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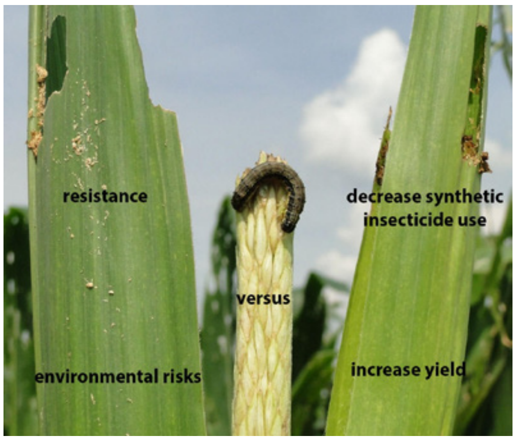
Transgenic Bt maize in South-and Central America: the pros and cons

Maíz Bt transgénico en Sur- y Centroamérica: los pro y contra



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Bt maize and *Spodopera frugiperda*.

Photo: I. Zenner-de-Polanía

ABSTRACT

The official authorization for planting Bt maize in most Central and South American countries was granted more than 20 years ago. This permission raised concerns, revealed inconsistencies in the information provided to farmers, uncovered unknowns, led to comments, and produced publications, often not scientific. Given the theoretical impact on the environment, economy, and health, the development of fall armyworm resistance, and the research capacity of these countries, the scientific literature is scarce, probably because of the lack of funding and the influence of patent holders and of producers and traders of transgenic maize seeds. This review aimed to debate the benefits and disadvantages of sowing maize hybrids that contain different Cry´s of the bacterium *Bacillus thuringiensis.* The reviewed documents did not provide conclusions. It will take years to determine whether transgenic maize cultivation has provided a benefit for growers and consumers of this plant species, which originated in these areas. However, it was deduced that there is a balance between the benefits and risks of Bt maize cultivation.

Additional key words: GMO; environmental impact; resistance; cost-benefit; beneficial insects.

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RESUMEN

La autorización official de siembras de Bt maíz fue otorgada en la mayoría de los países de Centro y Sur-América hace más de 20 años, lo que ha despertado inquietudes, revelado inconsistencias en la información producida para los agricultores, mostrado incognitas, motivado comentarios y producido publicaciones, a menudo no científicas. Dado el impacto teórico, ambiental, económico y salubridad y desarrollo de resistencia del cogollero del maíz, se considera que a pesar de la capacidad investigativa existente en estos países, la literatura científica reciente es más bien escasa, probablemente, por falta de financiación de estudios y la influencia de los dueños de los patentes, de la producción y venta de semillas de maíz transgéncio. Con esta revisión, se pretende relacionar los beneficios y desventajas originados por la siembra de los híbridos de maíz a los que se han incorporado Crys de la bacteria *Bacillus thuringiensis*. De los documentos revisados, todavía no se desprende una conclusión definitiva; habrá que esperar años para poder definir si las siembras de maíz transgénico representaron un beneficicio para los cultivadores y consumidores de esta especie vegetal originaria de esta zona. Sin embargo, en este momento se podría deducir que existe un equilibrio entre los beneficios y los riesgos de las siembras de maiz Bt.

Palabras clave adicionales: OGM; impacto ambiental; resistencia; costo-beneficio; insectos benéficos.

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INTRODUCTION

Maize (*Zea mays* L.) produces the most grains per area and is grown worldwide, including the United States, China, and Brazil, which are the top three producing countries, followed by Argentina. Mexico is ranked at number seven (Ranum *et al*., 2014; McCormick, 2020). In Central and South America, 18% of the world's maize is produced in 17% of the global area planted with this crop (FAS, 2020; Index Mundi, 2020). Argentina is the second most important country for maize exports, followed by Brazil (McCormick. 2020). These statistics are important because, with the exception of Mexico, the other two countries grow Bt maize.

