CLINICAL REPORT Guidance for the Clinician in Rendering Pediatric Care

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Use of Genetically Modified Organism (GMO)-Containing Food Products in Children

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Families increasingly raise questions about the use of genetically modified organism (GMO)-containing food products. These products are widely found in the US food supply but originate from a narrow list of crops. Although GMO technology could be used to increase the micronutrient content of foods, this does not occur in the United States; instead, GMO technology has been used to make crops resistant to chemical herbicides. As a result, herbicide use has increased exponentially. The World Health Organization's International Agency on Research for Cancer has determined that glyphosate, an herbicide widely used in producing GMO food crops, is a probable human carcinogen. Measurable quantities of glyphosate are detected in some GMO foods. Families who wish to minimize GMO food products can do so by focusing on a dietary pattern of primarily whole, plant-based foods while minimizing ultra-processed foods. Pediatricians play a vital role in their efforts to minimize fear-based messaging and support families through shared decision-making. Pediatrician awareness of GMO labeling can guide individualized conversations, particularly that non-GMO labeling does not indicate organic status and that increased cost of some non-GMO foods, especially if also organic, may limit this choice for many families.

abstract

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INTRODUCTION

Feeding a child has become increasingly complicated as parents navigate time and cost barriers, concerns about food allergy and sensitivity, questions about organic food and food sourcing, and the potential health effects of genetic modification of food. Labeling on packaged foods is especially complex and contains multiple mystifying terms and descriptors. Families looking to avoid allergens or to monitor for a particular nutrient or calorie source are familiar with the process of checking the label, but many aspects of food labeling reflect marketing rather than provision of health information.[1] As a result, families often struggle to select affordable, nutritious foods, identify relevant health information, and prepare practical meals.[2–7] Pediatricians have opportunities in this context to lead conversations with families about the health impact of certain foods, provide nutritional guidance, and help filter the overwhelming volume of information.

The use of genetically modified organisms (GMOs), also known as genetic engineering or bioengineering, in food has emerged as an area of concern and confusion for parents and families.[8–11] The term GMO refers to foods (or other products) designed through genetic engineering, a process that introduces a desired trait into the product by inserting novel DNA from a separate organism. Many foods are now labeled as "GMO," "non-GMO," or "GMO-free."

Globally, the techniques of biotechnology are widely used to enhance herbicide tolerance, promote higher crop yield, and extend shelf life. In some settings, they are also used to enhance the micronutrient content of crops. The guidance in this report is based on the use of GMOs in the United States. Determination of benefit in other countries needs to be considered within their context, but we currently have no evidence for a benefit to GMO usage internationally, with cost surfacing as a substantial deterrent. The potential health implications of genetic modification are an emerging science, and families need evidence-based guidance as well as transparency about what remains unknown to support decision-making about food choices.

Many families express concerns about the safety of GMO-containing foods, especially regarding the possible effects of the herbicides used in large quantities in their production.[7–9] Lingering concerns and new scientific findings may trigger questions to pediatricians—Is it safe to serve my children food containing GMO ingredients? What about genetically engineered salmon? In this report, key issues related to GMO-containing foods are reviewed and information about the health benefits and risks that may be associated with their use is provided. The report focuses on foods marketed in the United States but also includes some discussion of global issues. Current controversies regarding GMO labeling are discussed, and an overview of the risks associated with the use of herbicides to produce GMO corn, soy, alfalfa, and other crops is provided.

CHARACTERISTICS AND SCOPE OF GMO FOOD PRODUCTS

The use of genetic engineering to produce GMO food crops builds on the ancient agricultural practice of selective breeding. However, unlike selective breeding, genetic engineering vastly expands the range of genetic traits that can be moved into plants as well as the speed of their introduction. Depending on the traits selected, genetically engineered crops could be designed to increase crop yields, incorporate essential micronutrients, tolerate drought, thrive when irrigated with salt water, or produce fruits and vegetables resistant to mold and rot.[12] Foods containing GMOs or grown from genetically modified seeds have become widespread in the United States and throughout the world. Most of the soybean and corn crops grown today are genetically modified, and the majority of ultraprocessed foods sold in the United States contain GMO ingredients.[13]

