P. ISSN: 0971-8184 II E. ISSN: 0976-1926
DOI: 10.61949/0976-1926.2025.v38i03.03

Indian Journal of Plant Genetic Resources

REVIEW ARTICLE

GMOs and Native Crops in Bolivia: Navigating Biotechnology for Food Security and Sustainable Development

Cecilia González*

Abstract

Bolivia, a mega-diverse country with significant agricultural potential, faces systemic challenges that hinder the full utilization of its biodiversity for food security and economic development. This paper explores how biotechnology, particularly genetically modified organisms (GMOs), can address Bolivia's agricultural productivity constraints while preserving its native crops. Despite the demonstrated benefits of biotech crops-such as increased yields, reduced pesticide use, and economic gains-Bolivia's outdated regulatory framework and restrictive policies limit the expansion of genetically modified (GM) technology. Additionally, native crops and their wild relatives hold enormous untapped genetic potential for improving food resilience, yet they remain underutilized due to insufficient research and policy support. By modernizing biosafety regulations, strengthening scientific research, and promoting informed public discourse, Bolivia can leverage biotechnology to enhance food sovereignty and agricultural sustainability. The paper highlights the necessity of a balanced approach that integrates scientific innovation with environmental and socio-economic considerations to ensure long-term agricultural growth.

Keywords: Biotechnology, Genetically modified organisms, Biosafety regulation, Native crops, Food security.

Calle 6 #737, Obrajes. La Paz, Bolivia, South America.

***Author for correspondence:**

ceckis@gmx.net

Received: 26/04/2024 **Revised:** 24/04/2025

Accepted: 20/08/2025

How to cite this article: González C. (2025). GMOs and Native Crops in Bolivia: Navigating Biotechnology for Food Security and Sustainable Development. *Indian J. Plant Genet. Resour*. 38(3), 277-286. **DOI:** 10.61949/0976-1926.2025.v38i03.03

Introduction

The Plurinational State of Bolivia is a part of the eight mega-diverse countries in the world. However, the national strategy does not effectively utilize this biodiversity to achieve a sustainable model. With 11,312,620 inhabitants, its territory is the sixth largest in Latin America. Bolivia has one of the smaller growth domestic products (GDPs) in Latin America, with a 2023 GDP of around USD 45 billion, placing it towards the bottom of the regional ranking. About 36.4% of the population is below the poverty line in 2024, and its per capita income was estimated at around USD 3,919 in 2024(IMF, n.d.). In the last two decades Bolivia has become a major exporter of natural gas (28% of total exports). Other exports include gold (18%), zinc (12%), silver (9%), and soybeans and related products (11%) (Trading Economics, n.d.).

Brief Overview of Bolivia's Agricultural Landscape

Bolivian agriculture, contributing 11-15% to the GDP and employing many, faces significant challenges. Climate change severely impacts this vulnerable sector, demanding investment for adaptation and resilience to ensure food security. Obstacles include fuel shortages, roadblocks, land grabbing, smuggling, and biotechnology restrictions, all hindering productivity and competitiveness. These long-standing issues, exacerbated by inadequate government support and ineffective policies, threaten the collapse of food production unless immediate action is taken to address the structural problems. A recent report highlights a 17% drop in agricultural production in 2024 (Los Tiempos, 2024), which is a matter of significant concern regarding the long-term sustainability of agricultural productivity in Bolivia.

By 2023, according to Ministry of Rural Development and Lands (MDRyT) data, soybean production reached 3,761,881 tons, with a cultivated area of 1,787,185 hectares, which represents a growth of 8.8% and 17.2% over the previous year (MDRyT, 2024). The main buyers of this production are: Peru (40%), Colombia (39%), Ecuador (12%), and Chile (5%).

Soybeans have become the largest export for both Brazil and its neighbouring country, Argentina. Additionally, Paraguay and Bolivia rank among the top 10 global producers in a market valued at USD 155 billion. In 2022/23 Bolivia cultivated approximately 1.82 million ha of genetically modified (GM) soybean (https://www.statista.com/statistics/957549/bolivia-soy-cultivated-area/) and soybean production reached 3.67 million tonnes (https://www.statista.com/statistics/874054/soybean-production-volume-bolivia/)

Importance of Biotechnology in Addressing Agricultural Challenges

Genetically modified (GM) crops offer several potential benefits for agriculture and food security, but they are not a single solution to all challenges. In Bolivia, where agriculture faces numerous systemic challenges, GM crops could contribute to enhancing productivity and resilience. However, it is crucial to consider both the potential benefits and limitations.

Increased crop yields

Genetic engineering can enhance crop yields, which is particularly important in Bolivia, where agricultural productivity is constrained by various factors. For example, the adoption of biotech soybeans in Bolivia has been associated with a 200,000 ton increase in production per year (National Geographic, n.d.).

Pest and disease resistance

GM crops can be engineered to resist pests and diseases, reducing the need for pesticides. This is significant in Bolivia, where reliance on pesticides can be costly and harmful to the environment. The adoption of insect-resistant biotech soybeans in Bolivia has led to reduced insecticide use (Brookes, 2022a).

Herbicide tolerance

GM crops can be engineered to tolerate herbicides, allowing farmers to control weeds more effectively without harming crops. This can lead to reduced tillage, which helps maintain soil health, reduces fuel use, and saves labour (Brookes, 2022a).

Adaptation to environmental conditions

GM crops can be engineered to better tolerate environmental challenges, such as drought. In the 2023-2024 summer seasons, 1,907,000 tonnes of soybeans, corn, and sorghum were produced in Bolivia. This represents a 34% decrease from the previous summer. In winter, there was a drop of 64% compared to the winter of 2023 (Nueva Economía, 2024). GM crops could provide better resilience to such events.