The term Bt 'transgenic' or 'genetically modified' maize in this review refers to maize that has been genetically transformed through recombinant deoxyribonucleic acid (DNA) techniques, which result in the availability of insecticidal proteins from the bacterium *Bacillus thuringiensis* (Bt). As a consequence, maize hybrids that affect pests are available on the market. These transgenic maize cultivars produce endotoxins from the Cry1 and Cry3 groups, VIP exotoxins, and single-stranded RNA. These toxins and nucleic acids are added to control certain insect pests, including the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Blanco *et al*., 2016). However, controlling *S. frugiperda* with transgenic Bt maize has shown contradictory results (Aguirre *et al.*, 2016; Farias *et al*., 2016; Huang *et al.*, 2016; Vassallo *et al.,* 2019).

Planting transgenic Bt maize hybrids with the required technological package represents a clear advantage for farmers in terms of production. It has been estimated in numerous field studies that hybrids produce twice as much as open-pollinated maize (Hallauer *et al*., 1988). Investment in Bt seeds represents a productive advantage for farmers when these cultivars are sown under optimal management conditions.

The use of transgenic Bt maize in Central and South American countries have caused concerns and controversies in terms of its risks and benefits. Environmental dangers stand out because of the negative effect on the genetic diversity of "creole maize" given the gene flow with this maize. The possible impact on beneficial insects, whose temporary hosts are some maize pests, is notable, along with the generation of resistance in fall armyworms to Bt and the high cost of seeds. However, transgenic maize decreases synthetic insecticide applications andincreases production (Solleiro and Castañón, 2013; Chauvet and Lazos, 2014; NAS, 2016; Brookes and Barfoot, 2018).

This review aimed to present and analyze the risks and benefits of cultivating transgenic Bt maize in Central and South America, including Puerto Rico and Cuba, based on the available scientific and divulgative literature to offer a broad vision of this complex issue and provide basic information on plantings in the countries where *Zea mays* L. originated.

MATERIALS AND METHODS

The keywords: transgenic maize, Bt maize, Bt proteins, Cry, VIP, maize pollination, *Spodoptera frugiperda*, resistance, beneficial fauna, genetic engineering, genetic contamination, and autochthonous seeds and combinations thereof were used to systemically review scientific and informative documents, starting from the date the transgenic Bt maize plantings were authorized by the agricultural entities in the relevant countries, where Argentina was the first South American country that planted Bt. Maize in the 1998/1999 season. Therefore, the systematic literature search was conducted from 1998 to 2021. The databases Periódica (Mexico), SciELO org., Redalyc org., Science Direct, Scopus, Web of Science, and Google Academic were reviewed.

RESULTS AND DISCUSSION

In 1994, Roush raised the question: are Genetically Modified Organisms (GMOs) with Bt toxins more efficient in controlling pests than *Bacillus thuringiensis*-based insecticides¿ He concluded that transgenic plants that are less environmentally harmful could, at the very least, replace synthetic chemical applications (Roush, 1994).

In South America, Brazil represents one of the most successful examples of adopting hybrid maize. The government strongly supported the development of hybrids adapted to local conditions, and this country is now the second-largest producer, harvesting 9% of the world's maize (World of Corn, 2020). Brazilian hybrids include Bt proteins; however, despite the fact that the fall armyworm has shown resistance to these proteins, this technology continues to be attractive to farmers. This country saw an increased adoption rate of 88.9% in 2017, and Bt maize occupied 15.6 million hectares (ISAAA, 2017).

Argentina, the fourth-largest producer of maize (7.6 t ha^{-1}) (Index Mundi, 2020), produces 4.5% of the world's supply (World of Corn, 2020) and has a history similar to that of Brazil. Hybrid Bt maize is planted in more than 90% of the 6 million hectares dedicated to this grain (Rossi, 2007).