Food crops with genetically engineered tolerance to herbicides were first introduced in the 1990s. In 1994, the first GMO produce item, a tomato, became available for sale.[14] GMO tomatoes were later removed from the market in 1997 and are no longer produced in the United States. However, additional GMO produce items followed throughout the 1990s and early 2000s, including the now ubiquitous GMO corn, soybeans, canola, and sugar beets.[15] In the United States, the most commonly grown GMO food crops are corn and soybeans resistant to the herbicide glyphosate (Roundup).[12] The introduction of genes that make crops resistant to insects has also become widespread, and plant geneticists have moved bacterial genes that synthesize *Bacillus thuringiensis* (Bt) toxins into corn and cotton to increase insect resistance. Bt toxins accumulate in GMO crops as well as in food grain and silage derived from these crops.

Until recently, the genetic traits that the seed biotechnology industries have chosen to introduce into food crops in the United States have been limited to herbicide resistance and insect resistance, and the National Academy of Sciences concludes that there are not adequate data to support increase in crop yields as a result of GMO agriculture.[16] This singular focus reflects the fact that the major producers of GMO seeds are multinational chemical corporations that also manufacture some of the world's most widely used herbicides and insecticides.[12,17] The US Department of Agriculture (USDA) provides an annual review of the use of bioengineered food products,[15] tracking their use since 1996. Currently, more than 90% of soybean and corn crops in the United States contain herbicide resistance and/or insect resistance genes, and these traits have also been genetically engineered in canola, alfalfa, cotton, and sugar beet crops. Although the agricultural industry is a large consumer of GMO products for animal feed, many GMO ingredients derived from corn and soybean grain are also found in processed food products, including those made with processed cornstarch, soybean-based oils, and high-fructose corn syrup. The US Food and Drug Administration (FDA) maintains a list with descriptions of the use of many of these products.[18] In 2016, genetic engineering of potatoes introduced genetic traits to reduce browning, and they similarly integrated nonbrowning genetic traits in apples in 2017.[19]

Given the ubiquitous application of GMO technology to corn and soybean crops that have many uses in food, agriculture (livestock and poultry feed), and industrial contexts (fuel ethanol, adhesives, building materials, printing ink, cosmetics, and others), consumers often misunderstand the use of bioengineering to be more widespread in food. Notably, there are currently only 10 permitted GMO food crop products in the United States (Table 1).[20]

Although some GMO crops may be grown outside the United States and imported, the United States is the largest producer of GMO crops, followed by Brazil.[21] The narrow focus of the crops grown with GMO technology is important to emphasize; consumers often experience confusion about foods that are not grown with genetic engineering in any context, such as tomatoes, wheat, and strawberries. Families also express uncertainty about the presence of GMO in foods that are ultra-processed or have multiple components, which increases the likelihood of GMO ingredients.[11,22]

In 2015, genetically engineered salmon (AquAdvantage) was marketed after review by the FDA.[14] This salmon was engineered to allow it to be bred throughout the year in fish farms, not just in the usual seasons of spring and summer. AquAdvantage salmon also grow more quickly than wild and traditionally farmed salmon, shortening their distance and time to market. The approval of this salmon was highly controversial, and The Institute for Fisheries Resources challenged the FDA's decision in a federal court in 2020, leading to a court order that disallowed use of the product until completion of further safety investigations.[23] The court order expressed particular concern about the escape of the genetically engineered salmon from the fish farms into the general salmon community, potentially harming the endangered wild salmon varieties. The company producing AquAdvantage salmon reassured consumers that their fish are all female, sterile, and raised entirely in land-based facilities with minimal escape risk, and the FDA has provided additional reassurance.[24] The genetically engineered fish entered the US market in May of 2021.[25]