Economic gains

The adoption of GM crops can lead to economic gains for farmers. In Bolivia, biotech soybeans have saved money on insecticide use and increased production, generating an estimated USD 776 million in economic gains from 2008 to 2016 and USD 54 million in 2016 alone (Brookes, 2022b).

Although these explanations have been presented multiple times to policymakers, the adoption of GM seeds and the development of biotechnology research programs are still lacking, failing to address Bolivia's challenges and demands in a timely manner.

The GMO Landscape in Bolivia

Bolivia's experience with biotech soybeans

Since 2008, Bolivian farmers have cultivated the biotech soybean event GTS 40-3-2, which remained the only approved soybean variety in the country until 2024. Despite a severe drought in 2017, Bolivia's biotech soybean adoption rate reached 100% that year (ISAAA, 2017). The adoption of GM soy in Bolivia has led to several benefits, primarily through increased production, reduced production costs, and enhanced export revenues (IBCE and Guanella, 2016).

Benefits to the agro-industrial sector

The agro-industrial sector sees benefits in the form of increased value added in the oil industry. With increased soy production and milling, the value added to the industry could be around USD 15 million. The transport sector would also see an increase in revenues due to the increased need to transport the additional production; for example, the transport sector could generate an additional USD 3 million in revenues due to the need to transport an additional 10,000 truckloads of product.

Reduced environmental impact

The use of biotech soy has led to a reduction in the use of agrochemicals. This reduction in the use of agrochemicals has led to a reduction in the emission of carbon dioxide and the use of water. It is estimated that this could lead to a reduction of more than 7,000 tonnes of carbon dioxide emissions, equivalent to removing 3,200 cars from the road. Also, there would be a saving of almost 120 million litres of water, equivalent to the water consumption of approximately 1,200 families in Western Bolivia (IBCE and Guanella, 2016).

Benefits due to export revenues

Bolivia has also earned an additional USD 1.7 billion from exports of soy and its derivatives due to the adoption of GM soy between 2005 and 2015 (IBCE and Guanella, 2016). Overall, the adoption of GM soy in Bolivia has had a positive economic impact through increased yields, reduced costs, and enhanced trade opportunities, with additional benefits for the environment. To understand why it has been difficult to go from just one single event to four approved events, a review of the procedures, legislation, and difficulties must be explained.

Timeline of GMO Policy and Legislation

Here is a timeline of key policies and legislation related to GMOs in Bolivia (Moreira-Ascarrunz *et al*., 2019). It has to be mentioned that in February 2009, a new Political Constitution was issued. Take note that the 1997 regulation on GMO Biosafety has never been updated or harmonized with the new Political Constitution.

1992

The Convention on Biological Diversity (CBD) was established, which later influenced biosafety regulations. Bolivia ratified this in 1994.

1997

The Regulation on Biosafety was approved by Supreme Decree (DS) 24676, which primarily regulates the structure and functioning of the National Biosafety Committee (CNB). This regulation is the main legal instrument for regulating biotech crops in Bolivia.

1998

An application for approval of the biotech soybean event GTS 40-3-2 was submitted.

2001

Bolivia ratified the Cartagena Protocol on Biosafety with Law 2274.

2005

The first biotech crop approved for agricultural use in Bolivia, the glyphosate-resistant “RR” soybean, was authorized through Supreme Decree 28225. This occurred after years of a de facto moratorium on biotech crops.

2008

The soybean event GTS 40-3-2 was officially approved. This was about 10 years after the initial application. Since this time, no new events have been approved. The CNB has not functioned and, as a result, no new events have been approved.

2009

The new Political Constitution of the State (CPE) was approved. It includes the following articles regarding GMOs:

- Article 255 prohibits the import, production, and commercialization of GMOs and toxic elements that damage health and the environment. However, this is an exception to Article 409.
- Article 407, numeral 11, gives the State the power to control the entry of GMOs into the country responsibly and does not prohibit the production, import, or commercialization of GMOs.
- Article 409 states that the production, import, and commercialization of GMOs will be regulated by law. It is understood that this article does not prohibit the use of GMOs, but establishes that there will be a special law to regulate all its main aspects.
- Article 410 establishes that international treaties, such as the CBD and the Cartagena Protocol, are laws of a constitutional nature that apply in preference to state laws.

2011

The Law of the Productive, Community Agricultural Revolution (Law 144) was enacted, stipulating that:

- Agricultural technology packages involving GM seeds of species that are native to Bolivia, or that threaten genetic heritage, biodiversity, the health of life systems, and human health, will not be introduced into the country.
- All products for human consumption that contain or are derived from GMOs must be clearly identified.
- There will be measures to control the production, import and commercialisation of genetically modified products.

2012

The Law of Mother Earth (Law 300) was enacted, which prohibits the introduction, production, use, release into the environment, and commercialisation of GM seeds in Bolivia of which Bolivia is a center of origin or diversity. It also prohibits those that threaten genetic heritage, biodiversity, the health of life systems, and human health.

2015

Supreme Decree 2452 was issued to regulate the labeling of products containing or derived from GMOs.

2017

Bolivia cultivated approximately 1.3 million hectares of biotech soybeans, making it the fourth largest producer of biotech crops in Latin America.

2019

The simplified procedure was used to evaluate the HB4 soy, with drought stress tolerance (Decreto Supremo 3874, 2019).

