reject Genetically Modified Potatoes and Other GM Crops. Assessed 06 December 2024. https://homef.org/2024/09/30/nigerians-firmly-reject-genetically-modified-potatoes-and-other-gm-crops/; 2024.
27. Agaviezor BO. Awareness and Utilization of Genetically Modified Foods in Nigeria. In: Holban AM, Grumezescu AM, eds. *Handbook of Food*. Amsterdam, ND: Academic Press; 2018. https://doi.org/10.1016/b978-0-12-811519-0.00008-x.
28. Tsanni A. GMO debate affects public sentiment in Nigeria. Assessed 04 January 2025. https://allianceforscience.org/blog/2019/04/gmo-debate-affects-public-sentiment-nigeria; 2020.
29. Obi-Egbedi O, Ogungbite O, Oluwatayo IB. Genetically Modified Crops' Technology and its Awareness among Smallholder Farmers in Nigeria. *Zeszyty Naukowe SGGW w Warszawie - Problemy Rolnictwa Światowego.* 2020;20(4):58–67. https://doi.org/10.22630/prs.2020.20.4.22.
30. Zhang M, Chen C, Hu W, Chen L, Zhan J. Influence of Source Credibility on Consumer Acceptance of Genetically Modified Foods in China. *Sustainability.* 2016;8(9):899. https://doi.org/10.3390/su8090899.
31. Nwosu OK, Bello S. Overview of the biosafety system in Nigeria. *IOBC-WPRS Bulletin.* 2023;163:79–84.
32. Desquilbet M, Poret S. Labelling and co-existence regulation of GMOs and non-GMOs: an economic perspective. In: Bertheau Y, ed. *Genetically Modified and Non-Genetically Modified Food Supply Chains: Co-Existence and Traceability*. Oxford, UK: Wiley/Blackwell; 2013.
33. Hakim MP, Zanetta LD, de Oliveira JM, da Cunha DT. The mandatory labeling of genetically modified foods in Brazil: Consumer's knowledge, trust, and risk perception. *Food Res Intl.* 2020;132, 109053. https://doi.org/10.1016/j.foodres.2020.109053.

34. Zhan J, Ma Y, Deng P, Li Y, Xu M, Xiong H. Designing enhanced labeling information to increase consumer willingness to pay for genetically modified foods. *British Food J.* 2021;123(1):405–418. https://doi.org/10.1108/BFJ-08-2019-0637.
35. Delgado-Zegarra J, Alvarez-Risco A, Cárdenas C, et al. Labeling of Genetically Modified (GM) Foods in Peru: Current Dogma and Insights of the Regulatory and Legal Statutes. *Intl J Food Sci.* 2022;12, 3489785. https://doi.org/10.1155/2022/3489785.
36. Ryan CD, Henggeler E, Gilbert S, Schaul AJ, Swarthout JT. Exploring the GMO narrative through labeling: strategies, products, and politics. *GM Crops Food.* 2024;15(1):51–66. https://doi.org/10.1080/21645698.2024.2318027.
37. Du L. GMO labelling and the consumer's right to know: A comparative review of the legal bases for the consumer's right to genetically modified food labelling. *McGill J. Law Health.* 2014;8:1–42.
38. Orroño DI, Vesprini F. Directives and requirements for genetically modified (GM) crop regulation in Argentina. *Crop Breed. Appl. Biotec.* 2018;18:301–308. https://doi.org/10.1590/1984-70332018v18n3r44.
39. De Leon A, Manalo A, Guilatco FC, Gloriani-Barzaga N. The cost implications of GM food labelling in the Philippines. *Crop Biotech Brief.* 2004;4(2):1–4.
40. Bukola D, Agbu D, Okebukola E, Adedoyiin-Raji J. Modern Biotechnological Regulations as it Relates to Nigeria Economy-Literature Review. *J Comm Prop Law.* 2022;9(3):176–188.