NUTRITIONAL ASPECTS OF BIOENGINEERED FOODS

The use of GMO technology to enhance the nutritional value of specific crops has been a central aspect of GMO consideration.[16] The primary example of this is the product commonly called "golden rice." Developed by plant physiologists in Germany in the 1990s, this product uses genes from maize inserted into a rice product to create a strain of rice high in beta-carotene.[26] Researchers have documented its efficacy in providing vitamin A to humans, and there are similar findings for transgenic maize.[27] However, because of lower yields and deep-set cultural preferences, golden rice has not been widely grown, even in areas with substantial deficiency in vitamin A.[28] Potential use in Bangladesh, the Philippines, and other countries remains caught up in regulatory discussions. Although technically approved in the United States, golden rice is not currently part of the food system. Globally, the ethical challenges of the use of golden rice as a beta-carotene source in nutrition research has complicated implementation.[29]

TABLE 1 Potentially GMO-Containing Food Crops Permitted in the United States

Crops
• Alfalfa
• Apples
• Canola
• Corn
• Cottonseed
• Papaya
• Potatoes
• Soybeans
• Yellow squash and zucchini
• Sugar beets

Recently, other nutrients have also been considered for enhancement in crops using GMO techniques. Iron remains the most common nutrient deficiency globally, and GMO cassava has increased the amount of iron in this crop.[30] This technology may also enhance zinc bioavailability, an especially important nutrient in Africa, where cassava is a key component of the diet. Recent research has evaluated the role of wheat as a possible crop for increased iron and zinc using GMO techniques.[31] From a US perspective, iron and zinc remain important nutrients of concern for both children and adults. However, standard fortification techniques are widely used in US food products, and GMO techniques are not likely to become a substantial source for further increasing micronutrient intake.

Although nutritional modifications have garnered international attention, there is no evidence that genetic engineering impacts the taste, smell, or appearance of the products used as food in the United States. Consumers typically do not notice a difference between GMO and non-GMO foods.[11]

GMOS IN INFANT NUTRITION

There are no specific sources of GMO foods in infant feeding products. However, most infant formulas contain some amount of corn syrup, soy, or other products that may be made from GMO components. Other additives in infant formula, including docosahexaenoic acid[32] and prebiotics, are synthesized or made from sources including algae but are not considered GMO. Although some have challenged the non-GMO designation of some of the docosahexaenoic acid products, the US government has ruled that these additives are non-GMO, and they are allowed to be used in GMO-free and organic-labeled products.

PESTICIDE-RELATED ISSUES

Scope of Use of Glyphosate-Containing Compounds in GMO Foods

Since their introduction in the 1990s, the use of corn, soybeans, and other crops with genetically engineered tolerance to glyphosate ("Roundup-ready" crops) has expanded steeply, and glyphosate use has increased in parallel (Fig 1).[33] In the United States, glyphosate use has increased more than 250-fold—from 0.4 million kg in 1974 to 113 million kg in 2014. Global use has increased more than 10-fold and continues to rise.[12] Herbicide-tolerant GMO seeds and herbicides are typically sold in tandem.[12,17] Glyphosate is now the world's most widely used herbicide.

The advantage of herbicide-resistant GMO crops is that in the first years after their introduction, they substantially simplify weed management. Farmers are no longer required to do mechanical weeding and instead can spray herbicides before spring planting and again up to 3 times during the growing season, leaving their crops unharmed.[12]

An unfortunate consequence of the increasingly heavy use of herbicides late in the growing season on herbicide-tolerant corn and soybeans is that measurable quantities of glyphosate and other herbicides, termed "residues," remain present in GMO grains at harvest. As a result, glyphosate residues have been detected with increasing frequency in recent years in foods commonly consumed by children[34,35] as well as in drinking water.[36] The Canadian Food Inspection Agency recently found that 42.3% of 7955 food samples tested contained detectable levels of glyphosate; however, 99.4% of these samples met the current Canadian compliance rate.[37] Residues of glyphosate and other herbicides have also been detected in corn silage and animal feeds made from herbicide-tolerant crops, thus increasing risk of contamination of meat and dairy products.[38]