2024

Intacta MON87701 x MON89788 events approved by Administrative Resolution (Resolución Administrativa VMA N° 090/2024, 2024)

2024

HB4 soy is approved by the Administrative Resolution (Resolución Administrativa VMA N° 101/2024, 2024).

It is worth highlighting that despite some restrictions; the existing legal framework does not completely prohibit GMOs, but rather seeks to regulate their use, especially for crops where Bolivia is not a center of origin or diversity. The country also has international commitments to the CBD and the Cartagena Protocol which call for risk assessments before the introduction of GMOs. There has been discussion about updating the legal framework, particularly the 1997 Biosafety Regulations (DS 24676), to address new technologies like gene editing and to ensure that the country's agricultural sector can benefit from innovation while safeguarding its biodiversity.

Current Situation

Bolivia's agricultural sector is navigating a complex landscape shaped by both the adoption of GMOs and the constraints of a regulatory environment struggling to keep pace with scientific advancements. This section examines the interplay of these factors, which have significant implications for agricultural productivity and sustainability in the country.

Economic impacts

Since the approval of the glyphosate-resistant soybean event GTS 40-3-2 in 2008, Bolivia has become a notable adopter of agricultural biotechnology. By 2024, approximately 1.7 million hectares were cultivated with biotech soybeans, positioning Bolivia as the fourth-largest producer of such crops in Latin America (MDRyT, 2024). This adoption has been primarily driven by the economic benefits (Choquehuanca Céspedes *et al*., 2021):

- Increased yields compared to traditional varieties.
- Reduced costs associated with insecticide use.
- Enhanced export revenues, contributing to national economic growth.
- Improved efficiency of agricultural practices.

These factors have led to significant economic gains for Bolivian farmers. However, this success is largely limited to soybean production, whereas other crops are still lagging behind.

Regulatory framework and its challenges

The primary legal framework governing GMOs in Bolivia is the Biosafety Regulation, established by Supreme Decree (DS) 24676 in 1997. This regulation primarily outlines the structure and functions of the CNB. This regulation primarily outlines the structure and functions of the CNB. However, the framework faces several significant challenges (Moreira-Ascarrunz *et al*., 2019):

- *Outdated Legislation*

The 1997 regulation is over two decades old and struggles to address modern biotechnologies like gene editing.

- *Dysfunctional Regulatory Body*

The CNB has not been functioning effectively. Lack of competent members, especially from the governmental side.

- *Inconsistencies in Legal Framework*

The 2009 Political Constitution of the State includes articles that both restrict and permit the use of GMOs. Article 255 prohibits GMOs that damage health and the environment, while Article 409 states that GMOs will be regulated by law, suggesting that their use is not completely banned.

- *Conflicting Legislation*

Law 144 (2011) and Law 300 (2012) impose additional restrictions, particularly concerning GMOs where Bolivia is a center of origin or diversity. This has led to a complex and sometimes contradictory legal landscape that hinders decision-making.

- *Lack of Implementation*

Despite regulations and international commitments to the Cartagena Protocol on Biosafety, Bolivia struggles to implement a functional biosafety system capable of evaluating new applications.

Socio-political and scientific considerations

The situation is further complicated by ongoing debates regarding (IBCE and Guanella, 2016; Choquehuanca Céspedes *et al*., 2021):

- *Expansion of GMO use*

The question remains whether to extend GMO cultivation to crops beyond soybeans, like maize and cotton, which could further enhance economic benefits.

- *Technological sovereignty*

There is growing discussion around the need to foster national scientific capabilities rather than relying solely on imported technologies. This includes developing local expertise in biotechnology to ensure food and technological sovereignty.

- *Environmental concerns*

There are persistent concerns about the potential environmental impact of GMOs and their associated agrochemicals, despite evidence suggesting reduced pesticide use. Concerns also extend to the preservation of native seeds and biodiversity.

- *Public perception*

Public opinion is divided, with some groups opposing GMOs due to concerns about health, corporate control, and environmental risks.

These systemic factors highlight the complex challenges facing the agricultural sector in Bolivia, which extend beyond just the technology of crop production. The need for effective policy, functional administration, clear regulatory frameworks, and robust communication are critical for improving agricultural productivity and food security in the country.

Limited Focus on Native Crops

Bolivia has a high potential in terms of native crops, stemming from the richness of its agrobiodiversity and status as a center of origin or diversity for many important plant species. This term does not only refer to the variety of plants and animals but also to the variety of agroecosystems that have been developed to grow this variety of products. This potential also covers the traditional knowledge and cultural practices surrounding their cultivation and use (Villegas, 2008). This biodiversity is exemplified by the numerous varieties of crops adapted to different regions, such as over 55 races of maize, each with specific regional uses and deeply rooted in tradition (Rojas Beltrán *et al*., 2022). Additionally, Bolivia boasts a high diversity of potatoes, with many native varieties that are not only culturally significant but also nutritionally valuable.

Many of Bolivia's native crops are considered *superfoods* due to their high nutritional content. For instance, native potatoes from the Altiplano (high altitude flora) contain over 52 antioxidants, while traditional foods like *chuno*, a preparation to preserve dry potato tuber, have modified starch content that makes them more tolerable for diabetics (Rojas Beltran *et al*., 2022). Indigenous communities have preserved and cultivated these crops for millennia, developing unique agricultural practices and adapting their cultures to these foods. Traditional technologies, such as the processing of *chuno*, demonstrate sophisticated ancestral knowledge that has been passed down through generations.

