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Modern Biotechnology for Agricultural Development in Colombia

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Abstract

Colombia is currently one of the most promising countries with regard to its potential for agricultural development and for generating food supply for current and future human generations. This is owing to factors such as availability of land, water, topographical diversity, as well as political factors. Nevertheless, Colombia will reach this full potential if it adopts available technologies that can meet the current global challenges faced by the agriculture in the 21st century: among others, world population growth, increase in average life expectancy, high degree of malnutrition, climate change, wrong agricultural practices. Here is presented how modern biotechnology is an important ally as a wide range of technologies and innovative systems can be applied where they are most needed: for increasing cultivation productivity, resisting both biotic and abiotic factors, and ensuring food safety. In this study is showed evidence with regard to significant benefits of adopting biotechnological crops to contribute to food safety and how they are already being implemented in both developed and developing countries. Using modern technology, there are open opportunities for the country in search of circular bio-based economy, strengthen its food sovereignty and to serve as an agricultural breadbasket to Latin America and the World.

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Keywords: Agricultural challenges; biotech crops; Crop Production; food security; genetically modified crops; sustainable development; transgenic plants.

Biotecnología Moderna para el Desarrollo de la Agricultura en Colombia

Resumen
Colombia es actualmente uno de los países más prometedores en cuanto a su potencial para el desarrollo agrícola y para generar alimentos para las generaciones humanas actuales y futuras. Esto se debe a factores como la disponibilidad de tierra, agua, diversidad topográfica, así como a factores políticos. Sin embargo, Colombia alcanzará su pleno potencial de desarrollo agrícola sostenible si adopta las tecnologías disponibles que puedan hacer frente a los desafíos globales actuales que enfrenta la agricultura en el siglo XXI: entre otros, el crecimiento de la población mundial, el incremento en el promedio de la esperanza de vida, alto grado de desnutrición, cambio climático, uso de practicas agrícolas equivocadas. Aquí es presentado cómo la biotecnología moderna es un aliado importante ya que se puede aplicar una amplia gama de tecnologías y sistemas innovadores donde más se necesitan: aumentar la productividad y sostenibilidad del cultivo, resistir los factores de estrés bióticos y abióticos y garantizar la seguridad alimentaria. En este estudio se muestra evidencia sobre los beneficios significativos de la adopción de cultivos biotecnológicos para contribuir a la inocuidad de los alimentos y como ellos ya se están implementando en los países desarrollados y en vía de desarrollo. Usando tecnologías modernas, hay oportunidades abiertas para el país en la búsqueda de una economía circular de base biológica, que fortalezca su soberanía alimentaria y para servir como despensa agrícola para América Latina y el mundo.

Palabras clave: Cultivos biotecnológicos; cultivos genéticamente modificados; cultivos transgénicos; desafíos agrícolas; desarrollo sostenible; producción de los cultivos; seguridad alimentaria.

1 Introduction

In 2009, the Food and Agriculture Organization of the United Nations (FAO) identified the following as the greatest global challenges currently facing the agricultural sector: 1) production of more food and fiber with a smaller labor force to feed a growing population; 2) production of more raw materials for a potentially enormous bioenergy market (potential for alternative energy production); 3) contribution to the global development of numerous countries currently undergoing development, which are dependent on agriculture; 4) adoption of more effective and sustainable production methods; and 5) adaptation to climate change [1]. These challenges must be taken into account in Colombia as it initiates agricultural development in the present century by considering the following factors that provide opportunities for the country's development: first, Colombia is one of the seven countries with the potential to become "agricultural breadbaskets" for the world [2]; second, the political scenario in Colombia is favorable for growth because a peace accord has been signed by the government and the Revolutionary Armed Forces of Colombia (FARC), thus putting an end to more than 50 years of conflict [3], and the government, along with the FARC, has established important basic rules for rural and agricultural development [4]; and third, the results of the most recent Agricultural Census conducted in the country are favorable [5].

The measures that must be adopted to face the challenges described above must permit a growth in the sustainability, productivity, and resilience of agriculture in Colombia, and a great deal of effort must be made in and priority must be given to research and development. Otherwise, food production in the country and regions that are already facing a great deal of food insecurity will be seriously compromised [2]. The current paper presents a brief overview of the challenges that have been identified for the agricultural sector in the 21st century and demonstrates why modern biotechnology, which can help develop technological alternatives for the agricultural sector in Colombia, is considered an important ally for facing these challenges.