However, the effectiveness of transgenic Bt maize against pests could have a temporary negative impact on their natural enemies. Laboratory tests with various *B. thuringiensis* proteins have shown that toxins (eg, Cry1A, Cry1F, Cry2A, Cry3, and VIP) and single-stranded RNA have no significant effect on members of insect orders that contain most of the natural enemies (Lövei and Arpaia, 2005; Mason *et al.,* 2008). Tritrophic level tests, in which this pest was fed Bt proteins and exposed to predators and parasitoids, have not yielded conclusive results for the effect on natural enemies (Schmidt *et al.,* 2009; Hilbeck *et al.,* 2012; Lövei *et al.,* 2009).

In Brazil, after the positive results of bioassays and the establishment of the susceptibility baseline and control level, Bt maize with Cry1Ab was released (Omoto *et al*., 2016). By 2007, Bt toxins, Cry1Ab and Cry1F were commercially available. These hybrids were planted during the 2008/09 and 2010/11 seasons, and GM maize already represented 57% of the total cultivated area (Leite *et al.,* 2011). Estimates for the 2012/2013 season assumed an area greater than 1.1 million hectares for Rio Grande do Sul, of which 85.7% was for transgenic maize (Galvão *et al.,* 2011).

Argenbio (2020) highlighted Argentina as the forefront of adopting transgenic crops. Cultivation of Bt maize resistant to insects of the Lepidoptera Order began in the 98/99 season with 13,000 ha, which constantly increased until reaching 2,509,000 ha in the 2007/2008 season. An abrupt and constant decrease was observed until 700 thousand ha was reached during the 2014/2015 season (Argenbio, 2020).

In Colombia, despite concerns voiced over the biosecurity evaluations carried out by the Colombian Agricultural Institute (ICA in Spanish) as being incomplete, the cultivation of two transgenic maize (Bt) hybrids was authorized in 2007, excluding areas in indigenous reservations (Grupo Semillas, 2007). 6,901 ha were planted; this area increased continuously until reaching a maximum of 89,048 ha in 2014; a decrease was observed in 2015 (Grupo Semillas, 2016; Agro-bio, 2018). In 2017, the Department of Meta emerged as the leader of Bt maize (Agro-bio, 2018). According to the ICA and Agro-bio (Noticias ONIC, 2017), the hectarage increased from 6,000 ha in 2007 to 100,109 ha in 2016.

The cultivated area for Bt maize in other South American countries is small. In Uruguay, between 2003 and 2004, 21,850 ha were planted, representing 34% of the total area (Frommel *et al.*, 2006). Cultivation with the Bt protein was only authorized in 2013 in Paraguay; three years later, eight events were already officially released (SENAVE, 2016). With an area of 3,000 ha of Bt maize, Cuba began planting GMOs in 2012 (Fundación Antama, 2013).

The countries that prohibited Bt maize include Peru, where the Congress published "Protection of biological and cultural diversity" on December 9, 2011 within Law No. 29811, which established a moratorium on the entry and production of LMOs (living modified organisms) for a period of 10 years (2011-2021); this law excludes use "as human or animal food", as well as for processing and research in pharmaceutical and veterinary products, as regulated by the World Health Organization (WHO) (Ministerio del Ambiente, 2016).

Also, according to the list of nations that have prohibited planting GMOs published by Admin-Bt (2016), Ecuador only authorized imports, and Venezuela banned planting and importing products manufactured with Bt maize.

Benefits of planting bt maize

The benefits and risks are described below (Tab. 1).

Decrease in chemical insecticide applications and increase in maize yield

The benefits of planting transgenic maize hybrids include reductions in the use of synthetic insecticides for controlling the fall armyworm. This decrease protects beneficial fauna and reduces damage to the environment, air, water, soil, and health of farmers and consumers. In addition, there is an increase in production, not necessarily in productivity, since seeds represents a high cost.

