December 2025
Volume XLIII, No. 4
ISSN 1022-6303

The ICAC Recorder

International Cotton Advisory Committee

SPECIAL ISSUE: Part-I

15th ALIDA Meeting
ICAC Latin American Association for Cotton Research & Development

INTA, Reconquista, Argentina
8-11 September 2025

The ICAC Recorder

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PARTICIPANTS OF THE 15th ALIDA MEETING 8-11 SEPTEMBER 2025 INTA, RECONQUISTA, ARGENTINA

The ICAC Recorder

Editorial

ALIDA: The Legacy of Latin American Cotton and the Imperative of Regional Collaboration

***Latin America** is not merely a producer of cotton; it is the cradle of the two species that sustain the global cotton industry. Gossypium hirsutum and Gossypium barbadense together account for approximately 99% of global cotton production, with G. hirsutum alone contributing about 90–95%. Both species originated in the Americas. G. hirsutum is believed to have originated in Mexico, while G. barbadense traces its origins to Peru and the Caribbean region, including Barbados. As the center of origin of these two dominant Gossypium species, Latin America occupies a uniquely critical position in the global cotton landscape.*

The extraordinary biological diversity found in the wild and cultivated populations of cotton in this region represents a priceless genetic reservoir. Such diversity is fundamental to developing future cotton varieties with enhanced productivity, superior fiber quality, and resilience to climate change, pests, and diseases. Consequently, Latin America's cotton germplasm resources will play a decisive role in shaping the future competitiveness and sustainability of cotton worldwide.

Brazil, Mexico, and Argentina stand out as the region's cotton powerhouses, while Paraguay, Peru, Colombia, and several other countries make smaller yet significant contributions. Brazil alone cultivates cotton on approximately 2.0 million hectares and produces about 3.7 million tonnes, accounting for nearly 90% of the cotton lint produced in South America. Together, Brazil and Argentina contribute about 99% of the continent's cotton production. Though other cotton producing countries in the region have immense potential to scale up their production they are constrained by persistent and escalating challenges, including boll weevil pressure, pesticide resistance, water scarcity, emerging diseases, and genetic erosion. These challenges transcend national boundaries and demand regional and indeed global solutions.

It is precisely in this context that the Latin American Association for Cotton Research and Development (ALIDA) assumes its critical importance. Established in 1986, ALIDA has served as a vital platform for regional collaboration, scientific exchange, and collective problem-solving. To date, fifteen ALIDA meetings have been organized, with the most recent -the 15th ALIDA meeting held from 8 to 11 September 2025 at INTA, Reconquista, Argentina. Thus far, ALIDA meetings have been hosted by seven countries in the region: Argentina, Bolivia, Brazil, Colombia, Nicaragua, Paraguay, and Peru. Argentina stands out as ALIDA's strongest and most consistent supporter, having hosted five meetings, including the latest one. Brazil and Colombia have each hosted three meetings, while the remaining countries have hosted once.

The 15th ALIDA meeting brought together 78 researchers from eleven countries and reaffirmed the importance of regional solidarity. Discussions highlighted both the depth of scientific expertise within the region and the urgency of coordinated action. Topics ranged from ecophysiology and genetic conservation to integrated pest, weed, and disease management, and from digital agriculture and traceability to producer organization and gender-inclusive value chains. Beyond technical advances, the meeting underscored the value of personal connections, shared vision, and mutual trust foundations upon which future collaborative research, germplasm exchange, and innovation will be built.

Cotton in Latin America is more than an economic enterprise; it is a cultural heritage, a source of rural livelihoods, and a pillar of national and regional economies. Its long-term viability depends on the region's ability to harness its unique genetic wealth and translate scientific knowledge into practical, field-level solutions. ALIDA exists to ensure that this transformation continues.

Meetings such as ALIDA are invaluable, not only for the exchange of scientific ideas but also for fostering professional relationships and enduring friendships that catalyze collaboration. As we look ahead to 2026 and beyond, one message is clear: the future of global cotton will depend heavily on Latin America's leadership in preserving, studying, and deploying its genetic diversity. Through continued collaboration, open dialogue, and shared purpose, the region can secure a resilient, competitive, and sustainable cotton sector for generations to come.

This Special Issue (Part I) of the ICAC RECORDER (December 2025) captures the essence of the technical presentations and discussions -not merely for posterity, but as a living reference to support and stimulate future collaborations within Latin America and beyond. The forthcoming ICAC RECORDER (March 2026), ALIDA Special Issue (Part II), will feature articles on Latin American research networks, traceability, , technological innovations, agricultural engineering, and country-specific reports.

I wish to express my sincere appreciation to Ms. Silvia Noemí Córdoba, Advisor for Cotton and Plant Fibers, and Mr. Martín Giaccio, Deputy Secretary for Regional Economies and Small and Medium Producers from the Ministry of Agriculture, as well as Dr. Marcelo Paytas, Director, INTA Reconquista, for their leadership in coordinating and organizing the ALIDA meeting. I also thank my colleagues, Ms. Lorena Ruiz and Mr. Eric Trachtenberg, for their active participation and continued support. Special appreciation is extended to Dr. Marcelo Paytas for collating the contributions, undertaking the preliminary editing, and coordinating all the articles published in this special issue (part-1). I wish our readers a very Happy New Year 2026 and a prosperous future for cotton in the years to come. Happy reading.

– Keshav Kranthi

The ICAC RECORDER (ISSN 1022-6303) is published four times a year by the Secretariat of the International Cotton Advisory Committee,
1629 K Street, NW, Suite 702, Washingtonne, DC 20006-1636, USA. Editor: Keshav Kranthi <keshav@icac.org>. Subscription rate: $220.00 hard copy.

Latin American Association for Cotton Research and Development (ALIDA): An Introduction

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Dr Marcelo Paytas

INTRODUCTION

The cotton value chain is strategic for territorial development in many countries, particularly in Latin America and the Caribbean, and it is essential to consider all production processes involved, from the field to the garment.

Research, extension and development play a fundamental and strategic role in achieving sustainable and competitive production, value addition and marketing of Latin American cotton. Cotton research is essential to address productivity gaps, promote efficient use of resources and improve producers' quality of life.

The International Cotton Advisory Committee (ICAC) has participated since 1986 in the organization of the Latin American Cotton Research and Development Association (ALIDA), which brings together most cotton-producing countries in the region. Since its creation, ALIDA meetings were regularly held every two years; however, the frequency declined in the recent years due to COVID and other reasons.

The latest alida meeting was organized by the ICAC, and INTA (National Institute of Agricultural Technology), at the Reconquista Experimental Station in the province of Santa Fe, Argentina, as host institution. The meeting was held with the objective of convening cotton researchers and technicians from Latin America and the Caribbean to exchange experiences and knowledge that contribute to strengthening sustainable cotton production in the region, while exploring prospects for expanding cotton area and other opportunities along the value chain, from the field to the garment. Accordingly, the guiding theme of the meeting was: "Productive Horizons of Cotton in Latin America and the Caribbean."

The overall objective of the event was to develop a joint working agenda among cotton-producing countries of the region to strengthen the cotton value chain through collaboration and exchange in research and development.

In addition, progress was made in compiling updated information on the cotton situation in each country, public–private actor networks, challenges and opportunities. Knowledge exchange and updates on the status of research and development in the cotton sector of Latin America and the Caribbean were achieved. The event also contributed to defining a joint research and exchange strategy aimed at improving sustainable cotton production across the region.

The event was structured around four sessions, that provided a roadmap toward a more competitive and sustainable cotton sector. The first session focused on cotton ecophysiology and its interaction with natural resources, highlighting the agroclimatic diversity of Latin America and the Caribbean and producers' adaptation to different environmental contexts. Efficient soil and water management was emphasized as a key factor for achieving sustainable, resilient production systems adapted to diverse regional conditions.

The second session addressed genetic resource conservation and cotton breeding in Latin America, concluding that the integration of conventional breeding, biotechnology and germplasm conservation is essential to strengthen the competitiveness of Latin American cotton in the face of climatic, phytosanitary and global market challenges.

The third session focused on cotton plant protection in Latin America, addressing pest, weed, insect and disease management under an integrated and systemic approach. Key crop pests were analyzed, along with alternatives for lower environmental-impact control, highlighting biological control using entomopathogenic fungi, among others. Participants agreed on the need to generate information on the biology and dynamics of biotic constraints and to move toward a more sustainable plant protection approach, evolving from traditional control to integrated management in cotton agroecosystems.

The final session addressed technological innovation and institutional organization within the regional cotton value chain. Emphasis was placed on production network projects, women's participation and family farming, and associative models from Argentina and Brazil (APPA, AAPA and ABRAPA). Advances in traceability, fiber quality and certifications that strengthen international market insertion were highlighted. The session also presented Agriculture 4.0 technologies, including drones, robots and digital platforms, which shape the horizon of “smart cotton,” while acknowledging challenges related to financing and local adaptation. Among the main challenges identified were local adaptation, access to financing and generational renewal, while regional cooperation and technological innovation were seen as key opportunities for a competitive and inclusive cotton sector.

Participants from nine Latin American and Caribbean countries, together with ICAC members and public–private stakeholders linked to cotton research and development, enriched the event. Notable representations included: Brazil (EMBRAPA; ABC/MRE – Brazilian Cooperation Agency; Unoeste; FAO; ABRAPA); Paraguay (IPTA; FAO +Cotton Project Paraguay); Peru (National Institute of Agrarian Innovation – INIA; IPA; César Vallejo University); Colombia (AGROSAVIA Nataima Research Center; University of Tolima; CONALGODON); Bolivia (CIAT; FAO; INIAF); Ecuador (National Institute of Agricultural Research – INIAP); Mexico (SENASICA); Chile (Regional Coordination of the +Cotton Project, FAO); and Argentina (INTA; INTI; SENASA; universities UNNE, UNL, UBA, UNR, UTN, UNSE, UNC, UCSF, UNCAUS; CONICET; APPA; AAPA; INASE; Secretariat of Agriculture, Livestock and Fisheries; national and provincial governments; private sector). ICAC representatives included Eric Trachtenberg, Keshav Kranthi and Lorena Ruiz.

Figure-1. A section of the ALIDA participants

Figure-2 Group photograph of speakers at the 15th ALIDA meeting

KEY EVENTS

Cotton Sustainability: Women Cotton Producers Held Their Own Meeting: In parallel with the main event, a spindle spinning workshop was held at EEA Reconquista, coordinated by the Argentine Network of Women Cotton Producers. Producers and artisans shared ancestral knowledge and practices, demonstrating that cotton not only looks toward the future through innovation and technology, but also preserves its cultural and community identity. The training was led by Ricardo Contreras, a textile artisan from Santiago del Estero.

25 Years of APPA: The Association for the Promotion of Cotton Production of Santa Fe: By the late 1990s, the province of Santa Fe had limited data on cotton area. APPA, together with INTA, initiated surveys using satellite imagery and field transects, generating reliable statistics to guide decision-making.

Figure-3. The APPA silver jubilee event

Since its creation, APPA has brought together producers, cooperatives, local governments and institutions linked to the cotton value chain, with the objective of strengthening sector competitiveness and promoting sustainable management practices. In this process, the scientific and technological contribution of INTA Reconquista proved critical, transforming cotton into a driver of territorial innovation. This effort goes beyond sustaining a crop; it has built a network of knowledge, experiences and opportunities for the entire value chain.

The association celebrated its 25th anniversary in the region. More than two decades of joint work between APPA (Association for the Promotion of Cotton Production) and INTA Reconquista have consolidated cotton as a driver of innovation and development in northern Santa Fe.

Sustainability Workshop: From the Field to the Biofactory and Laboratories: All visiting representatives from Latin American countries, together with professionals from INTA Reconquista, participated in a technical exchange workshop entitled "Cotton Cultivation within Sustainable Systems: Management Approaches and Practices. Challenges and Achievements." The objective was to create a space for specialists to present approaches, experiences and management practices related to environmental management of systems that include cotton cultivation.

Figure-4. Representatives from nine countries of ALIDA network

Visits and exchanges addressed the following topics:

- Biodiversity and sustainable system design
- Soil management practices
- Water management
- Biodiversity and use of biological inputs
- Machinery development (application equipment for digestates from local industry and a mini cotton gin)
- Genetic improvement of the crop

For each topic, local specialists presented their ongoing work related to cotton and shared experiences with international participants.

The closing activity of the workshop, titled "Seeds of Collaboration," involved the development of a collaborative map identifying contributions and needs of all participants related to sustainable cotton production. These inputs will support the planning of collaboration agendas for 2026 within the ALIDA framework.

The ICAC Vision: Global Perspectives on a Strategic Crop: Beyond technical topics, the Reconquista meeting marked the relaunch of ALIDA, which had not convened since 2017. With the participation of public and private institutions from across the region, the message was clear: "Only through cooperation, innovation and long-term policies can cotton continue to be a driver of sustainable, competitive and inclusive development in Latin America and the Caribbean."

During the plenary session, ICAC representatives emphasized the global role of cotton. "*Cotton is the United Nations of fibres: a crop that reduces poverty, empowers women, combats climate change, and flourishes in regions where other crops struggle to survive.*," stated Eric Trachtenberg, ED-ICAC.

ICAC's Chief Scientist Keshav Kranthi added: "*As researchers, our responsibility extends beyond advancing meaningful science. It includes developing technologies that enable farmers to combat climate change, enhance yields and product quality, and, most importantly, improve producers' incomes. International cooperation is essential to achieving these goals*"

More than a technical agenda, the meeting left a clear conclusion: the future of cotton will depend on greater cooperation, stronger science and more shared innovation.

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Seeds of Collaboration: The Technical Cotton Workshops at INTA Reconquista

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Daniela Vitti

Introduction

INTA Reconquista became a strategic hub for Latin American cotton research and development, as part of the XV ALIDA Meeting.

The technical exchange workshop held from 8-11 September 2025, brought together researchers from INTA Reconquista and leading cotton scientists and experts from across Latin America who were participating in the XV ALIDA Meeting. The workshop was conceived as a platform for dialogue, experience-sharing, and the sowing of new ideas: true seeds of collaboration to develop a blue-print for the future of cotton in the region.

Objectives: Collaborative Bonds for Cotton

The primary objective of the workshop was clear: to strengthen existing relationships and foster new collaborative bonds among key actors involved in cotton research and development across Latin America.

By creating an open and inclusive forum, the workshop encouraged diverse perspectives, collective reflection on shared challenges, and joint exploration of solutions that position cotton as a strategic crop within sustainable agricultural production systems.