2 Greatest challenges for agriculture in the 21st century

2.1 A growing world population

Projections for the growth of the world population have revealed that by 2050, the total number of people worldwide will surpass 9 billion, a number that will have increased to 10.9 billion by 2100 [1], with Africa and Asia being the continents expected to have the highest density of people. In addition, the average life expectancy has substantially increased over the last few decades, from 46 years in 1840 to 85 years in 2000 [6], with an average of a 4-month increase in each year. This is especially true of the life expectancy of women and is a direct result of the contributions made by advances in science and technology toward the reduction of mortality, thereby extending the average human life expectancy [7]. As a result of such advances the World is facing other challenges such as accommodating more people, living longer, a growing need for food resources and demanding better nutritious and diverse diets.

In conjunction with the growing number and increasing life expectancy of the world population, the degree of malnutrition known to exist in many countries must also be considered. It is estimated that malnutrition currently affects 13 of every 100 people worldwide, resulting in an estimated total of 1 billion people currently suffering from malnutrition, 143 million of whom are children aged under 5 years who are critically affected [2]. These statistics are also observed in Colombia, where 4% to 14% of the population is at a moderate risk of malnutrition [8],[9].

Considering the population factor alone (without considering life expectancy), the projections show that to feed a world population of 9.1 billion people in 2050, food production must be increased by 70% between the present and that year [1], a challenge that would undoubtedly involve the use of more land areas. For example, the annual grain production would have to increase by almost 1 billion tons, not to mention the quantum leap that would be necessary in meat production, involving more than 200 million tons, which would allow a constant production and securing of approximately 470 million tons of meat by 2050 [1].

2.2 Availability of land suitable for agriculture

With a growing world population, increasing average life expectancy, and significant levels of malnutrition, one potential solution might be to simply plant more crops on larger land areas. However, studies have indicated that the available land that is suitable for agriculture is not unlimited. According to FAO [2], approximately 1.6 billion hectares (ha) were available for cultivation in 2016, whereas projections have indicated that the total area of land available for cultivating agricultural crops in 2050 is estimated to be 1.68 billion ha, representing only a 5% increase in land availability, this due to several aspects, for instance dietary changes in favor of vegetable food and less land-demanding meat as well as faster growth in livestock productivity [10],[11]. Contrasting the two growth rates (i.e., those of world population and land availability for agriculture) projected for 2050, a significant difference may be observed because land available for agriculture will grow by 5%, whereas the human population will grow by 21.3%. This reality leads to an even greater challenge of achieving food security, with the understanding that the requirement for more food may not be satisfied by political-economic strategies, which aim to simply increase the land area currently available for agriculture.

2.3 Climate change

Another important challenge facing humanity and agriculture is climate change. The Fifth Report of the Intergovernmental Panel on Climate Change (IPCC) has indicated that global climate change is currently occurring, caused by the increase in greenhouse gases, originating principally from human activities, such as the wide usage of fossil fuels (petroleum, natural gas, or coal), the decomposition of urban and livestock waste, and changes in land usage [12]. Although climate change is a relatively slow process, change in land usage is a process that may contribute drastically to the phenomenon, i.e., it occurs much more quickly and may therefore have damaging effects on ecosystems and environmental processes [11].

One-fifth of the Earth's surface is occupied by mountain ecosystems that support biodiversity on land and supply water to more than half of the planet, a factor that helps protect and preserve the world's natural resources [13]. The high degree of biological diversity, agrobiodiversity, and endemism; the large reserves of organic carbon in the soil; the provision of water for energy and agriculture; minerals; and general materials required for urban use all originate from high mountain ecosystems [14],[15],[16]. However, these ecosystems are considered to be one of the most fragile ecosystems on Earth due to their high vulnerability and low capacity for recovery [13],[16]. These considerations create a discouraging scenario for the sustainability of human activities, including agriculture.