Table 1. Positive and negative impacts from Bt maize

Positive impact	Country	Remarks	Articles	Comments
Reduced use of synthetic insecticides against *S. frugiperda*	All countries	Absence of chemicals results in protection of natural enemies; health; environment	8	Does not apply to small plots sown with conventional maize
Increase in yield	Argentina, Colombia, Cuba	Up to 30% in Cuba	5	No recent statistics available
Negative impact				**Year detection and other notes**
Confirmed resistance	Brazil	Cry1Ab, Cry1F Autosomal inherence for alleles	8	2009
	Argentina	Cry1F, Cry1Ab Gradual decrease in susceptibility	5	2012
	Paraguay	Cry1F, larval mortality only 58%	1	2017
	Cuba	Resistance monitoring, CryAAC toxic hybrid	2	2009
	Puerto Rico	Cry1Fa, Cry1Ac Concern possible migration to USA	6	2006
	Colombia	Cry1F; resistance baseline of populations required, including in Bt maize free territories	3	2014
Environmental risks	Colombia	Genetic contamination; transgenic free territories	4	Increase free territories; revaluation of distance between Bt maize plots and landraces
	Mexico	Interaction Bt maize and native races	2	Loss maize biodiversity
	Uruguay	Flow of trangenes	1	Contamination
	Brazil, Colombia, Argentina	Bt maize and beneficial insects; absence direct influence	9	Long term research required

According to Permingea and Margarit (2005), the advantages or benefits include the constant expression of endotoxin Cry in the plants, meaning multiple applications of insecticides for *B. thuringiensis* are not needed. The specificity of this toxin, absence of apparent damage to the environment, and the health of farmers and consumers are also benefits of Bt maize crops.

Biotecnologíasi (2015) highlighted three benefits from Bt maize cultivation in Cuba: a decrease in inputs for controlling *S. frugiperda*, protection of beneficial insects because of the absence of chemicals, and an increase in grain production of at least 30%.

The positive environmental impact of the decreased use of chemical insecticides does not apply to maize sown in subsistence plots since the small farmers cannot obtain transgenic seeds. These crops, which often range from only half to one hectare, are considered refugees, where no Bt products are used to control of fall armyworm.

For Brookes and Barfoot (2018), the main impact of the Bt technology was increased yield. In Argentina, the average yield gain was calculated as between 8 and 10% based on a 2004 analysis; however, more recent estimates place the increase in the last 10 years between 5 and 6%. For Brazil, in the 2008-2016 period, the average yield increase was estimated as more than 11.8% (Bookes and Barfoot, 2018). In Colombia, an average yield of 6 t ha^{-1} was obtained with Bt maize, increasing the average yield of landraces by 2.6 t ha^{-1} (Chaparro-Giraldo *et al*., 2015).

No statistics for decreased use of synthetic products for controlling *S. frugipera* were found in the literature. Before the introduction of Bt maize in Colombia, an average of four sprays per crop were carried out; a reduction of one chemical application is enough to benefit the environment.

Limitations of the constant use of transgenic maize

Risks from Bt maize are much better documented than benefits; where resistance and environmental risks are highlighted.

Resistance

The main risk, predicted since the beginning of GMO cultivation, is resistance (Tab. 1) in pests that are targeted by Bt toxins. A few years after the introduction of Bt maize, resistance was observed in the fall armyworm worldwide, threatening the sustainability of Bt maize (Huang *et al.,* 2014; Omoto *et al.,* 2016).

The establishment of the susceptibility baseline for populations of *S. frugiperda* and subsequent monitoring of tolerance and resistance were mandatory in all countries that authorized the use of Bt maize.

Brazil started monitoring in 2009 after detecting a decrease in the effectiveness against lepidopteran larvae, demonstrating a significant reduction in susceptibility to Cry1Ab in the fall armyworm (Omoto *et al*., 2016). Araujo *et al*. (2013) compared maize and rice biotypes of *S. frugiperda* from southern Brazil and concluded that the rice biotype was more susceptible to Cry1Ab than the maize biotype.