The opening day began with introductions and an exchange of experiences among participants, setting the stage for constructive dialogue.

search initiatives and concrete activities undertaken in Argentina, particularly by INTA Reconquista—to promote cotton production within a sustainability-oriented agricultural framework.

Technical Tour of INTA Reconquista Facilities

A central component of the workshop was a technical tour of INTA Reconquista's experimental stations. Participants visited several research areas, where specialists presented ongoing work and innovations related to cotton cultivation. The thematic focus of the stations included:

- Water management, addressing efficiency and resilience under variable climatic conditions
- Soil health and biodiversity management, with emphasis on agroecological practices
- Agricultural mechanization and metalworking innovations, aimed at improving operational efficiency
- Genetic improvement, targeting enhanced competitiveness, productivity, and resilience

As an inspiring conclusion to the tour, participants visited a live workshop on hand-spun cotton yarn production, organized by extension specialists from the Argentine Network of Cotton Women (RAMA – Red Argentina de Mujeres Algodoneras).

Throughout the tour, the participants discussed on cotton's role as a key component of sustainable agricultural systems, as well as on the practical challenges associated with implementing such systems at scale.

This experience underscored the social and cultural dimensions of cotton, highlighting the role of women and artisanal knowledge within the cotton value chain.

Mapping Collaboration

The closing session of the workshop was both symbolic and highly practical. Participants collectively created a "map of collaborations", using green and yellow post-it notes to identify individual and institutional contributions ("What can I offer?") and needs ("What do I need to move forward?").

This simple yet powerful exercise resulted in a visual representation of shared priorities and complementary strengths, effectively sowing the seeds for future joint projects and cooperation.

Figure-1. Participants at the irrigation water management systems at INTA

Figure-2. Demonstration of the mini cotton ginning machine developed by the agricultural engineering team of INTA

Looking Ahead: From Seeds to Partnerships

The workshop concluded with more than shared learning -it generated concrete commitments. The collaborative map developed during the session will serve as a foundation for designing thematic linkages and coordinated research agendas among ALIDA member countries, strengthening regional cooperation in cotton research and development. The seeds of collaboration planted at INTA Reconquista aim to grow into robust networks, joint initiatives, and innovative solutions for the cotton sector. Sustained collective effort will be essential to ensure that these seeds germinate into long-term partnerships that benefit researchers, producers, and value-chain actors alike. Ultimately, the workshop reaffirmed cotton's enduring significance in Latin America, not only as an economic crop, but also as a symbol of livelihoods, cultural identity, innovation, and sustainability across the region.

Session-1: Ecophysiology and Agronomic Management of Natural Resources

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Dr Martin Winkler

Participants

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Introduction

The first session of the meeting focused on the ecophysiology of the cotton crop and its interaction with natural resources, highlighting the agroclimatic diversity of Latin America and the Caribbean. Although the crop is the same throughout the region, agronomic management practices vary considerably according to environmental conditions, reflecting the technological and cultural adaptability of local producers.

The session was organized around four thematic axes:

- Ecophysiology and efficient use of natural resources
- Soil management and regenerative agriculture
- Water management and efficiency under rainfed conditions in Latin America
- Irrigation technologies and water use in Latin America

The initial presentations emphasized the ecophysiological requirements necessary to achieve high yields and good fiber quality. Key variables such as solar radiation, water availability, and temperature, that have a strong impact on management strategies were analyzed. Two main types of production systems were distinguished: intensive and extensive systems. This approach allowed the discussion of specific agronomic practices, including the use of different cultivars, plant densities, row spacing, growth regulators, among others. A clear distinction was also made between management practices typical of family farming and those applied in more technical systems, highlighting that the key challenge lies in achieving production stability under contrasting environments.

Regarding soil management, conservation was highlighted as the foundation for sustainable production. Discussions addressed the role of roots in soil structuring, soil carbon as an indicator of productivity, and the importance of strategies such as crop rotations, cover crops, and balanced fertilization. Particular emphasis was placed on boron as a critical micronutrient for cotton, the deficiency of which in certain soil types has a negative impact on crop productivity.

With respect to water management, the session analyzed the different hydrological conditions under which cotton is produced across the region.

The importance of efficiently utilizing rainfall was emphasized through practices such as optimized planting dates, appropriate plant densities, mulching, the use of tolerant varieties, and conservation agriculture techniques that enhance soil water-holding capacity.

The contribution of precision agriculture was also highlighted, together with the need for public policies that promote the adoption of these technologies.

Complementing this axis, the adoption of irrigation systems in different countries of the region was discussed. Constraints such as access to water, infrastructure, costs, and technical training were identified, and the direct impact of irrigation technologies on productivity was analyzed. National legislation was also reviewed, allowing a better understanding of the heterogeneity in access to and regulation of water resources across Latin America.

The session clearly demonstrated that although cotton production faces common challenges, these challenges manifest differently depending on regional contexts.

Efficient management of resources such as soil and water is essential to advance toward more sustainable and resilient production systems, offering greater opportunities for improvement throughout Latin America and the Caribbean.

Integrated Water Management for Cotton in Drought-Affected Latin America

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Dr Sofiane Ouazaa

Abstract

Water use efficiency (WUE) is a central target for sustaining cotton production in rainfed systems across Latin America, where high interannual rainfall variability and episodic droughts constrain yields. This article synthesizes ecophysiological principles and agronomic management strategies to enhance water capture, soil moisture conservation, and biomass conversion per unit of water in drought prone environments. Drawing on comparative case studies from Argentina, Brazil, and Colombia, we outline integrated intervention, spanning crop configuration, genetic selection, irrigation system, and precision agriculture to raise on farm WUE and resilience. We propose practical metrics, monitoring pathways, and an operational roadmap for implementation and scaling across heterogeneous production contexts.

Introduction

Rainfed cotton remains a cornerstone of rural economies across Latin America, supporting livelihoods and agro-ecological diversity, yet it is highly vulnerable to climate variability and drought during critical developmental stages such as flowering and boll filling. In Colombia, for instance, bimodal rainfall regimes, sandy soils with low water retention, and the influence of El Niño/La Niña cycles create recurrent water deficits that limit yield and increase production risk. Similar challenges are faced in the Argentine Chaco and the Brazilian Cerrado and Semiarid regions, where irregular rainfall (300–1200 mm) defines the growing environment. Improving WUE under these constraints requires an integrated strategy that addresses water capture, retention, and crop demand while remaining feasible for diverse producer contexts.

Integrated management for WUE in Latin America

WUE must be understood through the dual lenses of crop development and growth. Development of the progression through phenological stages is driven primarily by thermal time (accumulated growing degree days), not water. In contrast, the accumulation of biomass depends directly on water availability and the efficiency of converting intercepted radiation into biomass.

WUE can be assessed across three practical scales. The first scale is the crop level WUE, which is expressed as grams of biomass or kilograms of lint produced per millimeter of crop evapotranspiration (ETc). The second one, is related to field level water productivity (WP) defined as lint yield per hectare per unit of water supplied from rainfall and irrigation. The third one refers to the operational efficiency, which focuses on minimizing non productive water losses such as soil evaporation, runoff, and deep drainage. Improving WUE requires both enhancing the plant physiological efficiency and minimizing unproductive water losses through agronomic management.

Synchronizing crop cycle with rainfall

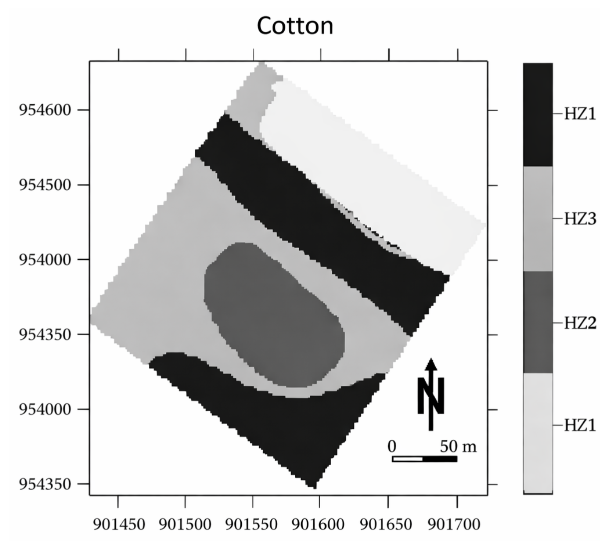

Figure-1. A vigor map to guide irrigation and management zones

Aligning sowing dates with the onset of reliable rains and selecting cultivar maturity classes to avoid critical reproductive phases during predicted dry windows are fundamental. In Argentina, staggered planting from October to December helps escape late frosts and terminal drought. In Brazil semiarid region, planting is concentrated in January–March to coincide with peak rainfall. Crop modeling tools can optimize sowing windows based on historical climate data.

Soil management and conservation

Increasing soil organic matter through crop rotations (with cereals or legumes) and retention of crop residues improves soil structure and available water capacity (AWC). Conservation tillage or no-till systems, combined with surface mulching, reduce evaporation and erosion particularly crucial in sandy soils.

Crop configuration and density

Figure-2. Adjust density according to variety, soil and system

Adjusting row spacing and plant density to water availability can significantly influence WUE. Ultra-narrow row systems (such as 0.38 m in Argentina) promote rapid canopy closure, reducing soil evaporation and improving radiation interception. In water limited regions, moderate densities may be preferred to reduce intra-crop competition.

Genetic and physiological leverage

Genetic improvement is critical for enhancing drought resilience, prioritizing traits such as deeper root systems for improved water extraction, shorter or intermediate growth cycles aligned with regional rainfall patterns, and physiological traits for conservative water use. Furthermore, the adoption of transgenic technologies such as Bollgard II and Roundup Ready Flex protects yield potential under stress by reducing pest and weed competition, indirectly supporting water use efficiency. To ensure successful integration, participatory varietal trials conducted over 2 or 3 seasons are essential for validating local adaptation and securing farmer acceptance.

Irrigation scheduling

Where water resources allow supplemental irrigation particularly during germination and reproductive stages, can substantially improve water use efficiency by preventing severe yield decline. Effective implementation relies on strategic practices such as deficit irrigation concentrated on critical growth phases rather than continuous supply, the adoption of localized delivery systems like drip or micro-sprinklers to minimize conveyance and evaporation losses, and sensor-based scheduling that utilizes soil moisture probes and evapotranspiration models to optimize both the timing and volume of water applications.

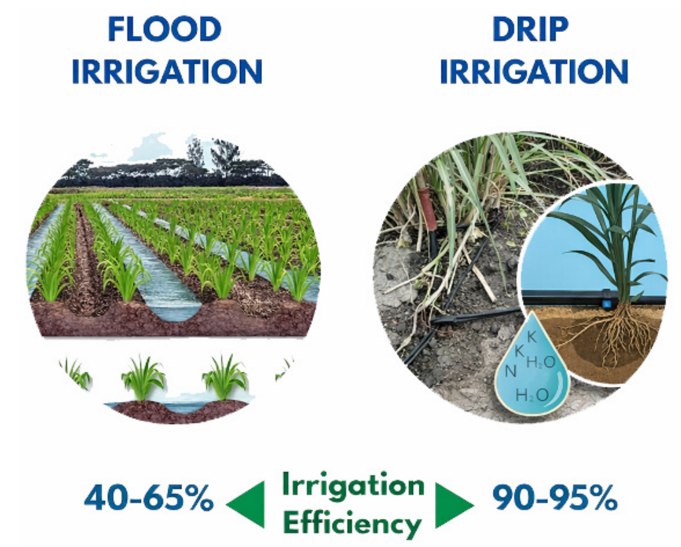

Figure-3. Establish appropriate irrigation systems to save water

Precision agriculture & early stress detection

Remote sensing tools such as multispectral UAVs and vegetation indices enable early detection of water stress and delineation of management zones. These technologies support variable rate management and improve the timing of irrigation and soil amendments. Success depends on local capacity for data interpretation and action, necessitating training and extension support.

Capacity building, policy, & scaling pathways

The adoption of water efficient technologies remains limited without parallel investments in enabling infrastructure and farmer knowledge transfer. Effective scaling models include establishing researcher led demonstration plots combined with participatory extension to build practical experience; implementing conditional subsidies that link access to efficient irrigation equipment with mandatory technical assistance; and fostering regional cooperation through networks such as ALIDA, FAO +Algodon. Strategic partnerships with institutions like Embrapa in Brazil and INTA in Argentina is the key to facilitate the exchange of adapted varieties, management practices, and localized lessons learned.

Conclusion

Enhancing WUE in rainfed cotton across Latin America demands an integrated and specific approach that blends eco-physiological understanding with practical management. Synchronizing crop cycles with rainfall, improving soil water retention, deploying resilient genetics, and precision irrigation are all critical components. The experiences of Argentina, and Brazil illustrate that success hinges on aligning technological options with local agro-ecological and socio-economic conditions. Continuous innovation, farmer engagement, and regional collaboration will be essential to secure sustainable cotton production under increasing climatic uncertainty.

Irrigation Technologies in Latin America

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Dr Nieves Rivera

Summary

This article analyzes the current situation, limitations, and opportunities related to irrigation management for cotton production in Latin America, a region characterized by strong agroclimatic, socioeconomic, and technological heterogeneity among producing countries. Subsistence family farming systems coexist with extensive and industrial production models. The analyzed data reveal a significant technological gap: while countries such as Brazil use highly efficient pressurized irrigation systems, such as central pivots, on nearly 100% of their irrigated area, other countries, including Peru and Bolivia, still depend largely on lower-efficiency systems such as surface (gravity) irrigation. The main constraints to technological adoption include deteriorated hydraulic infrastructure, limited access to financing, and insufficient technical training. The implementation of technologies such as drip irrigation and soil moisture sensors has demonstrated yield increases of 20–40%. Finally, public policies are examined, highlighting substantial differences between countries with robust regulatory frameworks—such as Peru's Technified Irrigation Law or Brazil's Plano Safra—and others with limited incentives. The article concludes that the sustainability of regional cotton production depends on a transition toward improved water-use efficiency supported by inclusive public policies.

Introduction

Latin America is characterized by a wide diversity of agroclimatic conditions, which strongly influence agricultural production systems. From arid to tropical environments, water resource management represents a major challenge, as multiple demands must be met in a context of climate change and increasing pressure on natural resources. In the cotton sector, this situation is reflected in the coexistence of two predominant production models: family farming, which is crucial for food security and local economies but often lacks resources for technological modernization; and extensive or industrial agriculture, associated with large-scale operations and complex technologies.

Water availability and seasonality vary significantly across cotton-producing regions, influencing the selection of irrigation systems. While some areas rely entirely on rainfall, others require mandatory irrigation to ensure crop viability. However, the adoption of efficient irrigation systems is constrained by structural, economic, and institutional barriers that differ according to national priorities and levels of development.