The presence of glyphosate and other chemical herbicides in food products derived from GMO crops increases risk of human exposure. A review of 19 studies on glyphosate exposure published since 2007 found glyphosate and its metabolites in urine samples obtained in the general population with levels ranging from 0.16 to 7.6 μg/L.[39] Two of these studies measured temporal trends in exposure, and both found increasing proportions of persons with detectable levels of glyphosate in urine in more recent years.[39] A recent pilot study from the Centers for Disease Control and Prevention showed that 80% of urine samples collected in the United States contained detectable levels of glyphosate. In this study, glyphosate levels were significantly higher among 40 individuals reporting pesticide exposure (0.63 μg/L) than among 50 persons consuming organic diets (0.42 μg/L).[40]

The presence of glyphosate and other toxic herbicides in food products is the main hazard to children's health associated with the consumption of GMO-based foods. The toxic and carcinogenic hazards of herbicide exposures are reviewed in the following section of this report. These toxic and carcinogenic risks substantially overshadow any theoretical risks to children's health that may be associated with the introduction of novel genes into corn, soybeans, and other food crops.

A second unfortunate consequence of the wide-scale and repeated use of glyphosate in the production of GMO crops has been the emergence of glyphosate-resistant weeds. More than 250 weed species in 70 countries are now known to be resistant to at least 1 herbicide, including at least 48 species resistant to glyphosate[41] (Fig 2). In the United States, glyphosate-resistant weeds are found today on over 200 million acres, and many fields harbor 2 or more resistant weeds. As more weeds survived heavier applications of glyphosate-based herbicides, farmers turned to treating crops with multiple other herbicides. Herbicides now widely used in addition to glyphosate include dicamba and 2,4-D.[17] These are older, more highly toxic chemicals; 2,4-D was a component of the Agent Orange defoliant used in the Vietnam War.

To combat rising herbicide resistance, the US Environmental Protection Agency (EPA) approved a new combination herbicide, Enlist Duo, in 2014. Enlist Duo is composed

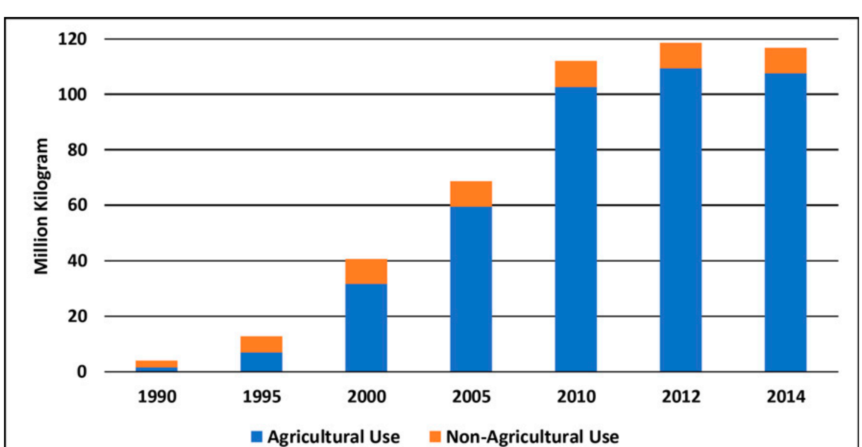

FIGURE 1
Global glyphosate use, 1990 to 2014. Source: based on data from Benbrook CM. Trends in glyphosate herbicide use in the United States and globally. *Environ Sci Eur*. 2016;28(1):3.