Therefore, agriculture is considered to be "threatened" or "pressured" by large-scale climate change because this change directly affects the frequency of meteorological phenomena, modalities of agricultural production, and spread of pests and pathogens [17],[18], resulting in severe consequences in areas experiencing serious problems of malnutrition, where poverty is abundant and capacity for adaptation is reduced [12].

However, as described in the above paragraph, although agriculture is a "passive" subject that experiences the consequences of climate change, it is undoubtedly, at the same time, an "active" subject that positively contributes to global warming because of the routine activities of agriculture. Agriculture directly favors global warming by its use of machinery and products that are mostly composed of chemicals derived from petroleum, thus accounting for up to 15% of CO2 emissions. In particular, agricultural sector generates direct greenhouse gases emissions through nitrous oxide emissions from soils, applications of fertilizers, dejections from grazing animals, methane production by ruminant animals [19]. In addition, agriculture indirectly favors global warming because the lack of land suitable for cultivation drives humans to resort to the destruction of forests reserved for conservation, thus indirectly contributing to CO2 emissions by almost 26% [18].

3 Colombia: An agricultural breadbasket for the world

The most recent Agricultural Census conducted in Colombia began its activities in 2014 and concluded its work with the 30th report published in 2016 [5]. This census covered 98.9% of the territory and included 32 analyzed departments. In total, 773 indigenous reserves, 181 territories belonging to communities of African descent, and all 56 National Nature Parks were investigated by an army of 25,000 people who participated as census officers [5]. This census allowed the government to identify the distribution and main use of the 111.5 million ha that comprise the total land area of continental Colombia (equivalent to 1,115,000 km2) [20]. According to the report by DANE [5], 56.7% of the total area of continental Colombia is reserved as forest reserves (corresponding to 63.2 million ha), 38.6% is reserved for agricultural and livestock purposes (corresponding to 43.1 million ha), and 2.2% (equal to 2.5 million ha) is reserved for usage other than as forest reserves or for agriculture/livestock purposes. Although these numbers reflect a significant usage of land in Colombia for agriculture, upon greater scrutiny, the census revealed that only 7.1 million of the total 43.1 million ha is suitable or reserved for the cultivation of food crops (equivalent to 6.3% of the total national land area) and that the remaining 34.4 million ha is reserved for animal feeding (Figure 1), an activity that is globally considered to be a critical factor for environmental problems because livestock contributes approximately 14.5% of all greenhouse gas emissions, increases soil degradation, contaminates water and air, and leads to a decline in regional biodiversity [21],[22]. This fact illustrates the necessity to correct the gap in the current distribution of land and thus regain an equilibrium in production (Table 1). This is undoubtedly an important opportunity for the growth of agricultural production in the country, which has been identified by the rest of the world [23].

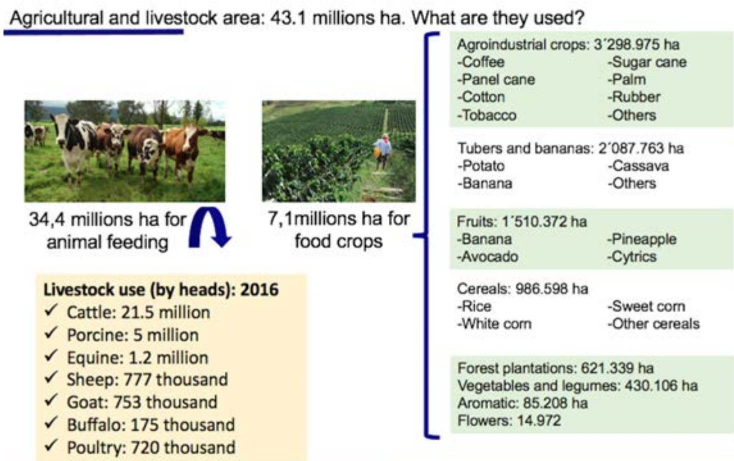

Figure 1: Current use of the 43.1 million hectares (ha) in Colombia suitable for agriculture.