In this context, efficient water use goes beyond a technical requirement to become an ethical and strategic responsibility. This article examines the status of irrigation in Latin American cotton production, identifying predominant technologies, barriers to modernization, and the policy frameworks regulating water use, with the aim of providing a comprehensive perspective to enhance sector sustainability.

Current Status of Irrigation in Latin America

Cotton production in Latin America shows marked heterogeneity in irrigation systems. According to data presented at the XV Session of the Latin American Association for Cotton Research and Development (ALIDA), both irrigation dependence and applied technologies vary substantially among countries.

Brazil, the region's largest producer, grows cotton mainly under rainfed conditions. Of the approximately 2 million hectares cultivated, only 8% receive supplementary irrigation. However, this irrigated area is highly technified, with nearly 100% using sprinkler systems, specifically central pivots, reflecting a high-investment production model.

Peru depends entirely on irrigation due to the arid conditions of its coastal production areas. One hundred percent of its 6,945 hectares of cotton are irrigated. Nevertheless, technological adoption remains limited: 88% of the area is irrigated by surface (gravity) methods, consuming between 7,000 and 8,500 m^3/ha, while only 12% uses drip irrigation, which is significantly more efficient (4,000–4,500 m^3/ha).

Argentina cultivates approximately 600,000 hectares of cotton, of which 18% receive supplementary irrigation. Gravity irrigation predominates (72%), with sprinkler systems accounting for 28%.

Paraguay represents the extreme case of climatic dependence, with 100% of its 60,000 hectares grown under rainfed conditions, relying on regional precipitation patterns.

Bolivia, with 3,732 hectares, has only 5% of its area under irrigation, of which 85% uses gravity systems. Mexico shows a high level of irrigation coverage (96% of its 67,800 hectares), where gravity irrigation predominates (80%) compared to sprinkler systems (20%). Finally, **Colombia and Ecuador** present mixed situations: in Colombia's dry Caribbean region, sprinkler irrigation covers nearly 100% of irrigated areas, while gravity irrigation predominates in inland regions.

Table 1. Cotton Area and Irrigation Systems in Latin America

Country	Total Area (ha)	Area under Irrigation (%)	Predominant System (% of irrigated area)
Brazil	2,000,000	8%	Sprinkler / Central pivot (≈100%)
Argentina	600,000	18%	Gravity (72%)
Mexico	67,800	96%	Gravity (80%)
Paraguay	60,000	0%	N/A
Colombia	8,000	40–50%	Sprinkler (Caribbean) / Gravity (Interior)
Peru	6,945	100%	Gravity (88%)
Bolivia	3,732	5%	Gravity (85%)
Ecuador	75	≈50%	Gravity (100%)

Source: Authors' elaboration based on data from the XV ALIDA Session

Constraints in Adoption of Irrigation Technologies

Although technified irrigation systems offer clear advantages, their adoption in the region faces significant constraints, grouped into four critical areas:

1. Deficient Infrastructure: Many irrigation districts suffer from deteriorated reservoirs and canals, limited pressurized systems, and a lack of automation. Poor road infrastructure further complicates water logistics and operational efficiency.
2. Training and Human Capital: Limited technical knowledge in the design, operation, and maintenance of modern irrigation systems persists. Insufficient continuous technical assistance and limited dissemination of cotton-specific technologies particularly affect small-scale producers.
3. Financial Constraints: High initial investment costs for technified irrigation equipment, combined with operation, maintenance, and replacement expenses—often involving imported components—restrict adoption. Limited access to affordable financing remains a critical barrier for family farming.
4. Water Availability and Management: Reduced water availability in river basins and competition with other uses or more profitable crops exert pressure on cotton producers. In arid regions with rotational water delivery systems, challenges related to water rights formalization and institutional management are common.

Efficient Technologies and Practices

Technologies that have demonstrated the greatest impact on water-use efficiency and productivity include drip irrigation and subsurface drip irrigation (SDI), achieving application efficiencies of 85–95% and yield increases of 20–40% compared to gravity irrigation. The use of soil moisture sensors and tensiometers allows optimization of irrigation scheduling, avoiding water stress and unnecessary losses. Fertigation improves fiber quality and reduces nutrient leaching.

Table 2. Efficient Irrigation Technologies and Practices

Technology / Practice	Water-use efficiency	Impact on yield
Drip irrigation	85–90% application efficiency	20–40% yield increase vs. gravity irrigation
Subsurface drip irrigation (SDI)	Similar or higher than surface drip (90–95%)	Improved uniformity, reduced foliar diseases
Soil moisture sensors and tensiometers	Prevent unnecessary irrigation	Maintain optimal soil moisture, avoid stress
Fertigation	Efficient fertilizer use, reduced leaching	Improved yield and fiber quality
Sprinkler irrigation (central pivot)	Moderate	Increased coverage and efficiency, reduced costs
Central pivot with remote control	High	Higher productivity per hectare, crop diversification
Automated drip irrigation with renewable energy	Very high	Improved operational efficiency and profitability
Water harvesting	Increased soil water availability	15–40% yield improvement, drought resilience

Source: Authors' elaboration based on data from the XV ALIDA Session

At larger scales, central pivot systems equipped with telemetry and automation powered by renewable energy sources maximize operational profitability.

Policies & Incentives to Adopt Irrigation Technologies

Public policy frameworks in Latin America are heterogeneous. Brazil leads with a solid institutional structure, including the National Irrigation Policy and robust financial programs such as Plano Safra and PRONAF, which provide specific credit lines for sustainable irrigation in family farming.

Peru has a clear regulatory framework through Law No. 28585 on Technified Irrigation and programs such as the Subsectoral Irrigation Program (PSI), which promote investment. In contrast, Argentina presents a decentralized water management system under provincial jurisdiction. Although credit lines exist through the Federal Investment Council, private financing remains limited.

Figure-1. Pivot irrigation

Figure 2. Alternate furrow irrigation

Figure-3. Drip irrigation

Bolivia has implemented initiatives such as the "Irrigation Decade 2015–2025" and the "Mi Riego" program focused on food security. Mexico operates irrigation modernization programs through CONAGUA, while in Colombia, for cotton specifically, there is a reported absence of direct official incentives, despite general water governance frameworks.

Conclusions

- **Technological Gap:** A marked duality exists in the region. While Brazil has consolidated a high-efficiency model using pressurized irrigation in its irrigated areas, most cotton-producing countries still rely heavily on gravity irrigation, resulting in inefficient water use and nearly double the water consumption per hectare.
- **Structural Constraints for Smallholders:** The adoption of efficient technologies is limited by economic and infrastructural factors. In many countries, family farming lacks the capital required for initial investment and access to specialized technical training, perpetuating low productivity and high climate vulnerability.
- **Heterogeneity in Water Governance:** The effectiveness of irrigation promotion policies varies widely. Brazil's successful model demonstrates that irrigation modernization requires not only technological availability but also an integrated public policy ecosystem—including targeted credit, legal frameworks, and extension services—elements that remain insufficient in much of the region.

References

Latin American Association for Cotton Research and Development (ALIDA). (2025). Introduction to irrigation systems in Latin America. Working document, XV Session.

Nieves Rivera, M., Marano, R., Gómez, N., & Salgado, R. (2024). Irrigation technologies and water use in Latin America. Presentation at the XV ALIDA Meeting, Latin American Association for Cotton Research and Development. https://siea.midagri.gob.pe/siea_bi/. Accessed October 2025.

Soil Management and Regenerative Agriculture

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Introduction

Yield stability of cotton in tropical and subtropical environments depends directly on improvements in soil quality and balanced nutrient management. In these regions, climatic instability—particularly the frequent occurrence of water deficits—has been one of the main limiting factors to achieving high yields. In this context, the adoption of conservation and regenerative management systems becomes essential to enhance the resilience and sustainability of cotton production; where yield stability refers to maintaining productive performance across seasons despite climate variability, especially drought.

Evidence syntheses indicate that multiple regenerative practices (e.g., cover cropping, reduced tillage, diversified rotations) can increase soil carbon sequestration rates, although responses vary by context and measurement approach (Villat & Nicholas, 2023). Crop diversification, including species with root systems capable of exploring different soil layers, combined with no-tillage systems and increases in soil organic matter content, represents one of the main strategies for restoring the quality of degraded soils. These systems promote simultaneous improvements in soil physical, chemical, and biological properties, resulting in greater efficiency of water and nutrient use and, consequently, improved yield stability.

Soil fertility

Low nutrient availability, soil acidity, and high levels exchangeable aluminum Al^{3+} are major constraints to agricultural production in tropical environments. Under these conditions, soil amendment through liming is an essential practice, as it supplies calcium (Ca) and magnesium (Mg), increases soil pH, and neutralizes Al^{3+} toxicity (Flores et al., 2024). In addition, the use of gypsum, as a more soluble source of Ca, has proven effective in promoting cotton root growth, particularly at greater soil depths (Pivetta et al., 2019).

The combination of soil amendment via liming and gypsum application not only improves soil fertility and yield stability under drought conditions (Andrade et al., 2025), but also enhances soil physical quality through increased formation of stable aggregates (Andrade et al., 2025) and promotes soil carbon sequestration (Andrade et al., 2024). Furthermore, phosphorus fertilization is a key strategy to stimulate cotton root growth, favoring greater soil profile exploration and improved tolerance to water stress (Rosolem et al., 1999). Therefore, the first step toward regenerative agriculture and soil conservation is adequate soil amendment combined with balanced nutrient supply.

Soil physical quality

Soil physical quality is a central component of conservation-based production systems. Reducing mechanical resistance to root penetration and promoting the formation of biopores are fundamental strategies to improve water infiltration, soil water storage, and cotton root development. Cover crop mixtures can also increase aggregate stability and shift organic carbon distribution among macroaggregate fractions (Gentsch et al., 2024). Recent studies have shown that soil compaction is inversely correlated with fiber yield, as it restricts both vegetative and reproductive growth of cotton (Jamali et al., 2021). No-tillage systems and crop rotation are indispensable practices for improving soil structure, increasing water conservation within the system, and consequently enhancing cotton yield (Nouri et al., 2021).

Soil microbiology

Soil microbiology represents one of the most recent and promising research frontiers in cotton production systems, with well-documented positive effects on fiber yield. The quality and diversity of soil microbial communities are fundamental for building resilient and productive agroecosystems.

Studies conducted in sandy soils undergoing degradation recovery have shown that rotating cotton with grasses and legumes during the off-season resulted in improvements in soil fertility, increased dehydrogenase enzyme activity, higher microbial biomass carbon, and significant increases in cotton fiber yield (Cordeiro et al., 2021a). Moreover, a positive linear relationship was observed between β-glucosidase activity and microbial biomass carbon with cotton yield, whereas yield was negatively correlated with the soil metabolic quotient (Cordeiro et al., 2021b). These results demonstrate that cotton can be successfully cultivated in soils under degradation recovery when conservation practices, crop rotation, and appropriate soil amendment are adopted.

Additionally, the use of bioinputs has proven to be a promising strategy within regenerative agriculture systems, particularly for stimulating root growth, improving nutrient use efficiency, and increasing crop resilience to water stress (Paiva & Bini, 2025; Arora & Mishra, 2024). However, despite the positive results reported in several studies, there is still a need for further long-term research conducted under field conditions and across contrasting soil and climatic environments to better understand the underlying mechanisms, the consistency of yield responses, and the integration of bioinputs with established soil amendment and fertility management practices.

Soil carbon sequestration

The use of cover crops and crop rotation, in addition to increasing cotton yield—especially in drought-prone environments—can contribute to soil carbon sequestration and long-term carbon storage, with outcomes depending on climate, soil type, and management history (Villat & Nicholas, 2023). This process is essential not only for improving soil fertility but also for mitigating the environmental impacts of agricultural production.

Recent evidence indicates that after five years of crop rotation involving cotton and cover crops, systems using mixed-species cover crops increased soil carbon stocks by up to 46% in the 0–40 cm soil layer compared with cotton/fallow systems (Cordeiro et al., 2022a). Notably, these areas had previously been occupied by degraded pastures, highlighting the strong potential of regenerative agriculture to restore soil carbon pools.

Crop rotation and cotton yield

Soil quality management and regenerative agriculture rely on crop rotation as a core strategy. Consistent evidence shows that greater crop diversification leads to larger gains in soil quality and cotton yield.

In sandy soils in Brazil, after two years of implementing cotton production systems in areas under recovery, a 41% increase in yield was observed compared with cotton/fallow systems. Rotating cotton with a single legume or a single grass species also resulted in yield gains, although of lower magnitude (approximately 21%) (Cordeiro et al., 2022b). In long-term systems established on clayey soils prone to compaction, higher yield gains were also reported when greater crop diversification was adopted, regardless of the tillage system used (Anghinoni et al., 2019).

Figure-1. Crop rotation

Figure-2. Organic mulch

Boron fertilization in conservation systems

Among mineral nutrients, boron (B) is one of the most limiting elements for cotton productivity in degraded soil environments, requiring efficient strategies to ensure adequate supply. Building soil organic matter and maintaining year-round soil cover can improve B supply by enhancing nutrient cycling and reducing B losses in high-rainfall environments (Sarkis et al., 2024).

Studies have shown that when boron fertilization is combined with crop rotation systems and mixed cover crops, cotton yield gains are greater (Cordeiro et al., 2022b). Although the total boron requirement for high-yielding cotton crops is approximately 600 g ha^{-1} (Rochester, 2007), yield responses have been reported with boron application rates ranging from 1 to 4 kg ha^{-1} in soils with low organic matter content (Cordeiro et al., 2024).

Conversely, in soils with higher organic matter and available boron levels, responses to mineral boron fertilization tend to be smaller (Cordeiro et al., 2024). Because B behavior is strongly affected by soil texture and organic matter, rates and sources should be tailored using soil and/or leaf diagnosis to avoid deficiency or toxicity (Vera-Maldonado et al., 2024)..

Thus, regenerative agriculture, based on crop rotation and the use of cover crops, is a key ally in ensuring adequate boron supply for cotton.

In addition, cotton plants adequately supplied with boron have shown greater nitrogen and potassium use efficiency, reducing the demand for N and K fertilizers and contributing to more sustainable production systems (Galdi et al., under review).

Final considerations

Cotton production can be effectively integrated with soil conservation and recovery strategies, resulting in greater yield stability under climate variability.

The main pillars of regenerative cotton systems include no-tillage, diversified cover crops, and adequate soil amendment combined with balanced nutrient management.