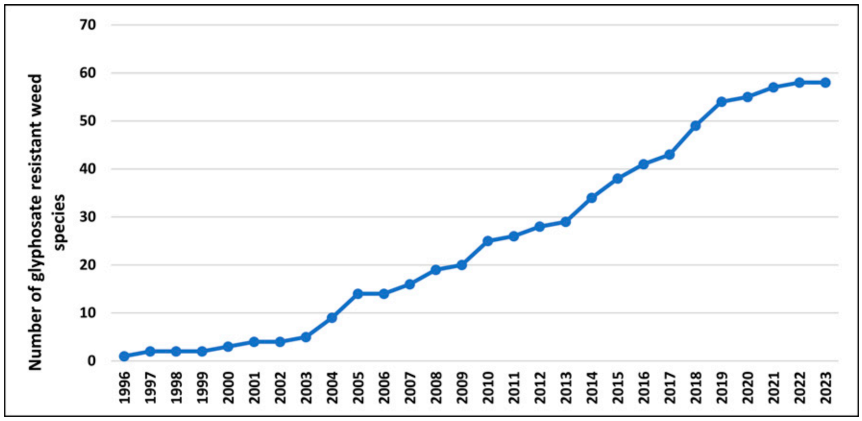

FIGURE 2
Increase in glyphosate-resistant weeds globally, 1996 to 2023. Source: based on data from Heap I. The International Herbicide-Resistant Weed Database. Available at: www.weedscience.org. Accessed May 10, 2022.

of glyphosate plus 2,4-D. It is marketed in tandem with newly approved seeds that are genetically engineered to resist glyphosate, 2,4-D, dicamba, and multiple other herbicides—referred to as "stacked" resistance.[12] A likely consequence of the use of multiple herbicides on GMO food crops is that residues of these multiple chemicals will be detected in crops at harvest and in food products made from these crops, thus further increasing cumulative risk of human exposure.

Risks Related to Use of Glyphosate-Containing Compounds in GMO Foods

The National Academy of Sciences reviewed the safety of GMO food crops in the early 2000s.[42,43] Those early reviews focused almost entirely on the genetic aspects of biotechnology. They concluded that the novel genes introduced into GMO crops pose no unique hazards to human health. However, neither evaluation examined the potential health hazards of the herbicides used in production of GMO foods, nor did they examine the hazards potentially arising from the use of Bt endotoxins in GMO corn.

In 2015, the International Agency for Research on Cancer (IARC), the cancer agency of the World Health Organization, undertook a major review of the carcinogenicity of glyphosate and other herbicides used in production of GMO foods. This review was catalyzed by case reports and case-control studies suggesting an increased risk of hematolymphopoietic cancers in farmers occupationally exposed to glyphosate-based herbicides and by the fact that glyphosate had become the world's most widely used herbicide. Through a highly structured review process based on comprehensive assessments of the published toxicologic and epidemiologic literature, IARC determined that glyphosate is "probably carcinogenic to humans."[44,45] IARC also determined that 2,4-D and dicamba are "possibly carcinogenic to humans."[44,46] IARC reported that these herbicides cause dose-related increases in cancers in experimentally exposed animals. IARC found strong evidence that glyphosate is genotoxic, that it causes oxidative stress, and that these effects can occur in humans. In humans, IARC established a link between glyphosate and an increased incidence of non-Hodgkin lymphoma.

Two meta-analyses of the association between glyphosate and cancer published after the IARC review have examined more recently published epidemiologic data. Both studies confirm the association between glyphosate and non-Hodgkin lymphoma. Researchers specifically found a statistically significant, 40% to 41% increase in incidence of non-Hodgkin lymphoma in persons exposed to glyphosate-based herbicides.[47,48] Similarly, a recently published pooled analysis of cohort studies of farmers exposed to glyphosate-based herbicides reported a statistically significant, 36% increase in incidence (95% confidence interval [CI], 1.00–1.85) of diffuse large B-cell lymphoma.[49]

In 2016, the National Academy of Sciences again reviewed the human safety data related to genetically engineered crops, restating their conclusions about a lack of substantiated evidence of a difference in risk to human health between conventional and genetically engineered crops.[16] The report acknowledged the challenges of identifying subtle and long-term health effects and similarly applies this concept to difficulty assessing long-term environmental impact. Notably, the report emphasized that there were no long-term, published epidemiologic studies directly assessing the potential health impact of genetically engineered food and associated herbicide exposure, so conclusions about health were largely made in the absence of available data.