Bolivia is also recognized as a center of origin or diversity for several crops, including beans, peanuts, tomatoes, tree tomatoes, potatoes, corn, quinoa, cañahua, achira (yacon, isano, cassava, blackberry, squash, and various passion fruits. Moreover, it is home to numerous wild relatives of these crops, which serve as a valuable source of genetic diversity for crop improvement. These wild relatives can provide traits such as pest and disease resistance, which are crucial for enhancing crop resilience (Alliance of Bioversity International and CIAT, 2013).

The potential for sustainable agriculture in Bolivia is substantial, given its diverse agroecosystems and traditional farming practices. There is a promotion of agroecology and agroforestry over monocultures, in order to preserve diversity and ensure that traditional crops continue to be available for future generations. According to Cockburn (2014), using native crops can strengthen food sovereignty by reducing reliance on imported foods and supporting local food systems. However, the tools and methodology of this type of production are not efficient and the demand is not covered by local production.

Despite being a producing country, Bolivia imported fresh potatoes worth USD 3.1 million from Peru in 2023, and in the first quarter of 2024, it imported potatoes valued at USD 100,259, according to data from the National Institute of Statistics (INE), compiled by the Bolivian Institute of Foreign Trade (IBCE). Until 2021, it also bought *chuno* and *tunta* (another dry processed potato) from Peru (Belmonte, 2024). Many stakeholders, including activists, foresee that these resources are under threat due to factors such as the expansion of agricultural land to export crops (like soy), the adoption of foreign crop varieties, the impacts of climate change, and a lack of government support for the agricultural sector. Therefore, there is a pressing need for scientific research to explore and understand the properties of native crops and their wild relatives. Conservation efforts, including *in-situ* and *ex-situ* conservation, are also imperative. Additionally, supporting farmers, especially in rural areas, by valuing and promoting their knowledge is crucial. Finally, promoting awareness about the nutritional value of native crops can encourage their consumption and help secure Bolivia's food future.

The Impact of Stakeholders

Whenever the GMO topic sparks a debate in Bolivia, it is usually 3 main stakeholders that are visible: The government, non-governmental organizations (NGOs) against GMOs, and organizations and individuals that are in favour of GMOs.

Government

In 1997, before Bolivia changed its name and constitution, the government passed a regulation establishing the basic steps for GMO risk assessment and approval. The first biosafety committee was formed and though there was the intention to request GEF funding to build the general framework that would cover not only the regulation but also the administrative structure, as well as build capacity, this never happened. Later in 2009, when the country changed its name to Estado Plurinacional de Bolivia, activists inside the key positions, managed to leave unclear articles in different laws or regulations, that still represent an obstacle to developing a coherent biotechnology and biosafety framework that would cover different fields. Furthermore, there is a lack of training among the personnel from the government involved in these topics, which makes it more complicated to deal with these topics.

Unfortunately, the new secondary education curricula approach biotechnology in an inappropriate manner, as they primarily focus on GMOs while emphasizing their risks and potential threats to Bolivia's biodiversity. School teachers, in general, spread the knowledge that *natural and organic* produce is better than anything that sounds complicated like GMOs. This pattern in secondary education leads most students to believe that this technology is harmful to the country.

NGOs against GMOs

Since the late 1980s, Bolivia has witnessed a rise in the number of NGOs and similar institutions that have an environmental protectionist agenda. Some radical changes in the economy led to a mass migration of miners to low lands. By the mid-1990s, the department of Santa Cruz started to copy the leading crop that was used in Brazil and Argentina. Soy was an unknown crop for that region, but since it was already adapted to similar conditions and new workers arrived, the new fields started to use soy as a promising crop. By this time, the first GMOs in soy were obtaining their first approvals in the US. At the same time, international agencies that lobby against GMOs started their activity. Some of them made alliances with Bolivian NGOs and similar organizations and by the 2000s they had moved a long way in creating a loud argument against these biotechnological innovations.

These organizations also were fast to join forces with academic professors. In this sense, even around university classes, you could learn about the terrible GMOs and the threat they were to small farmers and native seeds. Not much has changed since the early 2000s and you can still find scientists in the biological areas expressing their fear of this biotechnology. In recent years, these groups have made less noise about the new events approved. However, significant concerns exist regarding mining activity in Bolivia's Amazon region, which pollutes rivers and causes numerous health problems for local communities. Their actions are focused on addressing this complex issue.

Proponents of biotechnology

Proponents, who tend to be quieter and less visible, often lack the financial resources available to activist groups. This disparity can make it difficult for their voices to be heard. Most of the efforts have been made in the oriental part of the country, the lowlands where producers use GMO soy resistant to glyphosate. In this region, you have small, medium, and large-scale producers. In the beginning, it was mainly the large scale producers who would spread information based on science. But around 2012, small producers demanded to learn the technical part of GMOs as they were using these types of seeds as well. Gradually around 2015-2017, some academicians joined the campaign and also Agroavances.com was launched. This news portal focused on agricultural and biotechnology information and had strong support from producers in Santa Cruz. For 5 years, producers in general, were trained on how GMOs are made, their potential, and about biosafety of GMOs. This portal has limited support and the workshops and other events seldom take place. The big producers decided to work more on the legislation that would allow the opening of new events. The association of agronomists in this region also had some participation during those years but the commitment to keep educating about these topics has been reduced to almost none.

It's worth highlighting that Santa Cruz de la Sierra is where the only university that offers Biotechnology as a career is located. This bachelor's degree has finally graduated the first biotechnology engineers in Bolivia and eventually, these new professionals will face the challenge of not having a solid regulatory framework that allows them to work with biotechnology tools, in general, in different fields. This may lead to a stronger movement that could generate a relevant lobby that eventually could push to generate the conditions needed to work within this field.