Together, these practices improve soil physical, chemical, and biological quality, enhance root development, increase water and nutrient use efficiency, and strengthen soil carbon sequestration, ultimately supporting stable yields in drought-prone environments.

The use of bioinputs represents a promising complementary strategy within regenerative cotton systems; however, their contribution to yield stability still requires validation through long-term field studies conducted across contrasting soil and climatic conditions.

References

Andrade, M. G. D. O., Cordeiro, C. F. D. S., Calonego, J. C., Franzluebbers, A., & Rosolem, C. A. (2024). Soil amendment and N fertilization strategies to improve C sequestration and storage in soil aggregates. Soil Science Society of America Journal, 88(5), 1767-1777.

Andrade, M. G. D. O., Cordeiro, C. F. D. S., Roberto, A. F., Calonego, J. C., & Rosolem, C. A. (2025). Lime and gypsum reduce N-fertilizer requirements and improve soil physics, fertility and crop yields in a double-cropped system. Geoderma, 453, 117132.

Anghinoni, G., Tormena, C. A., Lal, R., Zancanaro, L., & Kappes, C. (2019). Enhancing soil physical quality and cotton yields through diversification of agricultural practices in central Brazil. Land Degradation & Development, 30(7), 788-798.

Arora, N. K., & Mishra, J. (2024). Next generation microbe-based bioinoculants for sustainable agriculture and food security. Environmental Sustainability, 7, 1–4.

Cordeiro, C. F. D. S., Rodrigues, D. R., Silva, G. F. D., Echer, F. R., & Calonego, J. C. (2022a). Soil organic carbon stock is improved by cover crops in a tropical sandy soil. Agronomy Journal, 114(2), 1546-1556.

Cordeiro, C. F.S, Echer, F. R., & Araujo, F. F. (2021a). Cover crops impact crops yields by improving microbiological activity and fertility in sandy soil. Journal of Soil Science and Plant Nutrition, 21(3), 1968-1977.

Cordeiro, C. F.S, Rodrigues, D. R., Rocha, C. H., Araujo, F. F., & Echer, F. R. (2021b). Glomalin and microbial activity affected by cover crops and nitrogen management in sandy soil with cotton cultivation. Applied Soil Ecology, 167, 104026.

Cordeiro, L. F. D. S., Malenowtch, J. V. C., Cordeiro, C. F. D. S., Detoni Filho, J. A. C., Furlani Junior, E., & Ferrari, S. (2024). Improving cotton yield and fiber quality in different tropical soils with boron fertilization. Agronomy Journal, 116(3), 1540-1550.

Cordeiro, L. F.S, dos Santos Cordeiro, C. F., & Ferrari, S. (2022b). Cotton yield and boron dynamics affected by cover crops and boron fertilization in a tropical sandy soil. Field Crops Research, 284, 108575.

Flores, C., Bayer, C., & Tiecher, T., et al. (2024). Impacts of tillage and liming on crop yields and soil acidity correction: Insights from a 32-year experiment in Southern Brazil. Plant and Soil.

Gentsch, N., Riechers, F. L., Boy, J., Schweneker, D., Feuerstein, U., Heuermann, D., & Guggenberger, G. (2024). Cover crops improve soil structure and change organic carbon distribution in macroaggregate fractions. Soil, 10(1), 139–150.

Jamali, H., Nachimuthu, G., Palmer, B., Hodgson, D., Hundt, A., Nunn, C., & Braunack, M. (2021). Soil compaction in a new light: Know the cost of doing nothing–A cotton case study. Soil and Tillage Research, 213, 105158.

Nouri, A., Yoder, D. C., Raji, M., Ceylan, S., Jagadamma, S., Lee, J., ... & Saxton, A. M. (2021). Conservation agriculture increases the soil resilience and cotton yield stability in climate extremes of the southeast US. Communications Earth & Environment, 2(1), 155.

Paiva, C. A. O., & Bini, D. (2025). Bioinputs in Agriculture: Trends and Challenges in Brazil. (APD/Embrapa). Sete Lagoas, October 2025.

Pivetta, L. A., Castoldi, G., Pivetta, L. G., Maia, S. C. M., & Rosolem, C. A. (2019). Gypsum application, soil fertility and cotton root growth. Bragantia, 78(2), 264-273.

Rochester, I. J. (2007). Nutrient uptake and export from an Australian cotton field. Nutrient cycling in Agroecosystems, 77(3), 213-223.

Rosolem, C. A., Witacker, J. P., Vanzolini, S., & Ramos, V. J. (1999). The significance of root growth on cotton nutrition in an acidic low-P soil. Plant and Soil, 212(2), 183-188.

Sarkis, L. F., Rabêlo, F. H. S., Hippler, F. W. R., & Guelfi, D. (2024). Soil organic matter influences the agronomic efficiency of boron fertilizers in sandy Oxisol cultivated with soybean. Scientia Agricola, 81, e20230231.

Vera-Maldonado, P., Aquea, F., Reyes-Díaz, M., et al. (2024). Role of boron and its interaction with other elements in plants. Frontiers in Plant Science.

Villat, J., & Nicholas, K. A. (2023). Quantifying soil carbon sequestration from regenerative agricultural practices in crops and vineyards. Frontiers in Sustainable Food Systems, 7, 1234108.

Session-2: Genetic Resources and Breeding

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Introduction

The second session of the ALIDA meeting focused on the conservation of genetic resources and issues related to cotton breeding in Latin America, highlighting recent advances, challenges, and regional perspectives. The discussion emphasized how the biodiversity of the genus *Gossypium* constitutes a strategic foundation to address the impacts of climate change, improve resistance to pests and diseases, and maintain the competitiveness of Latin American cotton fiber in the global market. In addition, the importance of coordinating efforts among public, private, and community-based institutions was underscored to ensure that scientific knowledge is translated into productive, cultural, and social benefits in each country.

The session was organized around four thematic areas:

- Conservation and germplasm banks in Latin America
- Breeding programs and their importance in Latin America
- Breeding techniques and species in Latin America
- Commercial varieties and available technologies

First, germplasm conservation efforts in different countries were presented. The current status of ex situ germplasm banks (such as those of INIAP in Ecuador, INTA in Argentina, EMBRAPA in Brazil, and INIA in Peru) was reviewed, together with experiences in in situ conservation of native species such as *Gossypium mustelinum* in Brazil and *G. darwinii* in the Galápagos Islands. The importance of preserving local species with naturally colored fibers, high cultural value, and breeding potential was highlighted, as these resources are currently threatened by genetic erosion, replacement by commercial cultivars, and regulatory pressures. Among the main limitations faced by germplasm banks are insufficient financial resources, inadequate infrastructure, and shortages of specialized personnel, as well as restrictive regulatory frameworks. The loss of genetic diversity would represent a serious threat to the capacity to adapt to climate change and emerging pests.

Subsequently, the regional landscape of cotton breeding programs was discussed. Different strategies and objectives pursued by both public institutions (INTA, EMBRAPA, INIA, UNP, UNALM, IAN, IPTA) and private companies (BASF, Bayer, TMG, IMA, IPA) were presented. These include improving yield and fiber quality, increasing tolerance to water and salinity stress, and incorporating resistance to diseases such as angular leaf spot, blue disease, ramularia leaf spot, and nematodes. Concrete examples of variety development with outstanding traits were shared, including long fibers comparable to Peruvian Pima, multiple pathogen resistance, and herbicide tolerance (IMICott technology in Argentina).

The session also addressed the genetic improvement techniques used in the region, ranging from conventional methods such as controlled crosses, mass and pedigree selection, and multi-environment testing, to modern tools including molecular markers, mutagenesis, assisted introgression, transgenesis, and gene silencing (RNAi). In several countries, transgenic varieties have already been released (Brazil, Argentina, Colombia), while in others regulatory restrictions remain in place (Peru, Ecuador, Bolivia). Successful cases illustrated the integration of technologies, such as the development of varieties resistant to key pests or with premium fiber quality.

Finally, the regional panorama of available varieties and technologies was presented. Cotton production in Latin America is dominated by *Gossypium hirsutum*, although there is growing interest in *G. barbadense* (extra-long staple fiber) in Peru and Brazil. High adoption of biotechnology in Brazil, Argentina's leadership in innovation (IMICott, boll weevil resistance), and regulatory constraints in Bolivia, Ecuador, and Peru were highlighted.

The conclusion was clear: effective integration of conventional breeding, biotechnology, and germplasm conservation is essential to strengthen the competitiveness of Latin American cotton in the face of climate change, pest pressures, and the global market.

Conservation of Cotton Genetic Resources in Latin America: Challenges and Opportunities

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Introduction

The *Gossypium* genus of the Malvaceae family includes approximately 50 species (45 diploids and 5 allotetraploids) (Wendel and Grover, 2015). Cotton species from America include several D genome diploid species (2n=2x=26) endemic to western Mexico (center of diversity) which lead to the evolution of endemics in Peru (*G. raimondii*) and the Galapagos Islands (*G. klotzschianum*) (Wendel and Grover, 2015). Besides these diploid materials, there are two poliploid wild species: island endemic *G. darwinii* from the Galapagos Islands and Brazilian *G mustelinum* (Lacape et al., 2007; Wendel and Grover, 2015). Besides, AD allotetraploid lineages belonging to the primary gene pool indigenous to America, include *G. barbadense* and *G. hirsutum* (Westengen et al., 2005). An updated review of *Gossypium* spp. in America is presented by Viot and Wendel (2023).

The earliest archeological reports of cotton in South America are of seeds dated 3500-3000 BC (Damp and Pearsall, 1994) and pottery dating 5500 RCYBP (Marcos, 1973; Stother et al., 2011) in Ecuador; and, cotton boll dated 5490 YBP for Peru (Dillehay et al., 2007). The history of cotton usage in other Latin American countries is more recent but also important. For example, in Argentina, *G. barbadense* (including *G. barbadense* var. brasiliensis) was introduced 600 years ago and *G. hirsutum* in 1556. In Brazil, *G. barbadense* was planted before 1500 even before the arrival of the Portuguese; similarly to *G. hirsutum* var. marie galante, which spread from Central America to Northern Brazil. In Colombia, *G. barbadense* has been used by indigenous people since the 12th and 13th centuries. Until date cotton production in South America continue to varying degrees for example Brazil, Argentina, and Peru present significant commercial productions followed by Colombia and Bolivia, and lastly Ecuador, where the domestic production is very limited due to the country's dependence on cotton imports.

Figure-1. Diversity of cotton germplasm (Campbell et al., 2010)

Conservation of Cotton Genetic Resources

Thanks to ALIDA meeting held from the 8th to 12th of September of 2025, at INTA Estación Experimental Agropecuaria de Reconquista, Santa Fe, Argentina, the following information was acquired from the country delegates.

Ex situ conservation

In Latin America, there are national gene banks conserving genetic diversity of cotton (*Gossypium* spp.). These national gene banks are managed by different institutions such as the Instituto Nacional de Tecnología Agropecuaria (INTA) in Argentina, Empresa Brasileira de Pesquisa Agropecuária (Embrapa) in Brazil, Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA) in Colombia, Instituto Nacional de Investigaciones Agropecuarias (INIAP) in Ecuador, Instituto Nacional de Innovación Agraria (INIA) in Peru, and Instituto Nacional de Innovación Agropecuaria y Forestal (INIAF) in Bolivia. Table 1 shows a list of species according to the known gene pools of cotton *Gossypium* spp. and the number of accessions per gene bank. Cultivated and wild cotton relatives are described from national or international origin.

Table-1. Species and number of accessions of *Gossypium* spp. conserved in six national gene banks in Latin America according to the species gene pools

Species	Genome	ARGENTINA		BRASIL		COLOMBIA		ECUADOR		PERU		BOLIVIA	
Source of collections*		Natl	Intl	Natl	Intl	Natl	Intl	Natl	Intl	Natl	Intl	Natl	Intl
Cultivated		-	-	-	-	-	-	-	-	-	-	-	-
G. hirsutum L.	AD_1	-	-	-	-	-	-	-	-	10	-		-
Cultivars (breeding materials)		180	349	489	-	118	271	-	154	-		-	
Landraces (local materials)			11	493	-			-	-	-	-	-	-
Unclassified		12	9	-	1610	8	48	-	-	-	-	-	-
G. barbadense L.	AD_2	-	-	-	-			-	-	-	-	23	-
Cultivars		-	-	94	-	1	5	-	3	422			
Landraces		35	2	1594	-	10	-	168	-		-		-
Unclassified		-	-		56	-	-	4	-		-		-
Primary gene pool		-	-	-	-	-	-	-	-	-	-	-	-
G. tomentosum Nuttall ex Seeman	AD_3	-	-	-	2	-	-	-	-	-	-	-	-
G. mustelinum Miers ex Watt	AD_4	-	-	102	-	-	-	-	-	-	-	-	-
G. darwinii Watt	AD_5	-	-	-	-	-	-	1	-		-	-	-
Secondary gene pool		-	-	-	-	-	-	-	-	-	-	-	-
G. herbaceum L.	A_1			-	18	1	-	-	-	-	-	-	-
G. arboreum L.	A_2	-	-	-	214	-	1	-	-	-	-	-	-
G. anomalus Wawra	B_1	-	-	-	3	-	-	-	-	-	-	-	-
G. triphyllum (Harvey & Sonder)	B_2	-	-	-	1	-	-	-	-	-	-	-	-
G. capitis-viridis Mauer	B_3	-	-	-	-	-	-	-	-	-	-	-	-
G. longicalyx J. B. Hutchinson & Lee	B_3	-	-	-	-	-	-	-	-	-	-	-	-
G. thurberi Todaro	F_1	-	-	-	-	-	-	-	-	-	-	-	-
G. trilobum (DC) Skovsted	D_8	-	-	-	11	-	-	-	-	-	-	-	-
G. davidsonii Kellogg	$D_{3\text{-}d}$	-	-	-	-	-	-	-	-	-	-	-	-
G. klotzschianum Andersson	$D_{3\text{-}k}$	-	-	-	-	-	-	0	-		-	-	-
G. armourianum Kearney	$D_{2\text{-}1}$	-	-	-	-	-	-	-	-	-	-	-	-
G. harknessii Brandegee	$D_{2\text{-}2}$	-	-	-	4	-	-	-	-	-	-	-	-
G. aridum (Rose &Stanldley) Skovsted	D_4	-	-	-	-	-	-	-	-	-	-	-	-
G. lobatum H. Gentry	D_7	-	-	-	-	-	-	-	-	-	-	-	-
G. raimondii Ulbrich	D_5	-	-	-	-	-	-	-	-	4	-	-	-
Tertiary gene pool		-	-	-	-	-	-	-	-	-	-	-	-
G. sturtianum J.H. Willis	C_1	-	-	-	-	-	-	-	-	-	-	-	-
G. robinsonii F. Mueller	C_2	-	-	-	2	-	-	-	-	-	-	-	-
G. nandewarense (Derera) Fryxell	C_{1N}	-	-	-	2	-	-	-	-	-	-	-	-
G. stocksii Masters in Hooker	E_1	-	-	-	-	-	-	-	-	-	-	-	-
G. somalense (Gurke) J.B. Hutchinson	E_2	-	-	-	-	-	-	-	-	-	-	-	-
G. areysianum Deflers	E_3	-	-	-	-	-	-	-	-	-	-	-	-
G. incanum (Schwartz) Hillcoat	E_4	-	-	-	4	-	-	-	-	-	-	-	-
G. australe F. Mueller	G	-	-	-	-	-	-	-	-	-	-	-	-
G. nelsonii Fryxell	G_3	-	-	-	-	-	-	-	-	-	-	-	-
G. bickii Prokhanov	G_1	-	-	-	-	-	-	-	-	-	-	-	-
Gossypium sp.		-	-	-	-	226	96	-	-	-	-	-	-
Gossypium with no known geographic		114		-		128		-		-		-	
Total accessions		712		4699		909		330		436		23	

Figure-2. Ex situ conservation: Left (Ecuador), Base Bank (-15°C), INIAP, EESC, Quito; Right (Argentina) Orthodox Seed Conservation, Active Bank (0-5°C) Saenz Pena-Chaco; Base Bank (-15°C), Castelar-Buenos Aires.

