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BIOTECHNOLOGY

Bioremediation, drought tolerance and biofortification in biotechnological uses

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ABSTRACT. The objective of this review is to bring information about innovations and technologies that, through genetic improvement, are being used to improve the sustainability and productivity of agricultural crops, improve human nutrition, as well as conservation and decontamination of soils. Bioremediation consists of using microorganisms that have the ability to modify or decompose certain pollutants, with the possibility of increasing their activity through genetic engineering, building new strains for the transformation of pollutants into inert substances. Genetic improvement is seeking to develop cultivars that are more tolerant to periods of water deficit. Plant biofortification consists of varieties of improved plants that have a higher content of vitamins and minerals, which are obtained through genetic improvement. Thus, biotechnology is once again essential for world agricultural production and can bring a series of other benefits to society.

Keywords: genetic improvement; transgenic; sustainability; genetically modified organisms.

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Introduction

It is estimated that by 2050, the world population will have reached nine billion individuals. The world will be facing major crises heralded by the reduction of oil reserves, the lack of drinking water and food shortages. In view of this, biotechnology is and will be one of the tools for exiting crises, especially in Brazil, an essentially agricultural country (Ash, Jasny, Malakoff, & Sugden, 2010). In this process, biotechnology has three challenges: increasing the yield potential of agricultural crops, protecting the yield potential of stressed crops, and increasing the efficiency of crop resource use to ensure production sustainability (Hawkesford et al., 2013).

Biotechnological crops, adopted worldwide, offer a series of benefits for the environment, health and improvement of the socioeconomic conditions of farmers and the population in general. Thus, they contribute to food security, sustainability and food production in the face of climate change (Raphael, 2019). For example, the use of crops with the Bt gene, which gives plants resistance to insects, reducing the use of insecticides, increasing the biodiversity of natural enemies and environmental sustainability (Lu, Wu, Jiang, Guo, & Desneux, 2012). From an economic point of view, the use of GMOs, in addition to increasing crop yields by up to 21%, reduced spending on pesticides by 40%, and raised the average profit of farmers to 69% (Klümper & Qaim, 2014; Qaim & Zilberman 2003). These conditions are essential, even more so nowadays, with the devaluation of the real against the dollar, and the increase in the price of inputs used in agriculture.

With the decrease in the use of pesticides, water is also saved. In order to improve the efficiency of water use in agriculture, in addition to reducing the use of pesticides, biotechnology also works on the development of drought-tolerant species, reducing intensive irrigation of crops and maintaining crop productivity even in conditions of water stress (Carrer, Barbosa, & Ramiro, 2010). It is known that in the world, great amount of the water is used in the agriculture. In Argentina, a drought resistant soybean cultivar was developed, with a 13% yield improvement in a crop with water scarcity and a wheat, with a 25% yield improvement in yield when exposed to stress conditions (Araus, Serret, & Lopes, 2019).

Besides production, a major problem found in the world is hunger and malnutrition. Approximately three billion people suffer from the effects of hidden hunger in the world (Dias et al., 2015). Therefore, it is not enough just to improve the efficiency of crops, but also to act in food distribution (a discussion that is not the focus of this review), as well as in the generation of food with higher concentration of nutrients, biofortified crops. In addition, genetic engineering seeks to develop genetically modified plants for soil decontamination, which over the years has been contaminated due to anthropological activity.

Therefore, the objective of this review is to bring information about innovations and technologies that, through genetic improvement, are being used to improve sustainability and agricultural productivity, improve human nutrition, as well as improve conservation and environmental decontamination.

Bioremediation

In recent years Brazil has suffered from environmental disasters, including oil spills on the coast and dam failures. In Mariana-MG, for example, the mudflow spread 50 million cubic meters of mining tailings, mainly including iron oxide (Escobar, 2015). Adding to these "accidents", the growth of industrial activity has also increased the concentration of substances such as heavy metals and petroleum hydrocarbons in the environment (Xi et al., 2018; Tomassoni, Santos, Santos, Carpinski, & Silveira, 2014; Jin, Yang, Zhang, Wang, & Liu, 2009). In addition to industrial contaminants, herbicides used in agriculture also have the potential for soil pollution due to their residual period, remaining in the environment for different periods of time, ranging from a few months to several years, which can cause the carry over effect, which consists of phytotoxicity in sensitive crops grown in succession to those that received applications. Leaching or surface runoff of molecules can also occur, reaching groundwater, rivers and other water bodies (Pires, Souza, Silva, Procópio, & Ferreira, 2003).