Colombia is characterized by its vast diversity in climate and life forms (biodiversity) [20], which is directly related to its location in the intertropical equatorial zone, more specifically in the northwestern corner of South America (at the convergence of Central America, South America, and the costal zones of both the Caribbean and the Pacific Ocean). In addition, the continental territory includes diverse altitudinal ranges due to topographical aspects, such as the three ranges into which the Andes range separates at the Colombian Massif, formations such as the Sierra Nevada of Santa Marta and the Serrania de la Macarena, the presence of inter-Andean valleys, and the vast extensions of planes and tropical rainforests in the south and west of the country [20]. Despite such diversity in climate and topography, an agricultural "X-ray" shows little diversity in the crops being produced, only seven of which are widely used and consumed within the countries (coffee, panel cane, sugar cane, cotton, tobacco, palm, rubber), most of these being agroindustrial crops [5].

Table 1: Distribution and land use in Colombia: Contrast between the rural agriculture and livestock plan for territorial organization (UPRA) and data from 2014-2016 census.

Ideal land distribution: UPRA	Land distribution: 2016 Census
58% Conservation zones	56.7% Conservation zones
16% Agroforest	0.0002% Agroforest
13% Agriculture	5.8% Agriculture
7% Livestock	30.9% Livestock
3% Forest	0.5% Forest
2% Bodies of water	2% Bodies of water
0.2% Establishment of urban zones	0.3% Establishment of urban zones

4 Agriculture: A development strategy for Colombia

The promotion of agriculture as a development strategy for a country such as Colombia is undoubtedly a key factor for achieving food security. Therefore, the following four areas must be prioritized in an agricultural development plan: increasing agricultural research, enhancing the access of each person to food, improving governmental policies for commercialization of food products, and increasing productivity while preserving natural resources [24]. In other words, it is fundamental that agricultural productivity be increased without expanding the agricultural frontier [3].

With the world's attention on Colombia, a country in which agriculture is considered as a strategy for economic and social development, the identification and engagement of the weak links (needs) must be prioritized to seek sustainable agricultural development in Colombian. A list of such factors that are currently preventing agricultural development in Colombia is as follows: poor (without nutrients) or contaminated soils, plants that are fragile or unable to adapt to inclement changes in climate, seeds and plants that are not resistant to biotic factors (plagues and pathogens), crops with a low level of productivity, low availability of fertilizers, inadequate irrigation systems, absence of climatic modeling, use of high-tech equipment that is not appropriate for the topographical characteristics of the country, lack of innovation in the post-harvest techniques, scarcity of routes for efficiently transporting the food to collection points, and excessive market intermediation, among other factors [25],[26].

5 Humankind and biotechnology

In view of all the challenges facing the agricultural sector in Colombia, which are the same as those facing the entire globe, how might it be possible to transform the country into a global agricultural breadbasket? Although the answer is not simple, one must envision the qualities that 21st century agricultural crops must possess. They must be resistant to pathogens and pests, easily adaptable to abiotic stress, possess higher nutritional value, and demonstrate a high yield potential to feed a growing human population using the same currently available area of arable land [27]. However, how can this be achieved? Although the answer is not simple, modern biotechnology can be considered an important ally.

The term "biotechnology" is derived from two single words: biology and technology [28]. Article 2 of the agreement concerning biological diversity defines biotechnology as "any technological application that uses biological systems and living organisms or their derivatives for the creation or modification of products or processes for specific uses" [29]. Beyond this definition, the concept of biotechnology has acquired a great deal of importance in the development of science in the last two decades, and perhaps, as a result, the term appears to have originated recently. Most people are unaware that in reality, the beginnings of such technology are to be found at the inception of agriculture, beginning with the use of biodiversity [30].

To clearly illustrate what is explained in the above paragraph, one must take a brief tour of human history. As sufficiently dealt with by Wieczorek and Wright [30] in their report, it is estimated that approximately 10,000 years B.C., humans first began cultivating their food using the naturally existing biodiversity as a starting point and eventually domesticating both crops and animals. During the process of domestication, people selected the best plants for propagation as well as the best animals for reproduction (breeding), with the clear intention of improving their products. Over several thousand years, the inclusion of desirable characteristics in the cultivar has allowed them to circumvent inclement climates, increase their resistance to pests and disease-causing pathogens, and improve productivity and nutritional value, among other achievements. Continuing the narrative, Verma et al [28] has described how after the domestication of crops (plants) and wild animals, humans began to make other discoveries, such as cheese and curd, which may perhaps be considered the first biotechnological developments because of the fact that enzymes originating from the stomach of a calf are added to sour milk, a process that at the time was not completely understood. Similarly, yeast is one of the earliest-used microbes that humans have exploited for their own benefit. Development of food products, such as bread, vinegar, and other fermentation products (including the production of alcoholic beverages, such as whisky, wine and beer), have been made possible by the use of microorganisms. Despite this long history, it was only in 1919 that the term "biotechnology" was first used by Karl Ereky, who applied it to define the interaction between biology and technology [31]. Since then, the term has been redefined on various occasions.