National cotton collections have been prioritized by the gene banks, however, four genebanks conserve also international accessions as duplicates from other genebanks. The primary focus for conservation have been cultivated materials of *Gossypium hirsutum* and *G. barbadense* and less for wild relatives of cotton. It is important to notice that landraces of *G. barbadense* –native to South America- have been collected at national level and conserved. On the other hand, the collections of cotton wild relatives in the region are apparently minor and underrepresented; for example, the Ecuadorian gene bank conserve only one accession of *G. darwinii* and none of *G. klotzchianum* both from the Galapagos Islands; or INIA does not present any conserved accession of native *G. raimondii*. Only in the case of Brazil there is a significant collection of its native cotton, *G. mustelinum*, with 102 accessions.

All the institutional gene banks within the six South American countries have ex situ conservation facilities for cotton germplasm. Generally, cotton seeds are stored under low-temperature conditions of 0 to 5 °C or -15 to -20 °C in trilaminate aluminum foil bags.

In situ conservation

For cotton wild relatives, different in situ conservation initiatives have been publish e.g. in Peru, in situ conservation actions for *G. raimondii* is reported by Delgado-Paredes (2021). In Brazil, Barroso et al. (2021) describes challenges and opportunities for in situ maintenance of *G. mustelinum*. For Ecuador, non-specific in situ conservation is carried out for the species *G. klotzschianum* and *G. darwinii* in the Galápagos Islands, however, these species occur in national park areas that cover 97% of the islands.

Germplasm Characterization

The characterization of accessions has been carried out at various levels, with morphological characterization being the most common and reported by all countries. Gene banks report the usage of cotton descriptors published by IBPGR (1985) or UPOV (2001), but molecular characterization is also mentioned. Examples of national level characterizations include: Argentina (Klein et al., 2022), Colombia (Carrillo et al., 2012), Ecuador SSR (Monteros-Altamirano et al., 2025 submitted), and Peru (Morales-Aranibar et al., 2023). Argentina also reports a botanical characterization of their materials.

Access of genetic resources

Global mechanisms exist for access to plant genetic resources for food and agriculture, primarily involving the International Treaty on Plant Genetic Resources (FAO, 2009) and the Nagoya Protocol (CBD, 2011). Since cotton is not listed in Annex I of the first, access is only possible through the Nagoya Protocol, which has been signed by almost all countries in the region. It is also necessary to review existing regional and national laws and regulations, which can be consulted in Arriel et al. (2023) or national websites.

Priority Species for Conservation

According to the gene bank representatives, some species were prioritized for conservation due to the risk of loss in the field, known as genetic erosion. These species are unique genetic materials that will serve as genetic bases for breeding in response to biotic and abiotic factors in the future. These species are adapted to different environmental conditions and present significant cultural, artisanal, and textile value.

For Argentina, *G. barbadense* (including var. brasiliensis), *G. hirsutum* landraces and obsolete *G. hirsutum* materials were selected as priority due to the risk of loss due to climatic and anthropogenic displacement besides its ornamental and cultural value. For Colombia: *G. arboreum* and *G. herbaceum*, which are currently found in herbaria; both introductions are old and have limited representation in the national collection, as do materials of *G. barbadense*.

For Brazil: *G. mustelinum*, the only native species of Brazil, was prioritized, although previously collected, this species exhibits high genetic diversity in the field; in addition to *G. hirsutum* var. marie-galante (mocó) and *G. barbadense* materials. In Ecuador there are no accessions conserved of native *G. darwinii* and *G. klotschianum* (also from the Galápagos); collections exist internationally (Dessauw and Hau, 2006) but they are not duplicated at INIAP gene bank. In Peru: The native species *Gossypium barbadense* L. (cultivated) and *Gossypium raimondii* (wild) were prioritized. In Bolivia: Collections of *G. barbadense* with colored fibers are mentioned. Finally, accessions of *G. barbadense* adapted to contrasting ecological conditions, especially those with colored fibers, were also mentioned as priority. In general, the genetic diversity of these species is poorly studied.

Current Gene Banks limitations

Several limitations have been identified by representatives of the South American gene banks:

- Lack of equipment is a common denominator for all gene banks; proper seed conservation requires equipment that allows for adequate seed handling and year-round operation, which also implies ongoing maintenance and expenses.
- The lack of molecular characterization as a methodology for genetic diversity studies is a deficiency in the region, both due to the high cost of equipment and the need for qualified personnel.
- The lack of morphological characterization has also been mentioned, given that, although morphological descriptors have been published, there are no regional consensus descriptors.
- Collection of germplasm in South America faces challenges due to logistical difficulties in accessing certain materials.
- International, regional or national regulations on access to plant genetic resources was also mentioned as a limiting factor.

- Common issues among the gene banks are budget limitations and shortage of qualified personnel.

Impact of losing genetic diversity

Loss of valuable genetic resources for breeding adaptation to current and future biotic and abiotic factors. This loss is also associated with the loss of traditional knowledge and cultural practices, which would contribute to dependence on international germplasm for local breeding in the region.

Conclusions

Currently, the genetic diversity available in the region is partially represented and conserved in national gene banks. There is important genetic diversity in South America which still need to be collected, conserved, characterized and used.

Although most of the efforts have been put in collecting and conserving cultivated materials the cotton wild relatives, representatives of the region, are still in need of collection, conservation and characterization.

In general, all gene banks of the region face technical, financial and personnel deficiencies but with a better inter-institutional cooperation and international support, most of those challenges could be sorted out in the short or medium term.

References

Arriel NHC, Cerón M, Cardoso KCM, Dileo PN, González C, Hoffmann LV. (2023). Jiménez H, Klein LM, de A Lima MM, Medina C, et al. and Larrañaga-Monsalve, J.F. History and status of local cotton *Gossypium* spp. in Argentina, Brazil, Colombia and Ecuador. Genetic Resources and Crop Evolution.; 70(8), pp.2193-2217.

Barroso, P. A. V., Hoffmann, L. V., & da Costa, N. D. L. (2021). Challenges and opportunities for in situ maintenance of the native Brazilian Cotton *Gossypium mustelinum* Miers. Frontiers in Ecology and Evolution, 9, 675340.

Campbell BT, Saha S, Percy R, Frelichowski J, Jenkins JN et al (2010) Status of the global cotton germplasm resources. Crop Sci 50:11

Carrillo, C., Montenegro Ramos, O., Barragán Quijano, E., Cadena Torres, J., Melo, J. P., & Mera, E. A. (2012). Líneas y variedades de algodón (*Gossypium* sp.) de fibra larga y extralarga para mercados de exportación: resultados de la investigación en algodón, ensayos de rendimiento y pruebas regionales 2009 a 2011.

CBD. 2011. Nagoya Protocol On Access to Genetic Resources and the Fair And Equitable Sharing of Benefits Arising from their Utilization to The Convention on Biological Diversity. Secretariat of the Convention on Biological Diversity. 25 p. ISBN: 92-9225-306-9 https://www.cbd.int/abs/doc/protocol/nagoya-protocol-en.pdf

Damp J, Pearsall D. (1994). Early cotton from coastal Ecuador. Economic Botany. 48 (2): pp. 163-165.

Delgado-Paredes, G. E., Vásquez-Díaz, C., Esquerre-Ibanez, B., Hashimoto-Moncayo, E. E., Bazan-Sernaque, P., & Rojas-Idrogo, C. (2021). In situ germplasm conservation of *Gossypium raimondii* Ulbricht (“algodoncillo”) in the Lambayeque region (Peru). Pakistan Journal of Botany, 53(6), 2135-2142.

Dessauw, D., and Hau, B. (2006). Inventory and history of the CIRAD cotton (*Gossypium* spp.) germplasm collection.

Dillehay TD, Rossen J, Andres TC Williams DE. (2007). Preceramic adoption of peanut, squash, and cotton in northern Peru. Science. 316(5833), pp.1890-1893.

FAO (2009). International Treaty on Plant Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations. 56 p. https://www.fao.org/4/i0510e/i0510e.pdf

IBPGR. (1985). Cotton descriptors (revised). International Board on Plant Genetic Resources. Rome. 25p.

Klein, L. M., Etchart, V. J., Tcach, M. A., Gonzales, A. J., Dileo, P. N., Tcach, N. E., & Spoljaric, M. V. (2022). Variabilidad morfológica y molecular en genotipos de algodón (*Gossypium hirsutum* L.) de tres orígenes geográficos diferentes. Ciencias Agronómicas, (40), e025-e025.

Lacape J, Dessauw D, Rajab M, Noyer JL, Hau B. (2007). Microsatellite diversity in tetraploid *Gossypium* germplasm: assembling a highly informative genotyping set of cotton SSRs. Mol Breeding. 19, 45–58. https://doi.org/10.1007/s11032-006-9042-1

Marcos J. (1973). Tejidos hechos en telar en un contexto Valdivia tardío. Casa de la Cultura Ecuatoriana, Guayaquil. (Separata de Cuadernos de Historia y Arqueología, Año XXIII – No. 40 Publicación de la Casa de la Cultura Ecuatoriana. Núcleo del Guayas). 1973. 164-175.

Monteros-Altamirano A, Buitrón-Bustamante J., Morillo-Velasteguí E., Simbaña A. Cañarte E., Paredes N., Suarez D. 2025. Survey of genetic diversity in the Ecuadorian national cotton (*Gossypium* spp. l.) collection assessed by SSR markers. Snp. Submitted.

Morales-Aranibar, L., Yucra, F. E. Y., Aranibar, C. G. M., Sáenz, M. C., Gonzales, H. H. S., Aguilera, J. G., ... & Teodoro, P. E. (2023). First report on the genetic diversity of populations of *Gossypium barbadense* L. and *Gossypium hirsutum* L. in the Amazonian Native Communities, Cusco-Peru. Plants, 12(4), 865.

Stothert K.E. (2011). Coastal Resources and the Early Holocene Las Vegas Adaptation of Ecuador. Chapter 15. In. N.F. Bicho et al. (eds.), Trekking the Shore: Changing Coastlines and the Antiquity of Coastal Settlement, Interdisciplinary Contributions to Archaeology. pp. 355-382. DOI 10.1007/978-1-4419-8219-3_15

Unión Internacional Para La Protección De Las Obtenciones Vegetales (UPOV). (2001). Guidelines for the conduct of tests for distinctness, uniformity and stability cotton (*Gossypium* L.). 1–26. https://www.upov.org/de/publications/tg-rom/tg088/tg_88_6.pdf

Viot, C. R., & Wendel, J. F. (2023). Evolution of the cotton genus, *Gossypium*, and its domestication in the Americas. Critical Reviews in Plant Sciences, 42(1), 1-33.

Wendel JF, Grover CE. (2015). Taxonomy and evolution of the cotton genus, *Gossypium*. In Cotton, 2nd edn. (Fang, D.D. and Percy, R.G., eds). WI: American Society of Agronomy Inc. pp. 25–44.

Westengen OT, Huaman Z, Heun M. (2005). Genetic diversity and geographic pattern in early South American cotton domestication. Theor Appl Genet 110(2):392–402. https:// doi. org/ 10. 1007/ s00122- 004- 1850-2

Breeding Techniques and Species in Latin America

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Abstract

Genetic improvement of cotton in Latin America is a strategic activity aimed at increasing productivity, improving fiber quality, and enhancing crop resilience to biotic and abiotic stresses under diverse agroecological conditions. Breeding programs across the region combine conventional selection methods with modern biotechnological tools, advanced genetic resource management, and the selective incorporation of transgenic events, achieving variable progress according to national priorities and institutional capacities. Countries such as Brazil and Argentina exhibit highly structured systems integrating hybridization, mutagenesis, marker-assisted selection, and biotechnology, resulting in multi-resistant cultivars with superior fiber quality.

Peru, Paraguay, and Bolivia emphasize germplasm conservation, hybridization, and multi-environment evaluation, while Colombia has successfully introgressed commercial transgenic traits into national germplasm. In contrast, Ecuador currently focuses on germplasm characterization with limited active breeding. Despite the broad technical toolbox available, progress in several countries is constrained primarily by economic, infrastructural, and human resource limitations. Overall, regional experience demonstrates that integrating traditional breeding with modern biotechnology, supported by regional cooperation, is essential for sustainable cotton improvement in Latin America.

Genetic improvement of cotton in Latin America constitutes a strategic component for increasing productivity, improving fiber quality, and strengthening crop resilience to biotic and abiotic stresses. Across the region, an integrated application of traditional breeding techniques, modern biotechnological tools, advanced genetic resource management, and the selective incorporation of transgenic events can be observed, enabling significant progress according to production priorities and the level of development of breeding programs in each country.

In this regional context, the implementation of breeding strategies and technologies exhibits marked heterogeneity, driven by differences in production history, availability and conservation of genetic resources, institutional capacities, and levels of technological adoption. This heterogeneity is further reinforced by the wide diversity of ecosystems and production systems present in Latin America, resulting in a highly variable agroecological scenario. These particularities define country-specific approaches, both in the establishment of breeding objectives and in the selection and combination of conventional and biotechnological tools. The following sections describe the most relevant experiences and advances in each country as an expression of the diversity of strategies applied to cotton genetic improvement in the region.