Horikoshi *et al*. (2016a) stated that resistance in the fall armyworm to Cry1F has been officially recognized in Brazil since 2011 in western Bahia; this insect has autosomal recessive inherence for alleles, related to protein resistance (Farias *et al*., 2014; 2016). Leite *et al.* (2016) selected a *S. frugiperda* strain under laboratory conditions with high levels of resistance to Cry1F. The bioassays, rearing larvae on Bt maize leaves, revealed that, within four generations, resistance was observed. Results from other bioassays revealed resistance in populations in the Cerrado region to Cry1Fa (Monnerat *et al*., 2015). Horikoshi *et al*. (2016b) evaluated the dominance of resistance, based on the survival of neonates, finding high survival rates for other toxins. According to Fatoretto *et al.* (2017), *S. frugiperda* has developed resistance to most transgenic Bt hybrids in a period of only three years in Brazil.

Other countries that have detected resistance to *S. frugiperda* include Argentina, Cuba, Colombia, and Puerto Rico. In Argentina, continuous monitoring of the evolution of resistance to Cry1F in the main planting areas evidenced an increase in larval survival between 2012 and 2016 (Vassallo *et al*., 2019). The first records date from the 2012/13 and 2013/14 seasons, observing unexpected damage in different transgenic Bt maize hybrids (Trumper, 2014). A survival rate of up to 15% of larvae was found under laboratory conditions when evaluating Cry1Fa (Flores and Balbi, 2014). Chandrasena *et al*. (2018) analyzed the development of resistance to Cry1F δ-endotoxin in populations of *S. frugiperda* in four maize-producing regions in Argentina, demonstrating a gradual decrease in susceptibility from 2009 to 2015.

Subsequent research on fall armyworm larvae collected from Bt transgenic maize fields and reserves confirmed a considerable decrease in the efficiency of Cry1F and showed an absence of efficiency in Cry-1Ab (Murúa *et al*., 2019).

Argentina stands out for its openness to transgenic events, as shown by the "Complete list of events and combinations of events approved for planting, consumption, and commercialization" (Agenbio, 2020). Four maize hybrids, two with resistance to lepidopteran insects and tolerance to the glyphosate and two with resistance to lepidopteran and coleopteran insects and tolerance to the herbicides glufosinate ammonium and glyphosate were approved in 2019. It can be assumed that these multiple authorizations are intended to counteract resistance.

Susceptibility to *S. frugiperda* in different transgenic Bt maize events was evaluated by Gómez *et al*. (2017) in Paraguay, where the mortality of larvae fed VT Triple PRO™ (Cry1A.105 / Cry2Ab2 / Cry3Bb) was 100%, while those fed 2B587HX™ (Cry1F) and Formula TL™ (Cry1Ab) only saw mortality at 58 and 56%, respectively.

Research on *S. frugiperda* resistance (Téllez *et al*., 2016; Mejía and Zenner de Polanía, 2012; Zenner de Polanía *et al.,* 2009) has assumed that populations in Colombia and Cuba have also acquired resistance. In 2006, Ayra-Pardo *et al.* (2006) stated that Cry1Ac and Cry1Ab did not cause mortality in newly hatched armyworm larvae. In Colombia, Jaramillo *et al*. (2019) evaluated populations of *S. frugiperda* during 2014-2016 in two genetically modified hybrids with Cry1F endotoxin and determined that this endotoxin no longer exerted satisfactory control.

In Puerto Rico, resistance to Cry1Fa maize planted since 2003 was first recorded by Storer *et al.* (2010), as confirmed by several other authors (Blanco *et al*., 2010; Storer *et al.,* 2012; Vélez *et al*., 2014; Arias *et al*., 2015; Zhu *et al*., 2015). Furthermore, these authors expressed concern about the viability of migration of resistant breeds to the southern United States. Recent studies carried out by Portilla *et al*. (2020) showed that adults are more resistant to Cry1Fa than to Cry1Ac and confirmed the resistance of larvae to the two toxins.

Bioassays with populations from Puerto Rico confirmed resistance to Cry1F and Cry1Ac and revealed susceptibility to Cry2Ab2 and Cry1A.105 (Gutierrez-Moreno *et al.,* 2020); these authors also tested three Mexican populations of *S. frugiperda* and found that they were highly susceptible to the four Bt proteins.