Similarly, few studies have examined the effects of glyphosate on the health of infants and children. A recent, nested case-control study within a large, ongoing epidemiologic cohort study in Puerto Rico investigated birth outcomes. The researchers discovered a statistically significant association between the presence of glyphosate and its metabolites in maternal urine samples (collected around the 26th week of pregnancy) and incidence of preterm birth.[50] Preliminary findings from a multicenter cohort study in the United States suggest that prenatal exposure to glyphosate may be associated with longer anogenital distance at birth in female infants, but not male infants.[51] A longer anogenital distance at birth is a marker of masculinization in utero. This finding suggests that glyphosate may be a sex-specific endocrine disruptor in humans with androgenic effects and is consistent with additional recent findings of the endocrine effects of glyphosate in rodents.[52]

Although there has been some concern about the possibility of glyphosate being present in human milk, an early result suggesting this was not the case was reported but not published in the peer-reviewed literature. More recently, published peer-reviewed data do not suggest an appreciable concern that measurable levels of glyphosate occur in human milk. In a European study of 114 samples, none contained glyphosate above the detection level of the assay performed using highly sensitive mass spectrometric methods.[53]

This topic merits additional monitoring, particularly considering the Centers for Disease Control and Prevention's recent report that glyphosate is detected in 80% of Americans 6 years and older via urinary sampling.[54] Although urinary detection merely reflects exposure and does not analyze or determine health effects, it provides a foundation to better understand the context and impact of widespread exposure. Improving the understanding of the cumulative effect of glyphosate exposures on human health will be challenging, but public health merits continued scrutiny and agricultural innovation that optimizes both health and environmental sustainability.[55]

LABELING AND REGULATORY REQUIREMENTS

Until recently, the United States lagged behind most other countries in providing regulatory guidance or labeling requirements for GMO foods. The regulatory policy known as the Coordinated Framework for the Regulation of Biotechnology was organized in 1986 and identified the FDA, USDA, and EPA as having coordinated regulatory roles.[16]

Under the umbrella of its food safety authority, the FDA oversees foods derived from GMOs. However, the ultimate responsibility for safety lies with the manufacturer. In 1992, the FDA determined that whole foods from GMO crops were essentially equivalent materially to conventional crops, and they issued a policy statement of presumptive safety or GRAS (generally recognized as safe) status.[56] As such, most GMO crops do not require review before marketing and sales, and labeling has been a voluntary process.[16]

As previously discussed, the vast majority of the approved GMO crops are genetically modified to promote herbicide tolerance, insect resistance, increased yield, or a combination of these traits. Thus, both the EPA and the USDA Animal and Plant Inspection Service manage assessment of environmental risks of GMO crops, including herbicide regulation and residue on food. Regulatory oversight often fails to detect changes that occur through agricultural experimentation in field trials, and these transgenic crop changes may inadvertently fall outside regulation when combined with previously approved crops. Because of the complexity and uncertainty around both regulation and possible health impact, transparency for consumers is important. Environmental health experts called for reconsideration of labeling in 2015,[12] while an international group of scientists drew attention to a lack of worldwide consensus about GMO safety,[57] and these expert voices led to successful legislative efforts in the United States.

In 2016, Congress passed legislation (known as the National Bioengineered Food Disclosure Standard)[58] requiring labeling of GMO-containing foods with the terminology "bioengineered" (Fig 3) under guidance of the USDA.[59] Notably, the Agricultural Marketing Service of the USDA defines the foods that meet the requirement for labeling since the disclosure is a marketing label not intended to inform consumers about the health impact of the disclosed ingredients.[60] Required since January 1, 2022, this labeling mandate identifies certain foods by inclusion of either the text "bioengineered food," a graphic symbol,[61] a QR code, or directions to learn more via text message or phone call.