In **Colombia**, where cultivation is mainly focused on *Gossypium hirsutum*, breeding objectives are oriented toward improving yield, fiber quality, disease resistance, and adaptation to production environments. Genetic variability is generated through directed crosses among elite plants and successive backcrosses for line conversion. Marker-assisted introgression, particularly using qPCR for the detection of transgenic events, has been essential for selecting parental lines carrying the cry1Ac, cry2Ab, and CP4 EPSPS proteins. Through a backcrossing strategy up to the RC4 generation, AGROSAVIA successfully incorporated these events into its germplasm, leading to the development of GM cultivars such as Nevada–123, Oasis–129, and Sanjuanera–151, which represent major milestones in the modernization of cotton production in the country.

Figure 1. RNAi GM events for resistance to boll weevil

In **Ecuador**, INIAP conducted an active breeding program between 1967 and 1994; however, this program is no longer active, and current efforts are limited to germplasm collection and characterization. Although this approach contributes to genetic diversity conservation, the absence of active breeding limits the development of new cultivars adapted to local conditions.

Brazil has one of the most structured cotton breeding systems in the region, with multiple active programs encompassing conventional selection and the planned introgression of biotechnological events. Priority objectives include productivity, fiber quality, crop cycle duration, resistance to pests and diseases, and drought tolerance, using both *G. hirsutum* race Marie Galante and *G. barbadense* as sources of desirable traits. Mass and pedigree selection constitute the foundation of line development, while marker-assisted introgression using SSR markers has enabled the incorporation of resistance genes to critical diseases such as angular leaf spot and blue disease, as well as to pests including root-knot and reniform nematodes. The integration of conventional breeding with biotechnology has resulted in cultivars such as BRS 700FL B3RF, a multi-resistant genotype with high fiber quality comparable to Pima cottons, and BRS 800 B3RF, resistant to bacterial blight, blue disease, and *Meloidogyne incognita*. These achievements reflect a highly efficient integrated breeding model.

Figure-2. The integration of conventional breeding with biotechnology has resulted in cultivars such as BRS 700FL B3RF, a multi-resistant genotype with high fiber quality

Peru, with a production history strongly linked to *Gossypium barbadense*, exhibits remarkable genetic diversity exploited by institutions such as INIA, IPA, universities, and regional governments. Breeding objectives include yield, fiber quality, crop cycle, and resistance to biotic stresses. Genetic variability is generated through hybridization and characterized using molecular markers, while conventional selection is supported by multi-environment trials to identify stable and well-adapted materials. Significant advances have been achieved through the integration of traditional selection and germplasm conservation, as exemplified by the historical development of Tangüis cotton. In addition, intervarietal hybridizations evaluated through comparative testing networks coordinated by IPA have enabled the identification of high-yielding lines with excellent fiber quality, while INIA has strengthened morphogenetic characterization of regional collections using ISSR markers to support future breeding programs.

In **Bolivia**, current efforts focus on strengthening the genetic base of cotton through the collection, phenotypic and genotypic characterization, and conservation of accessions, with emphasis on *G. barbadense*, a species native to South America. These studies have identified outstanding genotypes such as SJB-01 and CCA-348. In parallel, the country has initiated agronomic validation of transgenic varieties containing the MON 531 × MON 1445 events to improve pest and weed control and increase yield. The varieties PORA 3 BGRR, Guaraní BGRR, and Guazuncho 4 BGRR are being compared with conventional materials to assess agronomic performance, pest management efficiency, and economic returns. This approach marks a transition toward the integration of biotechnology into systems traditionally constrained by production limitations.

Figure 3. Experimental plots at EMBRAPA

In **Paraguay**, IPTA focuses on the improvement of *G. hirsutum*, emphasizing yield, fiber quality, boll weevil resistance, and drought tolerance. The country also conserves native *G. barbadense* collections, which exhibit a notable absence of boll weevil infestation and represent a genetic resource of strategic value. Breeding efforts rely primarily on conventional selection schemes, including F1 hybrid evaluation, combining ability analysis, and selection of promising lines. These efforts have resulted in cultivars such as IAN 425, IPTA 212, and IPTA 232, which combine excellent agronomic and technological traits, are well adapted to water-stressed environments, and are of growing interest to cooperatives in the Paraguayan Chaco.

Argentina presents a comprehensive and advanced system integrating conventional breeding, mutagenesis, molecular tools, transgenic event introgression, and genetic engineering techniques. National breeding objectives include yield improvement, fiber quality and stability, resistance to pests and diseases, herbicide tolerance, and adaptation to adverse environmental conditions. Genetic variability is generated through directed crosses and induced mutagenesis using sodium azide, EMS, and radiation, leading to the development of technologies such as IMICott, based on a point mutation in the ALS enzyme conferring resistance to imidazolinone herbicides. Systematic application of molecular markers (SSR, SNP, ddRAD-Seq) supports marker-assisted selection, QTL identification, and varietal differentiation in programs led by INTA. Argentina has also advanced in the introgression and stacking of GM events such as Bollgard II and Roundup Ready into national germplasm and has developed GM lines through RNA interference–based gene silencing targeting *Anthonomus grandis*, which are currently under evaluation. These achievements reflect a coordinated innovation system capable of addressing multiple production challenges simultaneously.

Considering Latin American countries, the tools applied to cotton genetic improvement encompass a broad and integrated spectrum, ranging from genetic characterization using molecular markers and QTL mapping to the generation of variability through hybridization and mutagenesis, as well as advanced genetic engineering approaches such as transgenesis and gene silencing. Selection is conducted using mass and pedigree methods as well as marker-assisted selection, while introgression of desirable alleles is achieved through conventional or marker-assisted backcrossing. However, despite the broad technical toolbox available, the main constraints in several countries are not scientific but economic and infrastructural. Insufficient and unstable funding, outdated or inadequate infrastructure, scarcity of inputs, lack of greenhouses, and limited availability of specialized suppliers significantly affect the pace of breeding progress. Human resources are also challenged by low salaries, limited permanent positions, restricted opportunities for continuous training, and the migration of highly skilled professionals.

Overall, multiple demands within the cotton sector can be addressed using biotechnological tools, although the development of transgenic materials involves lengthy and costly regulatory processes. While induced mutagenesis and, potentially, genome editing represent attractive alternatives, not all traits of interest can be modified through these approaches.

Regional experience demonstrates that the integration of traditional breeding with modern biotechnology generates strong synergies that substantially enhance program success. The establishment of public–private partnerships, strengthening of regional capacities, and increased cooperation among countries emerge as key strategies to overcome structural limitations and promote sustained growth of cotton production in Latin America.

Cotton breeding programs and their importance in Latin America

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Abstract

This article discusses the panorama of the currently 13 active cotton breeding programs in Latin America, analyzing their main objectives, progress achieved, and stages of development. The different strategies and objectives pursued by public institutions (INTA, EMBRAPA, INIA, UNP, UNALM, IAN, IPTA) and private companies (BASF, Bayer, TMG, IMA, IPA) are presented. The breeding programs are focused on improving fiber yield and quality, increasing tolerance to abiotic stresses, and incorporating resistance to tropical diseases such as angular leaf spot, cotton blue disease, Ramularia leaf spot, and nematodes. Concrete examples of the development of varieties with remarkable characteristics, including long fibers (BRS 700FL B3RF), multiple pathogen resistance (BRS 800 B3RF), and herbicide tolerance, including a national technology (IMICott technology in Argentina) are discussed.

Introduction

In Latin America, there are currently 13 active cotton breeding programs, most of which are national and public (Table 1). These programs are located in Argentina, Brazil, Peru, and Paraguay. The vast majority of breeding programs work exclusively with the species *Gossypium hirsutum*. Efforts have been made to develop improved cultivars of the species *G. barbadense* only in Peru and, more recently, in Brazil. Argentina has a cotton breeding program, conducted by Instituto Nacional de Tecnología Agropecuaria (INTA). Brazil has the largest number of programs, most of which are private, and among these, two are transnational (BASF and Bayer). One program is national and public, conducted by the Brazilian Agricultural Research Corporation (Embrapa), and two are privates: Instituto Mato-Grossense do Algodão (IMA) and Tropical Melhoramento & Genética S.A (TMG). Peru has three public breeding programs, conducted by Instituto Nacional de Innovación Agraria (INIA), La Universidad Nacional de Piura (UNP) and Universidad Nacional Agraria la Molina (UNALM) and 1 private conducted by Instituto Peruano del Algodón (IPA). Paraguay has three public cotton breeding programs, conducted by Instituto Agronómico Nacional (IAN), Programa de Investigación y Experimentación Algodonera (PIEA), and Instituto Paraguayo de Tecnología Agraria (IPTA).

Finally, we will mention other cotton breeding programs of great relevance to the Latin America that have been discontinued but deserve to be mentioned. The first cotton breeding program in Latin America, coordinated by the Instituto Agronômico de Campinas (IAC) in Brazil, began in 1924 and was discontinued recently. The IAC cotton breeding program was one of the country's pioneering efforts in cotton genetic improvement. Its initial goals were high yield, but they evolved over time to focus on disease resistance, fiber quality, and adaptation to mechanized farming. Its research has contributed to the development of a strong national cotton production system, often in collaboration with other institutions like Embrapa and IMA. In Ecuador, the Instituto Nacional de Investigaciones Agropecuarias (INIAP) conducted germplasm introduction and lineage testing. The program ended in 1994.

The development of Colombian cotton varieties has been in charge of two entities; In the first place, during the first years of developing cultivation, the development of new genetic materials was in charge of the Instituto Colombiano Agropecuario (ICA), and from 1993, of the Corporación Colombiana de Investigación Agropecuaria (CORPOICA, actual Agrosavia). The program was discontinued.

Table 1. Cotton breeding programs in Latin America

Country	Institution	Type
Argentina	INTA	National/Public
Brazil	Embrapa	National/Public
Brazil	IMA/TMG	Nacional/Private
Brazil	BASF	International/Private
Brazil	Bayer	International/Private
Peru	INIA/UNP/UNALM	National/Public
Peru	IPA	Nacional/Private
Paraguay	IAN/PIEA/IPTA	National/Public

Program objectives

Higher yields and improved fiber quality are the main objectives of all programs. However, some national/regional issues are addressed specifically in each country. The specific objectives of each program will be described below.

The breeding program at INTA (Argentina) have focused in improve genetic resistance to important diseases such as angular leaf spot (bacterial blight), cotton blue disease, and *Fusarium* wilt. In addition, progress is being made in the development of cultivars resistant to herbicide imidazolinone, applied in pre-emergence. For adaptation to the harvesting system used (stripper), the plant's conformation (architecture) is one of the objectives of the program, focusing in plants with a compact structure and low vegetative branching.

In Brazil, all complete cotton breeding programs have two breeding steps: the first is conventional breeding and the second is the introgression of transgenics. Genetically modified cotton has been approved in Brazil since 2005 and all cotton breeding programs in Brazil adopt biotechnological events in the development of cultivars. Almost all transgenic events developed worldwide for cotton cultivation are available in Brazil. The BASF and Bayer programs have their own biotechnologies, while the others require licensing for their use. The events approved for commercialization are: GL = GlyTol y LibertyLink; GLT = GlyTol, LibertyLink and TwinLink; TLP = TwinLink Plus; GLTP= GlyTol, LibertyLink and TwinLink Plus; STP = Seletio and TwinLinkPlus; RF = RRFlex; B2RF = Bollgard2 and RRFlex; B3RF = Bollgard3 and RRFlex; XF = XTendFlex; B3XF = Bollgard3 and XtendFlex; WS = Widestrike, and WS3 = WideStrike 3.

Below are listed the specific objectives of the Brazilian cotton breeding programs.

BASF:

1. Conventional program for the development of cotton lines resistant to: angular leaf spot, cotton blue disease, root-knot nematode, and Ramularia leaf spot;
2. Introgression of biotechnology traits: GL, GLT, GLTP, TLP, and STP.

TMG:

1. Conventional program for the development of cotton lines resistant to: angular leaf spot, cotton blue disease, root-knot nematode, and Ramularia leaf spot;
2. Introgression of biotechnology traits: GLT, GLTP, TLP, B2RF, B3RF, B3XF, XF y WS3.

IMA:

1. Conventional program for the development of cotton lines resistant to: angular leaf spot, cotton blue disease, root-knot nematode, reniform nematode, ramulosis, and ramularia leaf spot;
2. Introgression of biotechnology traits: GLT, GLTP, TLP, B2RF, B3RF y B3XF.

Embrapa:

1. Conventional program for the development of cotton lines resistant to: angular leaf spot, cotton blue disease, root-knot nematode, reniform nematode, and *Ramularia* leaf spot;
2. Introgression of biotechnology traits: B2RF, B3RF, XF and B3XF;
3. Development of cotton lines free of gossypol; 4) Development of transgenic *G. barbadense* (ELS fiber).

The Bayer breeding program in Brazil is incomplete and consists of adaptation tests of cotton lines previously developed in other countries with transgenics incorporated: B3RF, B3XF and XF.

The cotton breeding programs in Peru aim to generate Pima (*Gossypium barbadense*) cotton varieties with high yield, white fiber, extra-large fiber quality, resistance to biotic and abiotic stresses that face the prevailing impacts of climate change, promoting an integral and sustainable production system. Emphasis has also been given to some native colored fiber cottons. Finally, INIA also develops varieties of the species *G. hirsutum*.

The cotton breeding programs in Paraguay aim to obtain varieties with high yield potential in the field and in the field, good fiber quality, resistance and/or tolerance to the main diseases and adapted to different environments and production systems

Progress achieved and current focus

The progress achieved by the programs is summarized below.

INTA

During 1956 and 2025, 24 cotton varieties were developed by INTA. At INTA (Sáenz Peña experimental station), recent advances in the development of new germplasm, with emphasis on materials resistant to imidazolinones applied in pre-emergence is in course. As a result, it was released a variety with pyramiding multiple transgenic traits -resistance to lepidopterans, glyphosate and imidazolinones, which will lead to the name ARANDU INTA IMICott (Fig. 1). This variety also stands out for its resistance to foliar diseases and for having larger bolls.