Resistance in the fall armyworm to *Bacillus thuringiensis* Cry1Aa, Cry1Ab, Cry1Ac, Cry1F, Cry2Ab2 and Vip3A adds concern to resistance developed to multiple chemical insecticides (Arthropod Pesticide Resistance Database, s.f), which will make future management of the pest even more difficult.

Environmental risks

A second factor in the implementation of Bt maize crops includes environmental risks, summarized in two aspects: contamination of native maize and effect on beneficial fauna (Tab. 1).

In Colombia, Resolution 2894 (ICA, 2010) covers aspects related to the proper management of Bt maize and prohibits the cultivation in indigenous reservations to preserve the biodiversity of native maize. Zenus of the Indigenous Reservation of San Andres de Sotavento (Colombia) established "Transgenic Free Territories" because of possible genetic contamination from maize landraces as the result of nearby Bt maize cultivation. In 2014, there were seven such territories in the country (Grupo Semillas, 2015).

The ecological, agronomic, socio-economic, and cultural implications of the possible commercial release of transgenic maize in Mexico was characterized by Luna and Altamirano (2015), emphasizing the danger for the subsistence of small, Mexican farmers, the sovereign and food security of the country and the disappearance of traditional knowledge in the rural population. The greatest concern is possible damage to the diversity of native maize as the result of genetic interaction with native races that may lead to the progressive accumulation of transgenic DNA (Turrent *et al*., 2009).

Mexican populations of fall armyworms were recently tested in bioassays for susceptibility to Bt. proteins; the results suggested that a "possible deployment of Bt maize in Mexico will not be immediately challenged by Bt-resistant genes" (Gutierrez-Moreno *et al.,* 2020).

Pardo (2018) noted the degeneration of "criollo" maize, essential cultivars for studies of genetic improvement of maize, and Chaparro-Giraldo *et al*. (2015) evaluated the flow of Bt genes in an important maize area in Colombia and found that all crops of conventional maize in buffer zones, refuge zones, and areas with local Colombian varieties showed the presence of transgenes.

In Uruguay, Galeano *et al*. (2014) demonstrated the flow of transgenes from commercial transgenic maize crops to non-transgenic crops at distances greater than the regulatory 250 m, including more than 330 m. Therefore, studies on effective distances between Bt maiz plots and conventional ones should be carried out under multiple environmental conditions.

Generally, among environmental risks, use of biological and chemical insecticides is always of concern, with negative effects on the natural enemies of the target pests. For Bt maize, the literature reports, at least in the case of predators, the apparent absence of a detrimental impact. However, few studies have looked at the effect of the absence of prey, specifically eggs or larvae of *S. frugiperda*, on the development of predator populations. The action on species-specific parasitoids is worrying, since, if the host egg or larva is absent or cannot develop to the instar in which it is normally parasitized or the parasitized lava does not reach the age that allows the emergence of the parasitoid, there will be no survival of the beneficial insect.

There are criticisms about the scientific quality of some experiments on the safety of Bt maize for beneficial organisms. Onofre (2009) analyzed the document "CTNBio, Process Nº: 01200.002995 / 1999-54" (BFSTD, 2007) and stated that the short duration of the experiments, for example, seven days with the predator *Chrysopa carnea*. The same author indicated that "in several of them, only two repetitions were used (e.g. essay with *Hippodamia convergens*)" and concluded that this experiment design cannot provide conclusive results.

Zenner de Polanía and Álvarez (2008) evaluated the effect of genetically transformed crops on the main beneficial fauna and concluded that the decrease in populations of predators of the family Coccinellidae and specific parasitoids of the fall armyworm cannot be attributed to a direct effect of Bt maize but to the absence of an appropriate number of preys and hosts. Another study compared the beneficial entomofauna between batches of transgenic and conventional maize in the Department of Córdoba-Colombia and showed the absence of significant differences between these populations within the two crop types (Sánchez *et al*., 2018).