Most food manufacturers, importers, and retailers will need to ensure disclosure of bioengineered foods or ingredients, but notable exemptions include "very small" food manufacturers (annual receipts less than $2.5 million), restaurants, cafeterias, food trucks and stands, transportation services (on trains, airplanes), among others

FIGURE 3
USDA–mandated label for bioengineered food products.[61]

with labeling challenges, including cost concerns. There is an allowable 5% of bioengineered ingredients in a food product that does not require product labeling. Also excluded from the labeling requirements are meat and dairy products coming from animals that were fed bioengineered products.[58] With an intention to promote increased accessibility of animal biotechnology, the US Executive Branch tasked the USDA in December of 2020 to develop a regulatory framework for use of genetic engineering with farm animals.[62]

Because of consumer interest in transparency[10,63] and a lack of historic labeling requirements, some companies that voluntarily eliminated GMO ingredients added a label designating their products as "NON-GMO" after independent, third-party verification. A commonly used label requiring verification was designed by the NON-GMO Project,[64] a nonprofit organization dedicated to food transparency and sustaining a non-GMO food supply. This option will continue for companies that voluntarily submit their products for testing and participation in the NON-GMO Project labeling initiative.

As the new labeling regulations for bioengineered ingredients became mandatory on January 1, 2022, the USDA-mandated labels will join the many food products already voluntarily labeled as GMO-free. The distinction between foods labeled as not containing GMO ingredients versus foods labeled as bioengineered or USDA organic is likely to create confusion for many consumers.[22,65] A further aspect of confusion for consumers is the fact that companies can include the non-GMO label after testing on any product found to be free of GMO ingredients regardless of whether that product could ever be GMO. For example, salt can be labeled as non-GMO even though it would not be possible to genetically modify minerals.

Pediatricians can help families understand the scope of GMO products, labeling distinctions, and the key message that most minimally processed foods, including most produce, are not genetically engineered at baseline.

ORGANIC FOODS

All USDA-certified organic foods are GMO-free as a condition of this certification. In organic agriculture, the farmer cannot use GMO seeds and cannot feed organic animals GMO foods.[66] To ensure ongoing integrity for the organic market in the United States and for international trade, USDA agents began to test products from organic farms in 2013 to ensure lack of antibiotics, GMOs, and residue from pesticides.[67] Thus, a GMO seed, crop, or fodder cannot be used in organic foods, and farmers and processors must demonstrate this throughout the process to meet USDA regulations for certified organic foods.[66]

A major benefit of organic food is that it substantially reduces dietary exposure to pesticides. Studies show that consuming a primarily organic diet reduces the body's pesticide burden by about 90%.[68–71] Understanding the health impact of reduced pesticide exposure necessitates dedication to ongoing study of large epidemiologic cohorts.

AN APPROACH FOR PEDIATRICIANS SUPPORTING FAMILIES

Pediatricians support parents' most basic decisions about nutrition choices beginning in infancy, and they convey evidence-based guidance about the role of food in health across the lifespan. In the context of widespread use of GMO ingredients in food, including nearly all ultra-processed foods in the United States, families may seek guidance from pediatricians about the potential health implications of GMO foods. As new regulations for labeling increase the identification of foods with bioengineered ingredients, the potential for enhanced confusion and marketing-based messaging will likely increase. The goal of this clinical report is to guide pediatricians through these complexities and, thus, enable them to provide sound information to parents.

Through a family-centered communication approach, pediatricians and families can align with the common goal of promoting optimal child health. Understanding each family's access or barriers to food resources will guide nonjudgmental discussion. Providing fact-based information about the potential health effects of GMO-containing foods can motivate awareness, and connecting recommended changes with health goals will promote increased receptiveness to health advice about topics that can be controversial.[72]

Fortunately, conversations about complex subjects such as genetic engineering of food can open the door for conversations that emphasize the simplicity of a nourishing diet. These discussions also provide an opportunity to screen families for food security[73] and provide resources when needed. A suboptimal diet has emerged as a top risk factor for premature death and disability nationally and globally,[74,75] but pediatricians can frame this risk as an encouragement to focus on a simple, nourishing diet.

The most significant dietary contributors to poor health are the absence of beneficial foods, including fruits and vegetables, nuts and seeds, legumes or beans, herbs and spices, healthy fat sources, and whole grains. In their whole and minimally processed state, most of these foods are naturally non-GMO. Pediatricians can motivate reduction in consumption of ultra-processed convenience foods,[76] such as packaged treats, chips, and other calorie-dense, nutrient-poor options, while at the same time encouraging families to focus on affordable, accessible foods that are minimally processed, including legumes, nuts, whole grains, and seasonal or frozen produce. A positive message that encourages eating a variety of affordable, accessible, culturally relevant foods empowers families with knowledge of the benefits of promoting health through food.