Additionally, INTA (Reconquista experimental station) is developing materials adapted to the environmental conditions and management practices of the cotton region of the province of Santa Fe. For this reason, the objective of this program is to obtain adapted varieties with a higher fiber yield, good fiber quality, suitable sanitary characteristics and, in addition, to focus on selection in the structure and architecture of the plant. In this sense, we are looking for plants with compact structure and with few vegetative branches, which are appropriated to ultra-narrow production systems (furrows less than 0.52 cm apart) and suitable to be harvested by a cotton stripper, predominant systems in the province of Santa Fe.

Figure-1. Disease-resistant varieties: IAN 425 (above) IPTA 232 (below).

Figure-2. Compact architecture varieties.

Figure-3. Coloured cotton variety INIA 804 (Colorina)

Figure-4. Imidazoline resistant variety ARANDU INTA IMICott

Embrapa.

Since 1980, Embrapa has developed and released 41 cotton cultivars, initially adapted to semi-arid zones and, after the arrival of the cotton boll weevil in the country, adapted to the Brazilian Savannah (Cerrado). One of the focus was on developing cultivars with multiple disease resistance, particularly resistance to cotton blue disease, bacterial blight, Ramularia leaf spot and root-knot nematode. As examples of this effort, we can cite the development of varieties resistant to multiple diseases: BRS 372 (conventional) and BRS 500 B2RF and BRS 800 B3RF (transgenic). On the other hand, the program has also been pursuing improvements in fiber quality for the past 20 years. As a result, were released the cultivars BRS 336, BRS 433 B2RF, and BRS 700FL B3RF (fig. 2). The cultivar BRS 700FL B3RF is a transgenic long staple cultivar, with fiber length hither than 33.8 mm.

IAN/IPTA.

Between 1967 and 2020, eight conventional cotton varieties were developed and released, focusing on disease resistance. The most recent releases were IAN 425 and IPTA 232.

INIA/IPA/UNP/FUNDEAL.

In recent years, nine cultivars have been developed in Peru, mostly of the Pima type, with notable fiber quality. The most notorious cases are the FUNDEAL 6, IPA 59, INIA 803, and, INIA 804 (Colorina).

Session 3: Management of Biotic Adversities and Biodiversity

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Introduction

The third session of the meeting focused on the current status of plant protection in cotton, addressing different approaches organized into four thematic blocks:

- Cotton pest management in Latin America: selected perspectives
- Integrated weed management
- Integrated insect pest management
- Integrated disease management

The session began with the first thematic module, presenting a synthesis of global pest dynamics and the expansion of key pests affecting cotton, with emphasis on *Anthonomus grandis* (cotton boll weevil); *Helicoverpa armigera* and *Spodoptera frugiperda* (bollworm and fall armyworm, respectively); *Oxycarenus hyalinipennis* (cotton seed bug); and *Amrasca biguttula* (cotton jassid). The main insecticides used in Latin America were discussed, with specific reference to Argentina, including alternative active ingredients with lower toxicity and greater efficacy and selectivity for boll weevil control. Finally, the sustainability of cotton plant protection was addressed, highlighting biologically based methods, particularly biological control using entomopathogenic fungi. The need for further research on the use of endophytic fungal isolates as potential seed treatments was emphasized, as well as their association with biofertilizers or soil amendments, with a focus on carbon sequestration technologies using biochar and bokashi.

Regarding integrated weed management, the main families, genera, and species of weeds affecting cotton in different Latin American regions were presented. Current cotton production models were then described: one based on chemical and genetic control through genetically modified organisms (extensive cotton systems), and another based on cultural practices, manual control, and complementary chemical control (agroecological and intensive systems). The main challenge of chemical weed control—resistance to key active ingredients—was highlighted. The contribution of cover crops to weed management was discussed, with experiences from Brazil and Argentina. Finally, the challenges to achieving integrated weed management in Latin American cotton systems were outlined, adopting a systems-based perspective.

Figure-1. Boll weevil (above) Fall armyworm (below).

Figure-1. *Fusarium* affected leaf (left); weed infested crop (above right) and Leaf roll dwarf virus affected leaf (below right).

The third module, integrated insect pest management, began by emphasizing its main components, considering cotton within a broader production system. The principal insect pests affecting cotton in different countries were reviewed, including the cotton boll weevil, pink bollworm (*Pectinophora gossypiella*), bollworms (*Helicoverpa zea*, *H. armigera, H. virescens*, and *Spodoptera frugiperda*), whiteflies (*Bemisia argentifolii* and *B. tabaci*), thrips (Frankliniella spp.), aphids (*Aphis gossypii*), and bugs (*Horcias nobilellus* and Lygus spp.). The presentation reinforced the concept of integrated management and described the main control tactics for different pests, highlighting the successful eradication of pink bollworm in specific regions of Mexico. Subsequently, key challenges facing cotton production in Latin America related to insect pests were discussed, with emphasis on the resurgence of pink bollworm, the breakdown of resistance of fall armyworm to major biotechnologies, the need for training and capacity building in plant protection, and the strengthening of research efforts.

To conclude the session, the fourth module provided an overview of the main cotton diseases (bacterial, viral, fungal, and nematode-related), their importance in the countries involved, and the sanitary characteristics of commercial varieties.

A comparison was made between disease scenarios in Argentina and Brazil, two production systems with markedly different agroecological conditions. Key pathogens were described, including bacterial blight (*Xanthomonas citri* subsp. malvacearum), viral diseases (Cotton leafroll dwarf virus—typical and atypical variants—and Cotton mosaic virus), foliar leaf spots (*Alternaria alternata, A. macrospora*, *Cercospora* spp., *Ramulariopsis pseudoglycines, R. gossypii*, and *Corynespora cassiicola*), nematodes (root-knot nematodes: *Meloidogyne incognita* and *M. enterolobii*; reniform nematode: *Rotylenchulus reniformis*; and *Pratylenchus brachyurus*), damping-off, and boll rot. The economic impact of fungicide use for *Ramulariopsis* spp. control in Brazil was discussed, along with yield losses caused by root-knot nematodes. The presentation continued with current lines of research, including genetic improvement (multi-resistant cultivars), sanitary screening, integrated disease management (monitoring, surveillance, chemical and cultural control), and studies on atypical CLDV and CMV. The module concluded by outlining disease management challenges, focusing on foliar spot management (cultural practices to reduce inoculum in fields, resistance breakdown to strobilurins by *R. pseudoglycines*), diseases shared with soybean (reniform nematode, *C. cassiicola*, and *Sclerotinia sclerotiorum*), and the lack of information in Argentina regarding the dynamics of foliar spot causal species and their agronomic management.

The session clearly highlighted the need to generate information on the biology, ecology, dynamics, and spread of the different biotic adversities affecting Latin American cotton. It also emphasized the importance of rethinking plant protection approaches toward greater sustainability, evolving from pest control to integrated pest management of cotton within agroecosystems, from a systemic perspective.

The ICAC Recorder

Integrated Weed Management in Cotton Crops in Latin America

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Dr Diego Szwarci

Abstract

Weeds are one of the main limiting factors for productivity, fiber quality, and operational efficiency in cotton crops across Latin American countries. Their impact varies throughout the crop cycle, especially during the early growth stages. In the region, widespread adoption of production systems based on chemical control and genetically modified herbicide-tolerant crops has created high selection pressure on weed populations, promoting the emergence and spread of tolerance and resistance. This issue is not limited to cotton but is also seen in other large-scale crops, posing a regional challenge. In this context, Integrated Weed Management becomes an essential strategy, combining cultural, mechanical, chemical, and genetic practices. This paper analyzes the importance of weeds throughout the cotton cycle, the main production models in the region, and current challenges, emphasizing the need for integrated approaches to achieve sustainable cotton systems in Latin America.

Introduction

Cotton cultivation in Latin America faces several production challenges, with weed management being a key issue. Weeds impact yield, fiber quality, pest control effectiveness, and harvesting processes. Additionally, the growing problem of herbicide resistance has revealed the limits of relying solely on chemical control methods, emphasizing the importance of integrated management strategies. Weed interference in cotton can be divided into three stages. The first, after emergence and spanning from four to nine weeks, constitutes the critical competition period.

During this phase, weeds compete for water, light, and nutrients, while the crop prioritizes root development and exhibits slow aerial growth, reducing its competitive ability and causing irreversible yield losses if timely control is not implemented.

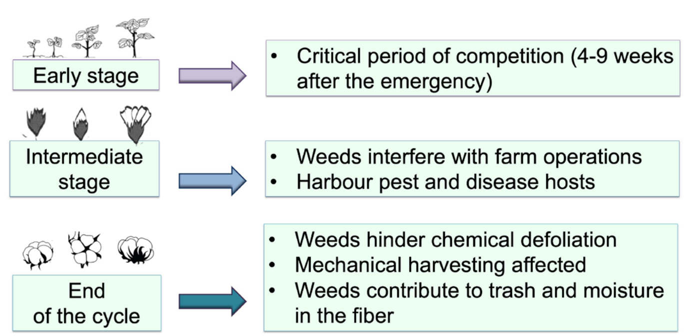
The second stage corresponds to the reproductive period, including squaring and flowering. Here, resource competition is lower, but weeds interfere with crop management, act as hosts for pests and diseases, and hinder spray applications. Established under the canopy, they can grow vigorously toward the end of the cycle, increasing their hardiness and control difficulty.

In the third stage, toward the end of the cycle, weeds no longer affect yield but obstruct chemical defoliation, hinder mechanical harvesting, and contribute to increased moisture and foreign matter in the fiber, affecting its commercial quality.

Main Weeds in Cotton

In cotton-producing countries of Latin America, key dicot species include *Amaranthus* spp., *Ipomoea* spp., *Conyza* spp., among others, and monocot grasses such as *Sorghum halepense, Digitaria* spp., *Eleusine* spp., *Echinochloa* spp. (Fig. 1). In Argentina, particularly in Chaco province, around 80 species associated with the crop have been identified, with predominance of the families Asteraceae, Poaceae, Amaranthaceae, and Malvaceae (Royo Simonella et al., 2022). This floristic diversity complicates management and reinforces the need for integrated strategies adapted to each region.

Figure-1. Challenges imposed by weeds



Production Models & Management Strategies

Two major production models prevail in cotton-growing countries of Latin America:

Intensive or agroecological systems, where cultural and mechanical practices dominate, such as crop association, mechanical control during fallow, and manual control in post-emergence, combined with limited and targeted herbicide use. This model is characteristic of countries such as Ecuador, Bolivia, and Peru, and some regions of Brazil.

Extensive and highly mechanized systems, where chemical control is the main tool, complemented by genetically modified herbicide-tolerant cotton. This model drove the massive adoption of glyphosate-tolerant crops, not only cotton but also soybean and maize, and promoted intensive use of this herbicide. This situation favored the emergence of tolerant and resistant weeds throughout the agricultural region. Consequently, the use of alternative herbicides increased significantly, creating a vicious cycle that accelerates the appearance of multiple resistance and its spread in cotton-growing areas.

In this scenario, the use of cover crops emerges as a strategic tool within integrated weed management. Trials conducted in Brazil showed significant reductions in weed dry matter through the use of multiple cover crops, such as *Pennisetum glaucum* in association with *Crotalaria juncea*, *Cajanus cajan*, or *Urochloa* spp., maintaining the effect up to 225 days (De Araújo et al., 2021). In Argentina, different cover crop combinations significantly reduced weed density compared to chemical fallow, which consistently showed higher infestation levels (Burdyn, 2020).

Components of Integrated Weed Management

Integrated Weed Management requires addressing the problem from a systemic perspective, integrating the crop with the agroecosystem and moving beyond an approach focused exclusively on chemical control. The foundation of IWM is diagnosis, supported by monitoring, correct species identification, and knowledge of their bioecology. Cultural practices include crop rotation and sowing date, adjustment of plant density and spatial arrangement.

Figure-2. Cover crops for weed management

Figure-2. Mulch (above) and crop rotation (below)

Crop-livestock integration also contributes to controlling certain weeds. These strategies are complemented by direct control tools, such as rational use of residual herbicides, mechanical control, seed destruction during harvest, manual control of specific patches, and targeted application through precision agriculture. Strategic use of biotechnology allows rotation of modes of action, reducing selection pressure and increasing selectivity, minimizing phytotoxicity risks and improving production stability.

Final Considerations

Integrated Weed Management is a fundamental pillar for the sustainability of cotton cultivation in Latin America. Combining cultural, mechanical, chemical, and genetic practices adapted to each production system is essential to address the growing resistance problem and ensure long-term productivity and fiber quality.

References:

Araújo, F. C. D., Nascente, A. S., Guimarães, J. L. N., Sousa, V. S., Freitas, M. A. M. D., & Santos, F. L. D. S. (2021). Cover crops in the off-season in the weed management at notillage area. Revista Caatinga, 34, 50-57.

Burdyn, B. (2020). Optimización del control químico en especies de Borreria en agroecosistemas del centro de la Provincia de Chaco. Tesis de Maestría, Universidad Nacional del Nordeste. Repositorio UNNE. https://repositorio.unne.edu.ar

Royo Simonella, L., López, M. G., Lovato Echeverría, R., Dávalos Aguirre, M., & Vanni, R. O. (2022). Guía para la identificación de malezas del cultivo de algodón (*Gossypium hirsutum* L.) en la provincia del Chaco. Cátedra de Botánica Sistemática y Fitogeografía, Facultad de Ciencias Agrarias, Universidad Nacional del Nordeste (UNNE), IBONE.

Integrated Disease Management of Cotton in Latin America

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Abstract

This article describes the most common cotton diseases of economic importance in Latin America, notably in Argentina and Brazil, including the impact on cotton yield/production and the main practices of management: chemical, genetic or cultural, as well as the current research on cotton diseases.

Introduction

The warm and humid weather during cotton growing season is a perfect environment to the development of several diseases, leading to emerging diseases that reaches epidemic levels quite often. Nowadays, in terms of economic impact, the main cotton diseases in Latin America are: Ramularia leaf spot, Target spot, Root-knot nematode, Cotton blue disease (CBD), Reniform nematode, Damping off, *Fusarium* wilt and Bacterial blight. Minor diseases can also occur occasionally, but with no economic importance, such as, for example, atypical form of CBD, *Verticillium* wilt, Cotton Mosaic Virus, and cotton boll rot.

Ramularia leaf spot

Ramularia leaf spot (RLS) is a disease of major importance on cotton fields in Brazil due to its effects on yield and cotton fiber quality. RLS can be caused by either *Ramulariopsis pseudoglycines* or *R. gossypii*. In Central Brazil *R. pseudoglycines* is prevalent. This main fungal disease causes early defoliation and photosynthetic area reduction, reducing lint yield and negatively affecting fiber quality. The first symptoms of RLS generally appear at the lower canopy, usually after the first squares (flower bud), between 4 and 8 weeks after planting, depending on the cultivar and environmental conditions. However, in fields with volunteer (self-sown) cotton plants and/or cotton stalk regrowth, primary inoculum is available earlier and first symptoms can appear as early as 20 to 25 days after crop emergence. Such scenario may lead to explosive epidemics towards the end of the season. Initial symptoms appear as light green to yellow-green lesions on the upper leaf surface from which the fungus develops white powdery sporulation (Figure-1).