The treatment of these contaminated areas is difficult and problematic, and this is due to the complexity of these substances. These compounds, herbicides and heavy metals, are toxic to the environment and to humans (Andrade, Augusto, Sales, & Jardim, 2010). In plants, they can cause inhibition of seed germination, decrease in photosynthetic pigments, slow nutrient assimilation and shortening of roots and aerial parts, which will affect plant development and productivity (Peng, Zhou, Cai, & Zhang, 2009). Some physical treatments can be used to destroy or chemically modify these contaminants; however, they present many limitations and a high cost, being an alternative, the use of bioremediation, a simple, cheap and efficient technology (Alexander, 1994).

Bioremediation is the use of organisms with the ability to modify or degrade pollutants, transforming them into inert substances. Pollutants thus function as a source of nutrients and energy for organisms (Andrade et al., 2010; Ueta, Shuhama, & Cerdeira, 1999; Jacques, Bento, Antoniolli, & Camargo, 2007). Bacteria, fungi and yeasts that can occur naturally or be cultivated are used. Even with the diversity of existing organisms, some pollutants are resistant to degradation and it is necessary to increase the ability of organisms to detoxify or degrade contaminants, which occurs through genetic engineering (Jain & Baijpai 2012).

A strain of *Pseudomonas fluorescens* called HK44 was the first genetically modified microorganism approved for field tests in 1999 in the United States for the purpose of bioremediation. The HK44 strain has a lux gene within a naphthalene degradative pathway, allowing the microorganism to bio luminesce while degrading polyaromatic hydrocarbons such as naphthalene, anthracene and phenanthrene, allowing to monitor the bioremediation process. When inoculating *P. fluorescens* HK44 in soils contaminated with hydrocarbons, bioremediation occurred within 660 days after inoculation. Using technology with bioluminescence, it is possible to determine in situ the bioavailability of environmental contaminants and carry out the monitoring and control of the biodegradation processes (Ripp et al., 2000).

4-Chlorobenzoic acid (4-CBA) is an intermediate product of the degradation of some recalcitrant chloroaromatic pollutants still present in industrial sites such as PCBs and DDT, the bacterium Arthrobacter sp. FG1 strain, genetically modified, is able to use this acid as an exclusive source of carbon and energy (Radice et al., 2007). The first step of 4-CBA degradation in *Arthrobacter* sp. FG1 consists of the hydrolytic dehalogenation of the chemical that is converted into 4-hydroxybenzoic acid, the genes encoding the FG1 dehalogenase were cloned into the 4-hydroxybenzoic acid degrader of *Pseudomonas putida* PaW340, thus obtaining the PaW340/pDH5 strain, capable of degrading 4-CBA (Radice et al., 2007).

The bioaugmentation technique was used in field research with atrazine-contaminated soil using a stabilized and killed whole cell suspension of a genetically modified bacterium called recombinant Escherichia coli designed to generate overproduction of atrazine chlorohydrolase. After two months, atrazine levels decreased by 52% at sites where dead recombinant *E. coli* cells were implanted (Strong, McTavish, Sadowsky, & Wackett, 2000).

The same bacterium from the previous study, *E. coli*, was genetically modified to discolor azo dyes, receiving the name *E. coli* JM109 (pGEX-AZR). The azoreductase gene was obtained by PCR amplification of *Rhodobacter sphaeroides* AS1.1737, which was inserted into the expression vector pGEX4T-1, under the control of a lac operon, transformed and expressed in *E. coli* JM109. By inoculating this bacterium in wastewater, it increased the biodegradability of dye residues and was effective in removing organic pollutants (Jin et al., 2009).

There are some limitations regarding bioremediation under environmental conditions, in which many other microbial species are present, and the synergistic action has not yet been elucidated (Irshad et al., 2021). It is difficult to count the colonies of bacteria that are inoculated in soils for bioremediation, so microorganisms with bioluminescent genes are essential to carry out the control and monitoring of biodegradation. More scientific research is needed to increase the survival and efficiency of genetically modified organisms under natural conditions.

The impacts of GMOs on nature are not yet known, because most of the work is carried out exclusively in laboratories, the release for application in environments in the "in situ" form goes through a strict legislation. Due to that it is not possible yet find microorganisms genetically modified used in bioremediation, for commercialization. As for example the pioneering work of Gunsalus and Chakrabart on the genetic basis of the degradation of recalcitrate compounds by *Pseudomonas* strains, a strain was developed by conjugation for bioremediation in environments contaminated with camphor, octane, salicylate and naphthalene, discovered in 1975 and patented in 1981, and has not yet been released for commercialization (Cases & Lorenzo, 2005).