Straightforward information with transparency about what is currently known and what is still under study is critical to prevent excessive concern and ensure ongoing trust in science. For families wishing to avoid GMOs in their food until more evidence is available, providing specific and individualized advice for simple changes is a great strategy. Some families may choose to prioritize purchase of organic foods to completely avoid GMOs, but many families lack access to organic foods for logistical or financial reasons.

SUMMARY AND RECOMMENDATIONS

1. GMO-containing food products are widely found in the food supply in the United States but originate from a relatively narrow list of 10 genetically engineered crops. GMO products are designed to increase crop outputs and not to affect the taste, smell, or appearance of food. Most of the food-based products derived from GMO crops are found in ultra-processed foods and animal feed.
2. GMO foods meeting certain criteria (there are many exceptions for smaller food companies, restaurants, and travel-based food distribution) must be labeled as GMO-containing since January 1, 2022. Stores can continue to sell older stocks of unlabeled foods.
3. Although GMO technology can be used to increase the micronutrient contents of foods, there is currently little use of these techniques to increase the nutritional value of foods and no reason to expect this to be a significant source of micronutrients in the US diet in the near future. At present, families in the United States should understand that genetic engineering has agricultural implications but does not increase the nutritional content of food.
4. Glyphosate, the principal herbicide used in the production of GMO food crops, has been classified by the International Agency for Research on Cancer as "probably carcinogenic to humans,"[44] meriting further study. Measurable quantities (residues) of glyphosate and other herbicides are now found in many GMO foods. Prenatal exposures to glyphosate are reported to be associated with increased risk of preterm birth and in utero endocrine disruption in children, but the impact of glyphosate residues on child health remains complex and incompletely understood.
5. Pediatricians who counsel families will find it helpful to be aware of the distinctions between organic, non-GMO, and bioengineered labeling. Organic labeling (which also guarantees non-GMO status) and the new bioengineered labeling standards and processes are regulated by the USDA. Non-GMO labeling remains voluntary and typically is managed by third-party organizations. Given the ability to label foods that cannot currently be genetically engineered, the presence of a non-GMO label does not indicate that unlabeled versions of the food necessarily contain GMO.
6. Families who wish to minimize GMO products can do so by focusing on a dietary pattern of primarily whole, plant-based foods while minimizing ultra-processed foods. The vast majority of unprocessed or minimally processed foods are naturally grown without genetic engineering, and both conventional and organic sources can be encouraged based on family preference and accessibility.
7. Families who desire to completely avoid GMO products can do so by purchasing organic products or those labeled as non-GMO based on third-party testing. Organic farmers are not allowed to use GMO seeds, GMO animal feed, GMO ingredients or conventional pesticides, antibiotics in farm animals, sewage sludge, and irradiation.
8. Each family makes the ultimate decision about whether to avoid GMO foods, but pediatricians can minimize fear-based messaging and support families through shared decision-making. Increased cost of some non-GMO foods, especially if also organic, may limit this choice for many families. It is important for caregivers, including pediatricians, to recognize the limitations that economics impose and emphasize the benefits of many minimally processed, affordable foods that are not bioengineered.
9. Schools and hospitals dedicated to the care of children can consider avoiding serving GMO foods to minimize glyphosate exposure when alternatives are available and affordable.
10. Further research opportunities are robust and include possible long-term health effects of GMO-containing foods, including carcinogenesis, as well as the potential benefits of nutritional modulation of foods using GMO technology. Additional research on the best approaches for consumer messaging is also highly relevant in the effort to improve child health through the continued promotion of fruits, vegetables, and other minimally processed, culturally concordant, nourishing foods.

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ABBREVIATIONSS

Bt: *Bacillus thuringiensis*
EPA: US Environmental Protection Agency
FDA: US Food and Drug Administration
GMO: genetically modified organism
IARC: International Agency for Research on Cancer
USDA: US Department of Agriculture

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