However, the most important event occurred in 1953, when Watson and Crick [32] reported the structure and function of DNA, the molecule considered to be the basis of life and of the function of cells and living beings, knowledge that is essential for scientific developments. As a result of their memorable contribution and of Kary Mullis's development that enabled the amplification of DNA in a test tube (polymerase chain reaction) [33], research in biological sciences was revolutionized and the foundations were laid so that in the 1970s, what we know today as modern biotechnology could emerge, involving the utilization of recombinant microorganisms for manufacturing highly valued proteins and peptides for biopharmaceutical applications [34]. Today, the potential of modern biotechnology is widely known, which makes use of recombinant DNA technology to genetically modify microorganisms, plants, and animals, with the goal of making them more suitable for a myriad of potential applications [35],[36], including improved agricultural products [37], the production of new antibiotics and hormones [38], [39], xenotransplantation [40], gene therapy [41], bioremediation [42], and the most recent technique: genome editing [43]. As a result of all this potential, it has generated a protocol to guarantee adequate protection in the sphere of activities involving the safe transference, manipulation, and utilization of living organisms modified using modern biotechnology, which may have adverse effects on the conservation and sustainable use of biological diversity [36]. It also takes into account human health risks, focusing especially on movement across borders.

6 Use of biotechnology for agricultural innovation

Since 1999, the FAO has issued advice concerning the benefits of biotechnology in agriculture for increasing the supply of food and alleviating hunger by withstanding adverse biotic and abiotic conditions [44]. Increasing crop productivity will depend on the use of technological tools, such as biotechnology [45]. Agricultural biotechnologies, encompassing the use of molecular markers, reproductive technologies, cryopreservation, and genetic engineering, play a fundamental role in the characterization, conservation, and improvement of crops, animals, forests, and microbe resources in both soil and water; they are currently being used in developed and developing countries to improve agriculture and contribute to food security [45],[46].

Considering the above information and the report by FAO [23], biotechnology can contribute in various developmental aspects of the agricultural sector. Because of the impoverishment and degradation of soil due to overplanting, we have fallen in significant challenges around water, nutrients and climate, which directly or indirectly affect crop production, due to plants are facing increasing biotic and abiotic stress, thus diminishing their productivity [47]. As a result, it is necessary to develop plants that are capable of resisting such living organisms (biotic stress), such as microbes causing plagues, pathogens, and undesirable plants [48], as well as of withstanding adverse environmental conditions, such as salinity, climate, and heavy metals, among other factors (abiotic stress) [49] (Figure 2).

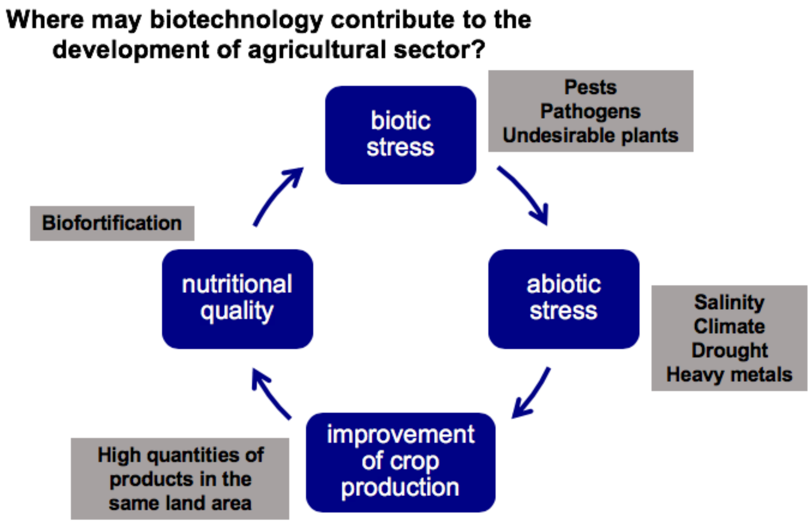

Figure 2: Factors for which biotechnology may contribute to the development of the agricultural sector.