41. Ebegba R, Bello S, Onwude J. Status of Nigeria's Biosafety Regulation. In: Uzochukwu S, Esiobu ND, Okoli AS, Nwoba EG, Christpeace EN, Adetunji CO, Ibrahim AB, Ubi BE, eds. *Biosafety and Bioethics in Biotechnology*. Boca Raton: FL. CRC Press; 2022:1–18.
42. Fagin D. Why we should accept GMO labels. Accessed 02 January 2025. https://nyuscholars.nyu.edu/en/publications/why-we-should-accept-gmo-labels; 2013.
43. Oh J, Ezezika OC. To label or not to label: balancing the risks, benefits and costs of mandatory labelling of GM food in Africa. *Agric Food Secur.* 2014;3(8). https://doi.org/10.1186/2048-7010-3-8.
44. Adesina E, Ajayi B, Amoo EO, et al. Consumers' Knowledge and Use of Nutritional Labelling Information in Lagos, Nigeria. *Sustainability.* 2022;14(1):578. https://doi.org/10.3390/su1401057.
45. Bode L, Vraga EK, Tully M. Correcting Misperceptions about Genetically Modified Food on Social Media: Examining the Impact of Experts, Social Media Heuristics, and the Gateway *Belief Model*. *Sci Comm.* 2021;43(2):225–251. https://doi.org/10.1177/1075547020981375.
46. Gbadegesin LA, Ayeni EA, Tettey CK, et al. GMOs in Africa: status, adoption and public acceptance. *Food Control.* 2022;141, 109193. https://doi.org/10.1016/j.foodcont.2022.109193.
47. Defez R. Deforming mirrors converting GMOs into smog. *Nutr Food Sci.* 2016;46(5):620–627. https://doi.org/10.1108/NFS-04-2016-0049.
48. Falola A. Towards Nutrition Security: Food Label Use Among Nigerians. *Intl J Food Agric Econ.* 2014;2(2):1–8. https://doi.org/10.22004/ag.econ.168586.
49. Ochulor CE, Njoagwuani EI OH, Mazi IM, Oladunjoye IO, Akegbe H, Omotosho AD, Odeyemi OA, Nwaiwu O, Tamasiga P. Improper food labeling and unverified food claims: Food safety implications. *Ame J Food Sci Nutr.* 2022;4:9–23. https://doi.org/10.47672/ajfsn.1225.
50. Oladipo OH, Ibrahim RR, Adeboye SE, Kuiper H. Readiness of the Nigerian public for the introduction of genetically modified crops into the food market. *Afri J Biotec.* 2020;19(7):426–438. https://doi.org/10.5897/AJB2020.17136.
51. ISAAA, 2024. Accessed 30 August 2024. https://www.isaaa.org/gmapprovaldatabase/cropslist/default.asp; 2024.
52. Aboul-Maaty NAF, Oraby HAS. Extraction of high-quality genomic DNA from different plant orders applying a modified CTAB-based method. *Bull Nat Res Centre.* 2019;43(1):1–10.
53. de Oliveira AC, Marien A, Hulin J, et al. Development of real-time PCR methods for cocoa authentication in processed cocoa-derived products. *Food Control.* 2022;131, 108414. https://doi.org/10.1016/j.foodcont.2021.108414.
54. Liu H, Wang J, Li P, et al. Rapid detection of P–35S and T-nos in genetically modified organisms by recombinase polymerase amplification combined with a lateral flow strip. *Food Control.* 2020;107, 106775. https://doi.org/10.1016/j.foodcont.2019.106775.
55. Verginelli D, Quarchioni C, Spinella K, et al. Comparative assessment of three commercial kits and in house optimized PCR assays for GMO screening in food and feed. *MethodsX.* 2024;13, 102878. https://doi.org/10.1016/j.mex.2024.102878.
56. Sambrook J, Russell DW. *Molecular cloning, a laboratory manual.* 3rd ed. New York, NY: Cold Spring Harbor Laboratory; 2001.
57. Xia Y, Chen F, Jiang L, Li S, Zhang J. Development of an efficient method to extract DNA from refined soybean oil. *Food Anal Methods.* 2021;14:196–207. https://doi.org/10.1007/s12161-020-01867-4.