Potential of Crop Wild Relatives and Biotechnology

Crop wild relatives (CWRs) are true treasures of nature that have been ignored for a long time. CWRs in Bolivia are an invaluable resource for enhancing food production, particularly when combined with biotechnology. Recognized as a significant center of origin for cultivated plants, Bolivia boasts a rich diversity of wild relatives across its varied ecosystems, which include the Andes and lowland regions. Bolivia hosts 34 wild potato species, 21 of which are endemic. These wild potatoes possess traits that are beneficial for cultivated varieties, such as resistance to diseases like late blight (*Phytophthora infestans*) and tolerance to climatic stresses including extreme heat and drought (Bioversity International, 2023). Additionally, the wild relatives of beans and peppers thrive in this region, contributing further to the genetic diversity available for crop improvement (Lane, 2022).

The application of biotechnology can significantly enhance the potential of these wild relatives in modern breeding programs. By utilizing genetic modification techniques, traits from wild relatives can be introduced into cultivated crops, leading to improved resistance against pests and diseases, as well as enhanced nutritional profiles (Eyzaguirre *et al*., 2022). For instance, successful breeding programs have demonstrated that wild relatives can improve yield and stress tolerance in crops such as wheat and rice (Hajjar and Hodgkin, 2007). Furthermore, incorporating genes from wild relatives can help develop new crop varieties that are more resilient to climate change and capable of higher yields. This approach not only addresses food security challenges but also reduces reliance on chemical inputs by enhancing the natural resilience of crops [International Center for Tropical Agriculture (CIAT), 2023]. The conservation of these wild relatives is essential for ensuring their availability for future agricultural advancements.

Despite the significant potential of CWRs as genetic resources, several challenges impede their full utilization in crop improvement programs. Two primary obstacles are faced by researchers and conservationists in many countries including Bolivia. Firstly, breeding incompatibilities present a substantial hurdle in the integration of beneficial traits from CWRs into cultivated crops. These incompatibilities can manifest as crossing barriers, hybrid sterility, or reduced fitness in subsequent generations. Such genetic barriers often need advanced breeding techniques, including embryo rescue, chromosome doubling, or bridge crossing, which can be time-consuming and resource-intensive. Secondly, habitat destruction emerges as a critical threat to the *in-situ* conservation of CWRs in Bolivia. The country's rich biodiversity is under increasing pressure from factors such as agricultural expansion, urbanization, mining activity, and climate change. This loss of natural habitats not only reduces the overall population of wild species but also potentially eliminates unique genetic variants adapted to specific environmental conditions.

To understand how helpful these wild plants could be for Bolivia, here are some examples. We are looking at how their good genes could be used to improve commercial crops.

Chili

Bolivia's native chili peppers (ajíes) hold significant agro-industrial potential that could be further enhanced through biotechnology. Reyes Colque *et al.,* (2021) highlight Bolivia's rich diversity of Capsicum species, making it a center of origin and domestication for these crops. The Pairumani Phytotechnical and Seed Center maintains a collection of 731 diverse chili accessions. Biochemical analyses of 96 cultivated and wild chilli peppers revealed valuable nutritional qualities, including capsaicin, colorants, anti-oxidants, flavonoids, quercetin, and vitamin E, which are key components for the food, pharmaceutical, and cosmetic industries.

Biotechnology and chilli peppers could play a crucial role in several areas. Firstly, it could aid in enhancing desirable traits, such as higher capsaicin content for spiciness or increased anti-oxidant levels, appealing to health-conscious consumers. Secondly, it could improve disease resistance in native chili varieties, reducing crop losses and reliance on pesticides. The study also identifies the potential for processing native chilies into pickles, sauces, and jams, maintaining their color, piquancy, and consistency; biotechnology could be employed to optimize these processing characteristics and extend shelf life (Reyes Colque *et al*., 2021). Moreover, the document points out the underexploited wild chili species ("ulupicas" and "aribibis") and their potential for cultivation. Biotechnology could assist in overcoming limitations to their cultivation, such as improving germination, uniformity, and pest resistance, making them more accessible to small farmers. The study also notes that Bolivia consumes a larger diversity of wild Capsicum than probably any other country in the world (Reyes Colque *et al*., 2021).

By combining traditional knowledge with modern biotechnology, Bolivia can create new, high-value chili varieties that are better adapted to local conditions, more nutritious, and more appealing to both domestic and international markets. This approach could empower small farmers, promote sustainable agriculture, and contribute to the country's bioeconomy.

Cacao

The study by Chumacero de Schawe *et al*., (2013) establishes that wild cacao populations in Bolivia are genetically distinct, which is invaluable for targeting conservation efforts and understanding the evolutionary adaptation of the species. That diversity could be harnessed to create new varieties with enhanced flavour, nutritional content, and resilience to environmental stressors. By safeguarding rare and endangered native cacao genotypes, the unique genetic heritage can be preserved for future generations. The Red Book of CWRs (VMABCC-BIOVERSITY, 2009) highlights the species' economic potential as well. Disease resistance is important, and biotechnology offers tools to develop disease-resistant cacao through genetic engineering or gene editing. Identifying and incorporating resistance genes from wild cacao relatives could create more resilient and productive cacao trees. This is supported by Chumacero *et al.,* (2013) data showing low population densities of these populations which suggest that understanding gene flow is elementary for understanding the reproductive success and management of tropical tree species in the area. This approach allows for the development of novel cultivars as well as preserving wild populations through local communities.