The last factor seen in Figure 2 is especially relevant given the current context in Colombia. According to the data reported by Cordy et al. [50], Antioquia and Colombia are the greatest global mercury polluters per capita in the realm of small-scale gold mining. Another area in which biotechnology may contribute to the development of the agricultural sector in Colombia is the improvement of crop production. Given the context described earlier involving a growing global population and limited availability of agricultural lands, it is necessary to develop seeds capable of producing high quantities of products (such as fruit, seeds, and biomass) in the same currently available land area, thereby reducing the impact on environment, a process described by the term "sustainable intensification" [51]. A final factor that is relevant in the development of the agricultural sector and is related to food security is the essential nutritional value [37]. The potential of biotechnology to add nutritional value to food crops by means of enrichment with quality proteins, vitamins, iron, zinc, cerotenoids, antocyanins, etc. Datta [52] would undoubtedly contribute categorically to the achievement of food safety. It is important to highlight that traditional plant breeding is time-consuming and requires extensive screening of large germplasm collections. In contrast, genome editing (GE) tools (modern biotechnology) (i) provide a precise means to alter just a few nucleotides, (ii) can be used to replace/modify a pre-existing allele with another orthologous one derived from wild/landrace progenitors, and (iii) enable the insertion of a new gene(s) into pre-determined regions of the genome [53].

Table 2: Biotechnologies that may contribute to the development of the agricultural sector.

Agricultural challenge	Biotechnologies
New cultivars	Technology based on cultivation of tissues Mutagenesis Genetic modification Interspecific hybridization
Selection and screening	Marker-assisted selection Improvement assisted by genomics
Production and management of agricultural systems	Micropropagation Diagnosis of diseases Bioprotection (Biopesticides) Vegetable nutrition (Biofertilizers)

In Table 2 and according to the data reported by FAO [46], one may consider the biotechnologies that provides solutions to the agricultural challenges and consequently lead to the development of this sector in Colombia. The table presents, in a clear and condensed manner, the way in which various biotechnologies may contribute solutions to the challenges currently faced in the agricultural sector. These include the following: the induction of genetic variations in crops by directed mutagenesis; development of new varieties of vegetables (using genetic engineering and genome editing techniques), generation of interspecific crossings; selection of promising crops with the assistance of modern molecular markers that also allow one to perform improvements assisted by genomics; generation of massive propagation systems that allow the use of vegetable material free from endogenous contamination caused by microorganisms; early diagnosis of pathogens that allows for efficient and precise use of tools and pathogen-control, environmentally friendly products; development of bioproducts that control plagues and disease-causing pathogens; development of formulations based on microbe complexes that permit the fixation of essential plant elements

(P and N, among others); and finally (but not of least importance), conservation of the germplasm of the genetic varieties, allowing access to sources of genetic material for future development (improvement programs).

According to the FAO, since humans began to engage in agriculture (approximately 11,000 years ago), approximately 7000 different species of plants have been cultivated, but today, only 30 crops are intensively used, fulfilling approximately 90% of the energetic food needs of the global population [54]. This clearly indicates the genetic erosion that has been caused by traditional agricultural practices e.g. the plow. mechanization and industrialization (dependence on fossil fuels) and chemical fertilizers-intensive methods. Fortunately, different research centers have been putting germplasm conservation plans into practice, for which biotechnology is a fundamental aspect [55]. In Colombia, International Tropical Agricultural Center (CIAT) maintains more than 36 thousand bean accessions, 6.5 thousand cassava accessions, and 23 thousand fodder accessions [56].