One of the obstacles to the release of transgenic microorganisms is the possibility of horizontal transfer, in which recombinant genes are transferred to other microorganisms and hosts, conferring resistance to antibiotics and heavy metals, for instance. To avoid this problem, some techniques have been developed, such as the use of defective transposons, once integrated into the chromosome they cannot do so again due to lack of transposase genes (Torres, Garcia & Diaz, 2004); elimination of antibiotic resistance genes, through excision of irrelevant DNA containing an antibiotic resistance gene, being excised by transient expression of ResA resolvase (Davison, 2002); suicide mechanism, which will happen when an environmental signal that interrupted suicide, such as the pollutant that is being degraded, is interrupted expressing the suicide gene causing cell death (Torres et al., 2004); Cell suicide after plasmid transfer, when the plasmid is transferred horizontally to another bacterium, cell death occurs in the recipient (Torres et al., 2004).

Bioremediation with genetically modified organisms allows an increase in biodegradation rates, as for example some GMOs that are able to degrade petroleum components 10 to 100 times faster than non-transgenic strains (Ezezika & Singer, 2010), in addition to being a sustainable practice, economically viable, and effective for decontamination. It is necessary to invest more in research focused on the area to elucidate questions mainly on the release of these microorganisms in the environment, so that when both soil and water bodies are inappropriate for use, they could be recovered.

Drought tolerance

Studies show that there will be year by year, an increase in average temperatures, which will increase the variability of climatic characteristics across the planet, generating prolonged droughts or intense rains more frequently than what already occurs today (Nepomuceno, Neumaier, Farias, & Oya, 2001). Drought is one of the environmental factors that causes greater stress in crops that are important to the world economy, such as soybeans. In Brazil, the drought caused a reduction in the productive potential of the crop, in the 2003/2004 to 2014/2015 harvests, losses estimated at US$ 46.6 billion (Haggag, Abouziena, Abd-El-Kreem, & Habbasha, 2015; Fuganti-Pagliarini et al., 2017).

Water deficit occurs when the water content of a tissue or cell is below the highest water content exhibited in the highest state of hydration, so the productivity of a given crop is directly linked to the availability of water, when a plant is able to absorb more water and/or use it more effectively will better tolerate the stress conditions caused by lack of water (Taiz & Zeiger, 2017). Genetic improvement has been sought to develop cultivars that are more tolerant to periods of water deficit, resistant to drought, and also the development of new technologies that help plants to tolerate prolonged periods of drought, until rain falls and the plant returns to normal development. These genetically modified cultivars will be essential for world agricultural production, making better use of environmental resources, being less affected by abiotic stresses, producing more in a smaller area, so that it is possible to feed the world population that grows year by year (Nepomuceno et al., 2001).

The genes that are used in breeding aiming at tolerance to adverse environmental conditions are involved with the encoding of enzymes from the biosynthesis of osmoprotectants, detoxifying enzymes, or genes that encode transcription factors, which are proteins that are involved in the initial stages of gene expression and regulation and signal transduction in response to stress (Nepomuceno, 2001).

Plants may show responses dependent or independent of the presence of abscisic acid (ABA). In the ABA-dependent pathway, a family of active genes is the AREB (abscisic acid-responsive element binding protein) (Furihata et al., 2006; Yoshida et al., 2010). When the plant is exposed to water deficit, this phytohormone promotes the closing of the stomata, through the guard cells and induces the expression of some genes. This gene has in its promoter regions, the conserved sequence ABRE (Abscisic acid responsive element), where the transcription factor AREB binds, activating the transcription of genes, whose products can act on tolerance to dehydration in plant tissues and seeds (Furihata et al., 2006; Yoshida et al., 2010).

In the ABA-independent pathway, another transcription factor family, called DREB (Dehydration Responsive Element Binding protein) was identified in Arabidopsis thaliana. They are proteins that act by triggering molecular events, which will induce the plant's defense response against cellular dehydration. The DRBEB1A protein acts as a transcription factor and has its structure in the ERF/AP2 (ethylene resoinsive factor- ethylene responsive factor/APETALA) domain, a cis-acting element present in the promoter region of several genes that are activated during drought conditions (Maruyama et al., 2009).