By merging traditional farming practices with carefully selected biotechnological interventions, Bolivia has a unique opportunity to unlock the full economic potential of its native cacao. This would contribute to a more sustainable and economically viable agricultural sector while preserving Bolivia's distinctive biodiversity, with careful assessment to the impact on low-density wild populations, and to manage the flow of gene exchange between cultivated and wild cacao in the area.

Quinoa

Wild relatives of quinoa exhibit significant genetic diversity, which is crucial for the improvement of cultivated quinoa. The CWRs Red Book of Bolivia (VMABCC-BIOVERSITY, 2009), identifies several wild quinoa species, subspecies, and varieties that are distributed across the Andean region, including Bolivia's highlands, valleys, and plains. These wild relatives are known for their resistance to various pests and diseases, making them valuable for genetic enhancement. The wild species possess traits such as drought tolerance and adaptability to harsh environmental conditions, which are essential for breeding programs aimed at developing resilient quinoa varieties (Zapata and Apaza, 2007). The genetic variability found in these wild relatives can be harnessed to improve cultivated quinoa's nutritional quality and stress resistance.

Based on the information, the biotechnological potential of utilizing wild relatives of quinoa for breeding encompasses several promising approaches. Marker-Assisted Selection (MAS) offers a means to identify and select for desirable traits linked to specific genes in wild relatives, thereby expediting the breeding process. Advanced methods such as CRISPR/Cas9 could be used to directly edit genes in cultivated quinoa, incorporating beneficial traits from wild relatives. Traditional breeding methods can be enhanced by creating hybrids that combine the hardiness of wild species with the desirable traits of cultivated quinoa. The importance of conserving genetic material from wild relatives is emphasized to ensure that these valuable genes are preserved for future breeding efforts.

Peanut

Peanut production in Bolivia has faced significant challenges, primarily due to low productivity and contamination with aflatoxins, which limits the availability of this important source of protein, vitamins, and minerals. The situation is exacerbated by high poverty rates, affecting 36.4% of the population, particularly in rural and peri-urban areas, leading to nutritional deficiencies (Valles Foundation, 2023).

To address these issues, cultivation has to be standardized, implement quality control, and production of peanuts. According to the "Libro Rojo de Parientes Silvestres de Cultivos de Bolivia" (VMABCC-BIOVERSITY, 2009), there are 79 wild species of peanuts (genus *Arachis*) identified globally, with 20 of these species found in Bolivia. Among these, 12 species are endemic to the country. The wild relatives of peanuts are significant for their genetic diversity and potential for improving cultivated peanuts through traits such as drought resistance and pest resistance (Krapovickas and Gregory, 1994; Atahuachi *et al*., 2009). Wild species, such as *Arachis duranensis*, *Arachis ipaënsis*, and *Arachis krapovickasii*, offer valuable genetic traits that can enhance the performance of cultivated varieties. These wild species possess genes that confer resistance to pests and diseases, making them valuable for breeding programs focused on enhancing the resilience of cultivated peanuts (Atahuachi *et al*., 2009). Additionally, they may have traits that enhance drought tolerance and nutritional quality, which are crucial for food security in changing climatic conditions.

Potato

In the year 2022/23, the production of potatoes in Bolivia amounted to 1.17 million metric tons. This represents a decrease of 5% compared to the previous year (Navarro Villa, 2024). Last couple of years, a good part of the production has been lost due to frost or drought. Bolivia is home to 34 wild potato species, notably 21 of which are endemic. These wild species are of significant interest for the genetic improvement of cultivated potatoes and have been the subject of numerous collection expeditions since the early 19th century.

The wild relatives of potatoes exhibit various traits that are valuable for improving cultivated varieties. For instance, *Solanum achacachense* shows potential resistance to late blight caused by *Phytophthora infestans* and frost, while *Solanum alandiae* has demonstrated resistance to several pests and diseases, including the potato wart pathogen (*Synchytrium endobioticum*) and soft rot (*Erwinia carotovora*). Other species, such as *Solanum arnezii*, have shown varying degrees of resistance to nematodes and other pathogens, making them significant for genetic enhancement efforts (VMABCC-BIOVERSITY, 2009).

The conservation of these wild potato species is critical, as they harbor genetic diversity that can be leveraged to enhance the resilience and productivity of commercial potato crops. The ongoing threats to these species, including habitat destruction and climate change, underscore the urgency of conservation actions. Since 2009, when the Red Book of Crop Wild Relatives for Bolivia was published, few concrete actions have been executed in order to preserve these varieties or to use their genetics to improve commercial crops.

The wild relatives of the above crops contain significant genetic resources that biotechnological advancements can unlock to improve the resilience, nutritional value, and productivity of cultivated crops. Realizing these benefits, however, hinges on establishing clear regulatory frameworks and ensuring that decision-makers are prepared to consult with a scientific committee for evidence-based guidance on employing biotechnology to enhance domestic food production.

Way Forward

Given the potential benefits of biotechnology for native crops in Bolivia, alongside limitations in the current regulatory framework, a clear path forward involves modernizing regulations and building relevant capacities. Drawing from the recommendations already given by Moreira-Ascarrunz *et al.,* (2019), several key actions can be taken to achieve this:

- The current biosafety regulation based on Supreme Decree (DS) 24676 from 1997 is outdated. Therefore, it needs to be updated to incorporate advancements in biosafety concepts and procedures.
- The new regulations should be based on scientific principles to foster confidence and optimize usage of resources. This involves evaluations based on scientific evidence related to environmental and food safety; to avoid legal contradictions, there needs to be a single, coherent legal body to do this.
- To ensure public trust, new regulations should include provisions for publishing applications and decisions on a website to promote transparency. Furthermore, it is essential to account for new innovations in genetic engineering, such as stacked events, gene editing,

and advances in synthetic biology, implementing monitoring to verify risk management activities.