7 Biotechnological agricultural crops worldwide

Biologists have been using genetic engineering since the 1980s to express new characteristics in agricultural crops [57] and could secure approval for the commercial release of the first biotechnological crop in 1996. The year 2015 marked the 20th anniversary (1996–2015) of the commercialization of this type of crop, also known as genetically modified (GM) or transgenic crops, now commonly referred to as "biotech crops." In a more recent publication published during the first week of May of 2017, the International Service for the Acquisition of Agro-Biotech Applications (ISAAA) [58] reported that in 2016, 185.1 million ha of biotech crops were planted [58]. To better appreciate the dimensions of this area, one must keep in mind that 185.1 million ha is equivalent to 20% of the total land area of China (total area of China: 956 million ha) or the United States (total area of United States: 956 million ha) and is also equivalent to 1.6 times the total area of Colombia (total area of Colombia: 111.5 million ha). A total of 26 countries, seven of which are considered as developed and 17 are considered as developing, had adopted and planted biotech crops as of 2016. The top five countries in the list of biotech crop producers are as follows: the country with the largest planted area of biotech crops was the United States (72.9

million ha), followed by Brazil (49.1 million ha), Argentina (23.8 million ha), Canada (11.6 million ha), and India (10.8 million ha) [58]. Likewise, there are many reports on crops that have been genetically altered for different characteristics, such as increase in grain production during drought for maize [59], increase in grain production for rice [60], and resistance in wheat against disease- causing fungi [61].

Despite worldwide adoption of biotech crops and the great potential of biotechnology as a tool for developing the global agricultural sector and promoting food security, the claims concerning the positive and negative effects of existing biotech crops are many. Scientific studies concerning the agronomic, economic, and environmental impact of biotech crops have been conducted, demonstrating benefits that are wide-ranging, positive, and significant, and center on an increase in agricultural productivity and a reduction in the use of products of chemical origin, resulting in a lesser impact on the environment and substantial decrease in greenhouse gas emissions [62],[63],[64].

Accordingly and as a result of the worldwide adoption of these crops during the last two decades, the National Academy of Science conducted a wide-ranging study that compiled and extensively reviewed all scientific research conducted globally during the last 20 years, with the aim of verifying the problems (negative claims) and evaluating any direct relationships to the use and the adoption of biotech crops [57]. This study reported that there is no conclusive evidence linking biotech crops to environmental problems in a cause–effect relationship. The conclusions were overwhelming, keeping in mind certain factors, such as the decline in the genetic diversity of agricultural crops due to factors, such as monetary reasons (the price of the crops and their production), that cause the grower to avoid crop rotation; however, no direct consequence was found involving the wide adoption of biotech crops after their global adoption in 1996.

In addition, the National Academies of Sciences-Engineering-Medicine [57] also reported the results of experiments comparing foods derived from biotech crops currently on the market and foods derived from non-GM crops ; these analyses were based on composition, acute and chronic toxicity tests in animals, long-term data involving the health of evaluated animal models that had been fed with transgenic foods, and epidemiological data. The results of these analyses concluded that no difference exist in terms of risks to the security of human health between GM foods and their conventional, non-GM counterparts. This proposed conclusion cautiously took into account the fact that any food, whether GM or non-GN, may exhibit minimal effects considered favorable or adverse to human health, which may not have been detected despite the exhaustive nature of the research conducted. It also took into account that the effects on health may develop over time.

7.1 Colombia: Biotech agricultural crops planted on a commercial scale

According to the data reported by the Colombian Agricultural and Livestock Institute [65] and published by Agro-Bio [66], Colombia joined the list of countries that adopted biotech crops in 2002 (approved in this country since 2000), initially with the planting of blue carnations. In Colombia the use of GM cotton was approved in 2003, and maize was approved for planting under a controlled planning scheme in 2007. More recently, at the end of 2009, Colombia approved the commercial planting of GM blue roses. This evolution of the adoption of biotechnology for use in agriculture has made Colombia one of 26 countries that have adopted biotech crops as a tool for meeting the challenges currently faced in agriculture, and since 2010 it has been one of 19 mega-countries that has plant 50 thousand ha or more of biotech crops [58].