The pathogen-induced WRKY gene was isolated in tomato using the *in silico* cloning method and reserve polymer-setranscriptase chain reaction (RT-PCR) and introduced into tobacco. The overexpression of the SpWRKY1 gene in transgenic tobacco increased tolerance to drought (Li, Luan, & Liu, 2015).

Scientists have developed a rice cultivar resistant to drought, through a protein extracted from corn that interferes with the opening of stomata. The amino acid sequence ZmPIF1 participates in the ABA signaling pathway to decrease stomatal opening and inhibit transpiration rate, increasing water saving and drought resistance in transgenic rice (Gao et al., 2018).

The ZmPIF1 protein can increase drought tolerance and rice grain yield, playing an important role in crop improvement, especially in times of water deficit. Rice plants that were genetically modified and went through periods of lack of water managed to recover and have a high productivity, whereas in conventional rice plants there was no reestablishment and grain production was highly affected.

Studies with tobacco plants introducing a protein found in algae and a cyanobacterial enzyme, through the Gateway cloning technology, increased the photosynthetic capacity of tobacco plants, increasing growth and using less water to produce high yields, which leads to greater efficiency of water use by plants, to resist periods of drought (López-Calcagno et al., 2020). Future studies will be carried out with soybean, corn, rice and cowpea plants.

Work carried out with dehydration-responsive transcription factors (DREB) and ABA-responsive element binding (AREB) were introduced in soybean cultivars conferring drought tolerance, under controlled conditions and in the field the results were promising (Fuganti-Pagliarini et al., 2017). However, the genetically modified soybean that is commercialized has only resistance to herbicides and insects. There is no cultivar that presents tolerance to abiotic stress available in the world market (Ribichich et al., 2020).

However, scientists from various parts of the world are working to develop drought-tolerant soybean cultivars, a major obstacle is the production of the grain, as it is necessary that the crop yield remains stable even in water deficit, and the cultivars that are improved genetically, to tolerate drought, they end up having a considerable loss in production as a penalty. Plants that naturally evolved to survive drought show changes in physiological characteristics, such as stomatal closure. A large part of the genes being studied in model plants induce stomatal closure and increase plant survival, but on the other hand reduce biomass and seed production under moderate stress conditions, which is constantly found in field conditions. (Skirycz et al., 2011).

Reports in the scientific literature had their tests in a greenhouse, and few or none performed under field conditions. Chen et al. (2019) carried out a greenhouse experiment with soybean plants overexpressing the GmSYP24 gene, which is responsive to dehydration, showing insensitivity to drought and high salinity, through stomatal closure and involving an abscisic acid signaling pathway.

Among the transcription factors found in plants, homeodomain-leucine zipper (HD-Zip I)-like proteins are associated with environmental stress factors (Perotti, Ribone, & Chan 2017). Sunflower plants (*Helianthus annus* L.) have several divergent HD-Zip I members (Arce, Raineri, Capella, Cabello, & Chan, 2011). It can be highlighted HaHB4 (*Helianthus annus* HomeoBox4), the expression of this gene is highly induced through environmental factors such as drought, salinity and darkness (Manavella, Dezar, Ariel, & Drincovich, 2008). Tests of the HaHB4 gene in Arabdopsis have been shown to be effective in drought tolerance, through complex physiological mechanisms that do not involve stomate closure, but a plant response involving a decrease in ethylene sensitivity (Manavella et al., 2006). This gene was introduced into wheat and soybean plants. In wheat, HaHB4 conferred drought tolerance proven in 37 experiments under field conditions (González et al., 2019).

In soybean, different genetically modified strains with the 35S or HaHB4 promoter were obtained, multiplied and evaluated in field tests, together with a wild-type control, from these events the b10H event was selected. Under water deficit conditions, this event proved to be efficient, not reducing seed production, there was a decrease in seed weight but, on the other hand an increase in the number of seeds produced, as a result of an increase in crop biomass and pod biomass, combined with the greater number of branches and pods compared to the control. Some architectural and physiological features were observed in the b10H event, such as increased hypocotyl diameter and xylem area. In addition to different molecular pathways being altered (Ribichich et al., 2020).

Commercial varieties of soy from the b10H event are currently being developed by licensees of various technologies. Countries such as Argentina, Brazil and the United States, which represent 80% of global soy production, have already approved the event for production and consumption purposes (Ribichich et al., 2020). The event was supposed to be on the market between the years 2020-2021, but with the pandemic of the new coronavirus the event has not yet been commercially launched, but there are expectations that in the very near future it can be in the fields helping in the production of soybeans against drought.