- The reactivation and strengthening of the CNB are crucial to providing technical advice to the National Competent Authority, using scientific criteria.
- A functional administrative system must be established with competent human resources, structure, and tools to effectively evaluate new applications.
- Finally, it is important to develop firm and concrete policies within Bolivian legislation to regulate modern biotechnology in the National Biosafety Framework and ensure norms for OGM regulation align with Bolivia's commitments.

By addressing these aspects, Bolivia can establish a robust regulatory framework that fosters responsible use of biotechnology for improving native crops for food and nutritional security while ensuring environmental protection and public trust.

Challenges and Considerations for GM Crops in Bolivia

- Addressing the complexities of GMO implementation in Bolivia necessitates a holistic approach that navigates concerns surrounding intellectual property rights, public perception, equity, regional adoption, and potential trade-offs. To ensure fair access and benefit-sharing, promoting public-private partnerships, supporting open-source seed initiatives, and bolstering local seed production are crucial steps. These measures can help diversify the seed market, reduce reliance on multinational corporations, and provide farmers with seeds adapted to their specific environmental conditions.
- Building public trust requires transparent communication and informed consumer choice. Investing in science communication initiatives and ensuring regulatory transparency are essential. Such measures empower consumers to make informed decisions while addressing potential misconceptions about the safety and benefits of GM technology. Moreover, targeted subsidies and strengthened social safety nets can level the playing field, ensuring that small farmers can access and benefit from GM technology without exacerbating existing inequalities.
- To fully harness the potential of GMOs in enhancing food security and promoting sustainable agriculture, it's essential to direct research towards developing crops tailored to local conditions while prioritizing public health. This includes increasing research funding for developing GM food staple crops and encouraging practices like integrated pest management, soil health management, and environmental monitoring.

By carefully considering potential trade-offs and prioritizing ecological sustainability, Bolivia can harness the potential of GMOs while minimizing environmental risks.

Conclusion

Bolivia's genetic wealth of native crops and CWRs offers considerable potential for strengthening food security through the strategic use of biotechnology. Native species such as quinoa, potatoes, and chili peppers possess significant economic and nutritional value. These resources can be leveraged through biotechnological applications to enhance the resilience, nutritional quality, and productivity of cultivated varieties. However, this will only be realized with the establishment of a clear normative framework provided decision-makers are fully prepared to rely on a scientific committee for evidence-based recommendations on the application of biotechnology. Public perception and education represent key factors influencing the acceptance and adoption of biotechnology in Bolivia. Negative public sentiment, often fuelled by misinformation and opposition from environmental NGOs and certain segments of the academic community, has contributed to a slower rate of adoption of biotech innovations. Focused and improved educational initiatives, particularly within secondary and tertiary education, are needed to provide balanced, evidence-based perspectives on the risks and benefits of GMOs and biotechnological applications. The prevailing legal framework governing biotechnology in Bolivia requires urgent reform. Current regulations are outdated, inconsistent, and insufficient in addressing modern biotechnological advancements like gene editing. While certain GM crops, like soybeans, have seen approval and widespread adoption, updated policies are essential to facilitate the responsible and sustainable expansion of biotechnology to a wider range of crops. Such policy revisions are critical to ensure both food security and environmental sustainability within the country.

References

Atahuachi M, FW Rojas and JE Mamani (2009) Fichas técnicas de especies del género Arachis. In: Libro Rojo de Parientes Silvestres de Cultivos de Bolivia. VMABCC-Bioversity International, La Paz, pp 121-130.

Belmonte MA (2024) Pese a ser un país productor, Bolivia importa papa fresca de Perú y cocida o en conserva de otros 20 países. Visión 360, 12 June 2024 (https://www.vision360.bo/noticias/2024/06/12/6152-pese-a-ser-un-pais-productor-bolivia-importa-papa-fresca-de-peru-y-cocida-o-en-conserva-de-otros-20-paises).

Bioversity International (2023) Conservation concerns for endemic potato species in Bolivia. Alliance Bioversity International-CIAT. (https://alliancebioversityciat.org/stories/conservation-concerns-endemic-potato-species-bolivia)

Brookes G (2022a) Feeding the world sustainably: Crop biotechnology continues to make a significant contribution, concludes new research. PG Economics (https://pgeconomics.co.uk/pdf/pressreleaseoct2022_01.pdf)

Brookes G (2022b) GM crops: Global socio-economic and environmental impacts 1996-2020. PG Economics. (https://pgeconomics.co.uk/pdf/

Globalimpactbiotechcropsfinalreportoctober2022.pdf).

Choquehuanca Céspedes D, J Zenteno Hopp, C González Paredes, G Colque Fernández and ME Álvarez-Buylla Roces (2021) Alimentos transgénicos: Entre la innovación y la dominación. 1st edition Friedrich-Ebert-Stiftung en Bolivia (https://library.fes.de/pdf-files/bueros/bolivien/18525.pdf)

Chumacero de Schawe C, W Durka, T Tscharntke, I Hensen and M Kessler (2013) Gene flow and genetic diversity in cultivated and wild cacao (*Theobroma cacao*) in Bolivia. *Am. J. Bot.* 100(11): 2271-2279.

Cockburn J (2014) Bolivia's food sovereignty and agrobiodiversity: Undermining the local to strengthen the state? *Theory Action* 7(4): 67–89.