In 2017 alone, Colombia planted 110,000 ha of biotech crops, 100,000 ha of which were GM maize planted in 23 departments (equivalent to 22% of the total maize planted in the country), where Meta, Córdoba and Tolima were the departments of Colombia with highest biotech maize plantation. On the other hand, 9,800 ha of GM cotton planted in six departments of the country (equivalent to 97% of the total cotton planted in the country), and 12 ha of GM blue carnations (under greenhouse conditions) in the department of Cundinamarca [66] (Figure 3). It was observed that Tolima, Córdoba, and Valle del Cauca (in that order) were the departments of Colombia that had highest biotech cotton plantation.

Figure 3: Hectares planted with biotech crops (maize, cotton, and blue flowers) in Colombia during 2017. Adapted from Agro-Bio [66].

7.2 Colombia: Research for developing biotech agricultural crops

Table 3 presents the current state of the institutions authorized to conduct research for developing agricultural crops using modern biotechnological techniques, along with their respective level of authorization (laboratory, biosecurity greenhouse, and field under confined conditions). The source used for collecting this information was the report by Chaparro-Giraldo [67], corroborated and updated using information from the ICA database [65], in which the resolutions issued by the institution are recorded. In addition to the information contained in Table 3, here is also presented: Agrosavia (before CORPOICA) conducts research on peas and cotton on the laboratory scale; the Universidad de Antioquia conducts research on stevia, also on the laboratory scale; and the Pontificia Universidad Javeriana conducts studies on the passion flower. It must be noted that it was not possible to find the authorization resolutions in the ICA database [65] for the information described for these last three entities.

Thus, the importance of biotechnology in Colombia as a tool for conducting development and innovation in the agricultural sector is demonstrated. In addition to the adoption of the commercial biotech crops described above, various stages of advances (under laboratory, greenhouse or experimental field conditions) have been made in the agricultural crops sugarcane, cassava, rice, potatoes, coffee, tobacco, sacha inchi, castor bean, soybean, maize, pea, cotton, and stevia, which certainly will be on the market in the country for mid-term and therefore on the map of biotechnological countries in the world.

Table 3: Institutions in Colombia authorized by the Instituto Colombiano Agropecuario (ICA) to conduct research in the development of biotech agricultural crops. All phases (at level of laboratory, greenhouse and field) under controlled conditions.

Institution	Resolution (ICA)	Research phase	Crop
CENICAÑA	3402 (16/11/2001) 2508 (15/09/2003) 3995 (23/12/2005)	Laboratory Greenhouse Field	Sugar Cane
CIAT	3854 (16/12/2005) 3855 (16/12/2005) 3856 (16/12/2005) 858 (18/03/2008) 4041 (06/12/2010)	Laboratory Greenhouse Field	Cassava Rice
CIB	1628 (18/05/2010) 4040 (06/12/2010)	Laboratory Greenhouse Field	Potato
CENICAFE	2186 (31/08/2000) 2492 (26/07/2010)	Laboratory Greenhouse	Coffee Tobacco
EAFIT UNIV.	4310 (15/12/2014) 4011 (14/04/2016)	Laboratory	Sacha inchi Castor bean Potato
UNAL	3523 (14/10/2008)	Laboratory	Rice Potato Soybean Maize

8 Conclusions

As described in this article, Colombia is experiencing a post-agreement political scenario, a scenario of peace, which has provided new opportunities for the country looking forward to pursue a circular bio-based economy, strengthen its food sovereignty and why not function as an agricultural breadbasket to serve Latin America and the world. This opportunity is supported by the amount of land available in Colombia for agriculture, it strategic location (the tropics), and the availability of water, among many other natural resources. However, this can occur only if competent technologies are adopted, which allow farming and agriculture to face the challenges (growing world population, increasing life expectancy, climate change, and limited lands available for planting at other latitudes in the world) in sustainable agricultural development in the 21st century. This is where modern biotechnology presents itself as the principal tool for facing the challenges described above, thereby generating alternative technologies for developing the agricultural sector in Colombia, aiming to increase the productivity, sustainability, and resilience of crops. The positive and significant benefits of adopting biotech crops to achieve food security with respect to natural resources (sustainable development of agriculture) have been scientifically verified, models of which have been implemented by developed and developing countries. It is everyone's responsibility to not compromise food production in the country and its regions as well as to contribute to the desired food security of the entire world.

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