To date, the only event that is already being marketed with drought tolerance is corn. This event expresses the bacterial RNA, Bacillus subtilis CspB and *Escherichia coli* CspA chaperones that confer tolerance to environmental stresses, such as water deficit, cold and heat. Several field tests with water restriction were carried out, and the event maintained a high production when compared to the control, there was a decrease in the weight of the grains, but to compensate the number of grains produced increased (Castiglioni et al., 2008).

An obstacle to the commercialization of these events is the long regulatory processes that genetically modified crops have to go through, having as an additional constraint for improved crops with tolerance to abiotic stress, the non-universal nature of abiotic stresses, which applies especially to water deficit, in which the effects can be apparent as a broad spectrum of alternatives derived from multiple combinations of growth stages, intensities and duration throughout the cycle (Tardieu, 2012).

There are few events marketed in the world, which have tolerance to environmental stresses, but there are many researchers who are searching to develop events related to this topic, with several scientific studies published, especially with the changes in the climate and intense droughts that have occurred over the years and tend to be intensified These events have incredible potential for the coming years, aiming to improve plant production in more arid parts of Brazil and the world, thus increasing food security, especially in poorer countries or states that suffer from intense droughts.

Biofortification

Studies show that 3 billion individuals suffer from micronutrient deficiencies or hidden hunger because their low income does not allow to buy or consume red meat, chicken, fruits, fish and vegetables in the proper amount. Among the micronutrients that are linked to public health problems in Brazil and in the world, iron, vitamin A and iodine, including calcium, zinc, selenium and copper, stand out (Izydorczyk et al., 2021). Furthermore, the United Nations Food and Agriculture Organization estimate that approximately 792.5 million people worldwide are malnourished, 780 million live in developing countries (McGuire, 2015).

The main foods produced and consumed by the population are poor in micronutrients essential for the growth and development of the human body. Food biofortification can be one of the effective solutions to alleviate this problem, through conventional or transgenic methods, developing cultures with higher micronutrient content and specific phytonutrients. The biofortification strategy is to ensure that foods that are preferred and have a high yield can contain nutrients and minerals that will supply the malnutrition of the poorest population (Saltzman et al., 2013; De Steur et al., 2015, Birol, Meenakshi, Oparinde, Perez, & Tomlins, 2015).

It is important to understand that biofortification can present three common approaches, which include agronomic, conventional and transgenic biofortification. Agronomic biofortification aims, through the application of fertilizers, for temporary increases in micronutrients. Through conventional plant breeding, biofortification can also be achieved, where parental lines with high levels of vitamins or minerals are chosen and are crossed for generations, producing plants with agronomic characteristics and desired nutrients. In the case of transgenic approaches, the nutrient does not exist naturally in the crop of interest or is present in low concentrations, and is synthesized or overexpressed, an example being pro-vitamin A in golden rice (Saltzaman et al., 2013).

Genetic engineering techniques can be used for the improvement of new cultivars, this technique uses an unlimited set of genes for the transfer and expression of desirable traits from one organism to another, which are evolutionary and taxonomically different (Malik & Maqbool, 2020). In this way, through genetic engineering, it is possible to introduce new genes, overexpress genes that the plant already has, downregulate certain genes or interrupt the pathway of inhibitory gene synthesis, in order to fortify a particular crop with a specific micronutrient (Perez-Massot et al., 2013). Transgenic crops are fundamental, especially when a plant, which has high consumption by a certain population, suffers from a lack of some micronutrient, making it possible to supply hidden hunger without making food more expensive.

Embrapa has developed some biofortified cultivars, through conventional breeding, mainly to serve the poorest regions of the country. It coordinates the BioFORT Network, which brings together all biofortification projects in Brazil, which aims to improve nutrition through school feeding programs and the supply of seeds and seedlings (Saltzman et al., 2013). This network was initiated by the HavestPlus project, which is financed by the Bill & Melinda Gates Foundation and the World Bank, among other contributors (Loureiro, Cunha, Nastaro, Pereira, & Nepomoceno, 2018).

Many countries are in the race to obtain the transgenic biofertilization of some plants, as is the case of the Golden Rice rich in vitamin A, which was first developed at the Swiss Federal Institute of Technology, research promoted by Syngenta, and passed on to the International Rice Research Institute (IRRI) in the Philippines (Saltzaman et al., 2013). As of 2006, some events have been backcrossed into varieties for the Philippines, Indonesia, India and Bangladesh (Beyer, 2010). Another variety of transgenic rice that was developed by IRRI in partnership with the University of Melbourne is iron-rich rice. Bioavailability testing is ongoing and launch is scheduled for around 2022 in Bangladesh and India (Johnson et al., 2011).