Decreto Supremo 3874 (2019) Gaceta Oficial del Estado Plurinacional de Bolivia (https://faolex.fao.org/docs/pdf/bol189466.pdf).

Eyzaguirre P, A Lane and R Hajjar (2022) Application of crop wild relatives in modern breeding: An overview of resources, experimental and computational methodologies. *Front. Plant Sci.* 13: 1008904.

FDA (n.d.) Why do farmers in the U.S. grow GMO crops? U.S. Food and Drug Administration (https://www.fda.gov/media/142249/download#:~:text=Why%20do%20Farmers%20in%20the%20U.S.%20Grow%20GMO%20Crops%3F,food%20loss%20and%20control%20weeds.&text=Farmers%20can%20use%20less%20spray%20pesticides%20when%20they%20plant%20GMO%20crops.).

Hajjar R and T Hodgkin (2007) The role of crop wild relatives in food security and climate change adaptation. *Genet. Resour. Crop Evol.* 54(1): 1-12.

IBCE and L Guanella (2016) Impacto Socioeconómico y Medioambiental en Bolivia a partir de la soya y maíz genéticamente mejorados. Comer. Ext. (https://ibce.org.bo/publicaciones-descarga.php?id=2351&opcion=1)

IMF (n.d.) Bolivia Datasets. International Monetary Fund (https://www.imf.org/external/datamapper/profile/BOL).

International Center for Tropical Agriculture (CIAT) (2023) Enhancing food security through crop diversity: The role of wild relatives. Alliance Bioversity International-CIAT (https://alliancebioversityciat.org/stories/essential-crop-wild-relative-species).

ISAAA (2017) Global Status of Commercialized Biotech/GM Crops in 2017: Biotech Crop Adoption Surges as Economic Benefits Accumulate in 22 Years. ISAAA, Ithaca, NY.

Krapovickas A and WC Gregory (1994) Taxonomy of Arachis (Leguminosae) in the Americas. *Peanut Sci*. 21: 1-10.

Lane A (2022) Crop wild relatives: A valuable source for enhancing crop resilience. CGSpace (https://cgspace.cgiar.org/server/api/core/bitstreams/f00077d6-d53d-4a78-a763-fd5ab19b5cfd/content).

Los Tiempos (2024) CAO reporta una caída del 17% en la producción agrícola durante 2024. Los Tiempos, 19 December 2024.

MDRyT (2024) Reporte Sectorial N° 2. Soya y Derivados. Ministerio de Desarrollo Rural y Tierras, Bolivia.

Moreira-Ascarrunz S, L Asturizaga-Mendoza and C Gonzalez (2019) Análisis crítico y propuesta sobre cambios y adiciones al Reglamento Boliviano sobre Bioseguridad (DS 24676) para tener un Comité Nacional de Seguridad de la Biotecnología en funcionamiento. *Rev. Invest. Agropecu. For. Bolivia.* 6(11): 32–56.

National Geographic (n.d.) Are genetically modified crops the answer to world hunger? National Geographic (https://education.nationalgeographic.org/resource/are-genetically-modified-crops-answer-world-hunger/).

Nueva Economía (2024) Tras caída del 50% en la cosecha de granos en 2024, productores doblan esfuerzos para proveer alimentos. Nueva Economía, 17 December 2024 (https://nuevaeconomia.com.bo/news/tras-cada-del-50-en-la-cosecha-de-granos-en-2024-productores-doblan-esfuerzos-para-proveer-alimentos).

Resolución Administrativa VMA N° 090/2024 (2024) Ministerio de Medio Ambiente y Agua, Bolivia (https://snia.mmaya.gob.bo/web/PDFs/RVMA/Resoluci%C3%B3n%20Administrativa%20VMA%20N%C2%B0%20090.2024.pdf).

Resolución Administrativa VMA N° 101/2024 (2024) Ministerio de Medio Ambiente y Agua, Bolivia (https://snia.mmaya.gob.bo/web/PDFs/RVMA/Resoluci%C3%B3n%20Administrativa%20VMA%20N%C2%B0%20101.2024.pdf).

Reyes Colque X, T Avila Alba and A Choque Siles (2021) Los ajíes nativos y su potencial agroindustrial. *J. Boliv. Cienc*. 17(Esp): 53-62.

Rojas Beltrán J, E Rojas Vargas and P Paco Cabrera (2022) Significance of potato biodiversity and other crops in the Andes of Bolivia. Fontagro, 10 May 2022 (https://www.fontagro.org/new/noticias/361/en/significance-of-potato-biodiversity-and-other-crops-in-the-andes-of-bolivia).

Valles Foundation (2023) Peanut and oregano production in Bolivia: A strategy to combat poverty and malnutrition. Valles Foundation.

Villegas P (2008) Los Recursos Naturales en Bolivia. *In*: Gandarillas M (ed) CEDIB, Cochabamba (https://www.cedib.org/wp-content/uploads/2009/04/RRNN-parte-1-1.pdf).

VMABCC-Bioversity (2009) Libro Rojo de Parientes Silvestres de Cultivos de Bolivia. PLURAL Editores, La Paz (https://archive.nationalredlist.org/files/2015/02/1.1-libro-rojo-parientes-silvestres-de-cultivos_mmaya_2009.pdf).

Zapata B and KS Apaza (2007) Proceso seguido para la evaluación del grado de amenaza de especies emparentadas con cultivos. *In:* Libro Rojo de Parientes Silvestres de Cultivos de Bolivia. VMABCC-Bioversity International, La Paz.