The biological parameters of the predator, the coccinellid *Eriopis connexa*, were studied, feeding adults armyworm larvae reared on Bt and conventional maize. The predator fed with larvae reared on Bt maize showed a statistically longer duration in the larval stage, and the adult weight and fecundity were lower (Curis and Bertolaccini, 2013). The longer lifespan could favor predators since they would consume a higher number of prey. A lower fecundity, however, is a detriment to the population of this natural enemy.

Resende *et al.* (2016) analyzed the influence of Bt maize on the populations of secondary pests and natural enemies, finding that richness and diversity were not directly affected. The natural enemies monitored belonged to the predator families Reduviidae, Anthocoridae, Miridae, Carabidae, Anthocoridae, Geocoridae, and Chrysopidae, among others.

A survey of insect diversity in Bt (Cry1Ab) and conventional maize was carried out by Frizzas *et al.* (2017), finding that the transgenic maiz had no impact on predators but showed a negative effect on the pupal parasites of *S. frugiperda, Achytas* (Tachinidae). The authors explained that, in the conventional maize without insect sprays, the parasite had higher chances of finding a host than in the Bt maize. For *Apis mellifera,* the main pollinator collected, no negative effect was observed.

Mexico is concerned about the risk that Bt maize, once approved for planting, could have on beneficial insects, mainly predators such as *Orius insidiosus, Coleomegilla maculata* and *Chrysoperla carnea.* Therefore, Hernández-Juárez *et al*. (2019), under specific biosafety conditions carried out in field trials, concluded that Bt maize does not represent risks for the abundance, frequency, or population density of the three beneficial arthropods. Souza *et al*. (2019) also stated that the beneficial fauna could be affected directly and indirectly and insisted that further research on their interaction with GM plants is urgently needed.

Research on the behavior of the fall armyworm´s parasite *Palmistichus elaeisis* revealed several negative effects when reared on Bt-treated larvae, mainly lower survivorship, altered host searching, and poorer reproductive performance, which revealed poor compatibility between Bt. and the parasitoid (Rolim *et al.,* 2020). Another recent bioassay carried out by Spagnol *et al.* (2020) showed that Bt maize does not harm the egg parasite of *S. frugiperda, Trichogramma pretiosum*

Despite the recent research that evaluated the influence of GMOs on the beneficial fauna, the toxins incorporated into maize do not cause direct effects on these arthropods. This result can be explained by the fact that the proteins incorporated into the currently available Bt maize hybrids specifically affect Lepidoptera larvae and do not affect the orders that contain predators or parasitoids.

CONCLUSION

Despite numerous studies that have evaluated the pros and cons of Bt maize cultivation, no outright decision can be made as to whether to authorize plantings for the economic benefit of maize growers or the initial economic advantage of patent holders and seed producers. The expiration of some patents may have an impact on the cost of seeds, making them available to more planters. The future will show if the interaction of Bt maize and native races will have the prospected negative influence on the loss of maize biodiversity.

Long term studies on the impact of Bt maize, with both known and new endotoxins of *Bacillus thuringiensis,* on the natural enemies of *Spodoptera frugiperda* are imperative. Simultaneously, susceptibility baseline determinations have to be carried out.

The detected resistance of *S. frugiperda* to several Cry toxins encourages research to develop new Bt maize eventsr to overcome the development of this phenomenon.

The conclusion reached by García (2007) is notable: "In a relatively incipient field of science, such as genetic engineering, questions made in this matter are necessary and more than justified, since, without them, there would be no way to guarantee the necessary controls in a matter as delicate as the one at hand, especially due to the magnitude of the scope and the aforementioned implications".

Finally, if the pros of planting Bt maize were placed on a Roman balance and the cons on the other plate, equilibrium could be observed between the two points of view.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the author, who declares that there exists no conflict of interest that puts at risk the validity of the presented results.

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