58. Querci M, Van den Bulcke M, Žel J, Van den Eede G, Broll H. New approaches in GMO detection. *Anal Bioanal Chem.* 2010;396:1991–2002. https://doi.org/10.1007/s00216-009-3237-3.
59. Food and Agricultural Organization. Stock-taking report: food biotechnology communication materials in the world. Background paper for the 2020 technical consultation meetings on developing a communication toolkit about food biotechnologies. Rome, IT: FAO; 2020. Doi: 10.4060/cb1394en.
60. Food and Agricultural Organization. Developing a communication Toolkit on Food Biotechnologies: Proceedings of the Technical Consultation Meetings Rome, IT: FAO; 2020. Doi: 10.4060/cb2022en.
61. Bedair M, Glenn KC. Evaluation of the use of untargeted metabolomics in the safety assessment of genetically modified crops. *Metabolomics*. 2020;16:111. https://doi.org/10.1007/s11306-020-01733-8.
62. Adeosun KP, Ihemezie EJ, Ume CO, Egu LU. The nexus between maize importation, local production and local prices: Empirical analysis from Nigeria. *Alanya Akademik Bakış.* 2019;3(2):201–213. https://doi.org/10.29023/alanyaakademik.481553.
63. GIEWS-FAO. Global Information and Early Warning System. Accessed 30 August 2024. https://www.fao.org/giews/countrybrief/country.jsp?code=NGA; 2024.
64. Organization of Exporting Countries. Corn in Nigeria. Accessed 15 July 2024. https://oec.world/en/profile/bilateral-product/corn/reporter/nga; 2024.
65. World Grain. Nigerian soybean demand on the rise. Accessed 15 July 2024. https://www.world-grain.com/articles/15474-nigerian-soybean-output-demand-on-the-rise; 2024.
66. Anaele R, Clark EV. Russia-Ukraine War: Implication on Nigeria's Economy. *EBSU J Soc Sci Hum.* 2023;13(3):52–64.
67. Cheng X, Li H, Tang Q, Zhang H, Liu T. Wang T Trends in the global commercialization of genetically modified crops in 2023. *J Int Agric.* 2024;23(12):3943–3952. https://doi.org/10.1016/j.jia.2024.09.012.
68. Huo L, Liu Y. Genetically modified rice: do Chinese consumers support or go against it? Based on the perspectives of perceived risk and trust. *Front Psychol.* 2022;13, 813862. https://doi.org/10.3389/fpsyg.2022.813862.
69. Lefebvre S, Cook LA. Griffiths MA Consumer perceptions of genetically modified foods: a mixed-method approach. *J Cons Mar.* 2019;36(1):113–123. https://doi.org/10.1108/JCM-12-2016-2043.
70. Li R, Basu AK. Pricing Strategy for GM Food: Impact of Consumer Attitude Heterogeneity and GMO Food Labelling. *Ann Oper Res*. 2020;291(1):463–474. https://doi.org/10.1007/s10479-019-03154-w.
71. Zhang M, Fan Y, Chen C, Cao J, Pu H. Consumer perception, mandatory labeling, and traceability of GM soybean oil: evidence from Chinese urban consumers. *GM Crops Food.* 2020;12(1):36–46. https://doi.org/10.1080/21645698.2020.1807852.
72. Peng C, Wang Y, Chen X, et al. A localized CRISPR assay that detects short nucleic acid fragments in unamplified genetically modified samples. *ACS Sens.* 2023;8(3):1054–1063. https://doi.org/10.1021/acssensors.2c01955.
73. Ding L, Wang X, Chen X, et al. Development of a novel Cas13a/Cas12a-mediated 'one-pot' dual detection assay for genetically modified crops. *J Adv Res.*. 2024 https://doi.org/10.1016/j.jare.2024.07.027.
74. Fraiture MA, Herman P, Taverniers I, De Loose M, Deforce D, Roosens NH. Current and new approaches in GMO detection: challenges and solutions. Biomed Res Int. 2015:392872. Doi: 10.1155/2015/392872.