In staple crops such as rice, the engineering of anthocyanin biosynthesis can provide a biofortified rice, which will help to improve the health of the population because anthocyanins have a high antioxidant activity. Studies carried out in China, using a high-efficiency transgene stacking system, made a construction of eight anthocyanin-related genes driven by endosperm-specific promoters, in addition to a selectable marker and a gene for excision of the marker, generating a new germplasm of biofortified rice called "Rice with purple endosperm" having a high content of anthocyanins and antioxidant activity in the endosperm (Zhu et al., 2017).

Another cereal that has been studied is wheat, which is deficient in pro-vitamin A, iron and quality proteins. The provitamin A content increased through the expression of the bacterial PSY and carotene desaturase genes (Wang et al., 2014). The amount of iron was increased through the expression of the soy and wheat ferritin gene (Xiaoyan, Yan, & Shubin, 2012; Borg et al., 2012). For proteins such as essential amino acids lysine, methionine, cysteine and amount of tyrosine in wheat grains were elevated using the Amaranthus albumin gene, which is considered a weed (Tamás et al., 2009).

In some countries, cassava is one of the main foods, as it is easy to grow for the individual's own consumption and is rich in starch, however, it contains little protein, vitamins and nutrients such as iron, so the BioCassavaPlus (BC+) program created the genetically modified cassava that has increased levels of nutrients (zinc, iron, protein) and pro-vitamin A, in addition to longer shelf life, reduced cyanide levels and disease resistance (Sayre et al., 2011).

The Uganda National Agricultural Research Organization together with the Queensland University of Technology are developing transgenic bananas with high levels of provitamin A, through genetic engineering techniques, using suitable and well-characterized genes and promoters for targeted transgene expression, the forecast is that bananas with vitamin A will reach the field in 2021 (Paul et al., 2017). For more examples of plants biofortified through transgenics, consult the following references (Garg et al., 2018; Kumar, Muthujumaran, Sharmila, & Gurunatham, 2019).

In recent years, a lot of research has been carried out focusing on molecular studies on the content of amino acids and proteins of grains, value of the glycemic index, vitamins, minerals and their transporters, phytic acid, phenolic compounds and flavonoids, zinc and iron content. However, much research is needed for the commercialization of newly produced biofortified crops (Das, Adak, & Majumder, 2020). It is undeniable that biofortification will be increasingly present in daily food, by providing technology through the seeds of the main staple crops, it will probably be a great advantage to meet the nutritional need of poor populations at an affordable cost, especially in rural communities where the subsistence agriculture is performed.

One of the main problems of crops biofortified through transgenics is the release for commercialization, due to bureaucratic processes, an example is rice biofortified with provitamin A (Golden Rice), which was approved only after more than ten years fulfilling the requirements. In 2019, it was approved in the

Philippines for direct human consumption and for animal feed, after undergoing severe biosafety assessments by the Philippine Department of Agriculture (Malik & Maqbool, 2020).

Government agencies that are designated to carry out the release process for human consumption must review protocols so that unnecessary regulations that are based on the preconception that the population has towards GM foods are removed, so that more biofortified foods reach the table of thousands of undernourished people, especially in developing countries that are ravaged by hidden hunger.

Conclusion

Genetic improvement with the help of biotechnology is fundamental for the development of cultivars and microorganisms adapted to serve human interests, in tolerance to the new environmental conditions and realities that the field faces. The time of existence of organisms and the selection that took place throughout their existence is much longer than the beginning of agriculture and genetic improvement directed by man. Genetic modification shortens the existing disadvantage in this process, solving, in a shorter period of time, the challenges posed by the environmental modification that agriculture and the economic system promote. The cultivars that are being launched on the market are more efficient in the use of environmental resources, more productive and more nutritious, producing more per cultivated area and gradually improving the problem of hunger, which affects millions of people around the world. It is not enough to produce more food in smaller areas, but these foods need to be more nutritious. In addition, it is also essential to care for the soil, decontaminating it, so that it can be used for several generations. Environmental preservation is essential to maintain the water cycles of the world, and to maintain stability in agricultural productivity. There are still few works in the literature on the topics discussed in this study, and Brazil, in addition to having few examples to be cited, is fighting an ideological and often political fight over the release of organisms. Carrying out more research linking agricultural and environmental development with genetically modified organisms is an opportunity for the development of science and scientists in the country.

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