Figure-1. *Ramulariopsis gossypii*

A pre-breeding effort along the years 2003 to 2011 allowed to characterize several cotton accessions from the Embrapa's cotton germoplasm collection and identify resistance sources. Recombining partial resistant cotton genotypes and subsequent selection in segregating populations allow us to develop the cotton cultivars BRS 372 and BRS 416 with high resistance level to RLS (Suassuna et al., 2020).

Using a segregant population derived from BRS 372 and the susceptible cultivar CD 408 and a cotton 63K single nucleotide polymorphism (SNP) array developed by Hulse-Kemp et al. (2015), the resistance was mapped, and SNPs markers were identified linked to two QTLs, one in chromosome A01 and other in chromosome A04 (Boldt & Suassuna, unpublished). It was developed a TaqMan real-time PCR assay for RLS marker-assisted selection. When both QTLs are in homozygous condition, the same RLS resistance level of BRS 372 is achieved. From the BRS 372 cultivar, others were developed maintaining the same level of resistance, such as BRS 500 B2RF and BRS 800 B3RF. Despite the extreme importance of the disease in Brazil, in Argentina its importance is not relevant, with appearance occurring at the end of the crop cycle.

Figure-2. *Ramulariopsis pseudoglycines*

Figure-3. *Ramulariopsis pseudoglycines* affected plants

Root Knot Nematode

The Root-knot nematode (RKN), *Meloidogyne incognita*, is one of the most important economic pests of cotton worldwide. Host plant resistance is the most economical, practical, and environmentally sound method to provide protection against this pathogen.

Figure-4. Root knot nematode infested field

Figure-5. Roots infested with root know nematodes

Figure-6. Root knot nematode infested root

Figure-7. Symptoms on a leaf from a plant infested with root knot nematode

The resistant line Auburn 623RNR and a number of elite breeding lines derived from it remain the most important source of root-knot nematode (RKN) resistance. Genetic analysis has identified two epistatically interacting RKN resistance QTLs, qMi-C11 and qMi-C14. The qMi-C11 locus predominantly affects root gall suppression whereas the qMi-C14 locus largely reduces egg production but has little effect on galling. Further, while the main effects of each QTL appeared to serve as the major genetic basis in conferring resistance for both galling and egg production phenotypes, resulting in a near-immunity to infection when both QTLs are present. The origin of the resistance loci was traced to the two moderately resistant parents of Auburn 623 RNR, with the qMi-C11 locus on Chromosome 11 inherited from Clevewilt 6 and the qMi-C14 locus on Chromosome 14 inherited from Wild Mexican Jack Jones.

Two simple sequence repeat (SSR) markers are closed linked with both QTLs: CIR316 associated with resistance on chromosome 11 and marker BNL3661 on chromosome 14. The SSR markers CIR316 and BNL3661 were converted to SNPs markers and have been routinely used in Embrapa´s cotton breeding program to allow the development of resistant cultivars in the last years.

Currently, several cotton cultivars resistant to root-knot nematodes are available on the market: BRS 800 B3RF, IMA 5801 B2RF, IMA 712 B3XF, DP 2111 B3RF, DP 2176 B3RF, TMG 51 WS3, TMG 33 B3RF and FM 970 GLTP.

Cotton Blue Disease

Cotton blue disease (CBD) is an important viral disease in South America. Cotton leafroll dwarf virus (CLRDV) (Genus: Polerovirus; Family: Luteoviridae) causes the CBD, and occurs in Africa, Asia, South America and North America. CBD was named for the dark green to bluish color, inward rolling, and leathery texture of leaves on the infected plants.

Figure-8. cotton leaf roll dwarf virus: aggressive 'typical CBD' (above) and less aggressive genotype 'atypical CBD' (below)

In early-season infections, epinasty can be severe, with reddened petioles and veins, and pronounced stunting of plants. In Brazil and other South American countries, CBD is a limiting problem for cotton production when susceptible cultivars are used. This disease can reduce cotton yield of susceptible varieties by up to 80% if cotton aphids are not properly controlled during the early growing season. The development and use of resistant variety offers the best management tool for CBD control. Commercial production in Brazil depends heavily on having highly resistant varieties available.

The resistance to CBD controlled by one single dominant gene, designated Cbd, in the resistant cultivar 'Delta Opal' and two simple sequence repeat (SSR) markers were identified as linked to Cbd at the telomere region of chromosome 10 (Fang et al., 2010). SSR marker DC20027 was mapped very close to Cbd. Additionally, four SNPs were identified and mapped on chromosome 10 associated with Cbd. Along with SSR marker DC20027, Embrapa´s cotton breeding program uses the SSRs NG0204310 and NG0203481 markers, flanking Cbd, to select resistant genotypes. Since 2010, all cotton cultivars developed by Embrapa are resistant to CBD.

A less aggressive resistant-breaking genotype of CLRDV was observed in Brazil and Argentina on cotton varieties known to be resistant against CBD. This new disease was referred to as 'atypical' cotton blue disease (ACBD) to differentiate from the 'typical' CBD. So far, no sources of complete resistance to ACBD have been identified.

Bacterial blight

Bacterial blight, caused by *Xanthomonas citri* subsp. malvacearum (Xcm), is a major disease of cotton occurring in most cotton producing countries of the world, causing significant yield losses. The bacteria penetrates the host plants through open stomata or wounds, and creates water-soaked lesions on cotton leaves (Figure 9), stems, and bolls, followed by premature leaf senescence and reduced lint yield.

Figure-9. BLB water soaked lesions along the veins on a leaf

The disease management includes sanitary practices during ginning and seed processing, planting of acid-delinted and fungicide-treated seeds, destruction of residues from the previous crop, crop rotation, and use of resistant varieties. The deployment of resistant varieties is the most effective and economical means to control the disease and minimize yield loss.

At least 20 Xcm races occurs worldwide and race 18 is the most virulent and is prevalent in Brazil. Resistance to bacterial blight has been studied extensively and there are at least 22 reported resistance genes or gene complexes in cotton that confer differing degrees of resistance to various Xcm races carrying different avirulence genes in a typical gene-for-gene manner. Of these 22 genes, B12 confers a high level of resistance to all Xcm races presently found in Brazil.

SSR markers were identified as closely linked to the resistance gene B12: CIR246, BNL3545 and BNL3644 on chromosome 14 [D02]. Additionally, SNPs markers NG0207069 and NG0210142, flanking B12, can be used to select genotypes harboring the entire region on chromosome 14. Since 2012, all cotton cultivars developed by Embrapa are resistant to bacterial blight.

Target spot

Target spot is caused by the fungus *Corynespora cassiicola*, and the symptoms are initially small spots on the older leaves and progresses to spots rounded or irregular shape, with dark brown borders and a white brown center, and frequently forms concentric rings around lesions.

In high epidmics, the leaves acquire a yellowish color and easily detach from branches, resulting in defoliation of the plant (Figure 3). There are no cotton cultivars with resistance, and the only method of control is with the use of fungicides.

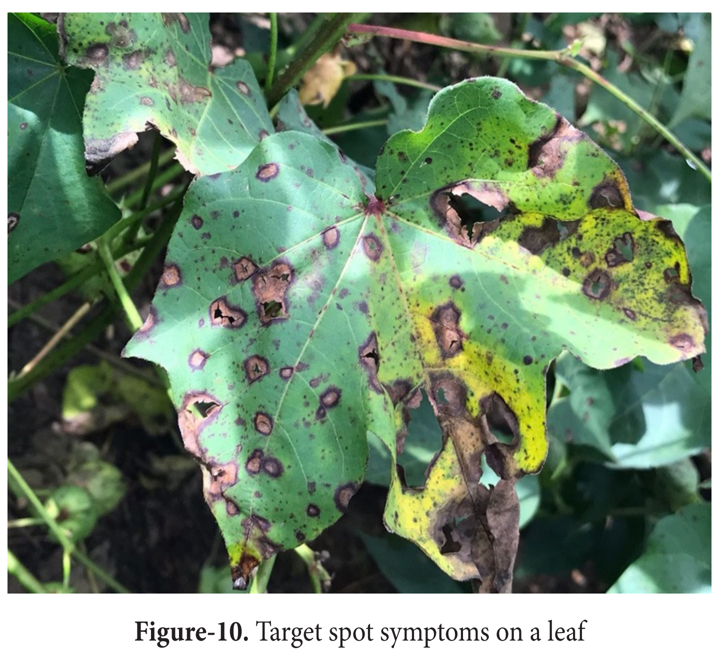

Figure-10. Target spot symptoms on a leaf

Economic impact of diseases on cotton

Currently, there are no precise data on losses in performance and fiber quality associated with illnesses (Brazil and Argentina). However, it is possible to estimate the annual cost of using fungicides in Brazil. The annual economic impact due to the use of fungicides on cultivars resistant and susceptible to Ramularia in Brazil is US$ 25 million in resistant cultivars (for the control of *Corynespora cassiicola*), representing approximately 848 thousand hectares, with three applications of fungicides; and US$ 101 million in susceptible cultivars, representing approximately 1.27 million hectares, with eight fungicide applications.

For nematodes, it is estimated that in sandy soils, with population densities greater than 200 individuals of M. incognita per 200 cm3 of soil, losses fluctuated between 24.8 and 30% over a period of three years.

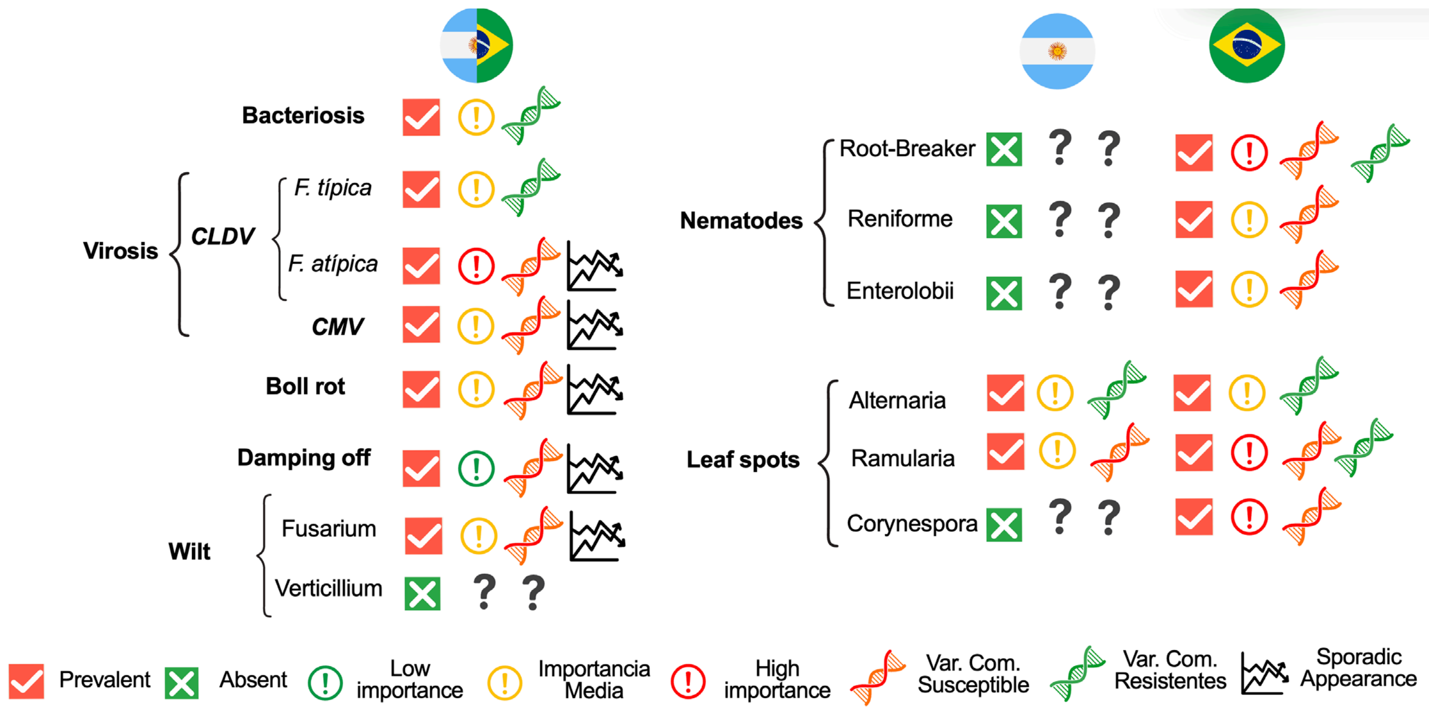

Figure-11. Economic importance of cotton diseases in Argentina and Brazil: The left panel lists diseases—such as bacterial leaf blight, viral diseases, boll rot, and wilts—that are common to both Brazil and Argentina and exhibit broadly similar prevalence and economic significance in the two countries. The right panel highlights nematodes and leaf spot diseases, whose levels of occurrence and economic impact differ substantially between Argentina and Brazil.

Current research on cotton diseases

Currently, the cotton breeding programs are focused on develop multi-resistant cultivars, mainly to bacteriosis, nematodes and CBD, using marker assisted selection.

Additionally, efforts have been made in the identification and dynamics of cotton foliar pathogen species, mainly the genus *Alternaria* and Ramulariopsis as well as the identification of races of Xcm.

Identifying sources of resistance to pathogens *Meloidogyne enterolobii* and *C. cassiicola* will be extremely relevant in the future, as these diseases tend to increase in economic importance.

Figure-12. Diseases such as boll rot (left), mosaic virus (centre) and damping off (right) are prevalent in both Brazil and Argentina.

Integrated Pest management of Cotton in Latin America

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Jesús García-Feria

Introduction

Cotton is affected from pre-emergence to harvest by a complex of pests. Based on the collaborative work carried out by the Working Group, the main insect pests of cotton in Latin America were identified as the cotton boll weevil (*Anthonomus grandis*), pink bollworm (*Pectinophora gossypiella*), bollworms (*Helicoverpa zea, H. armigera, Chloridea* (*Heliothis*) *virescens*, and *Spodoptera frugiperda*), whiteflies (*Bemisia argentifolii* and *B. tabaci*), thrips (*Frankliniella* spp.), aphids (*Aphis gossypii*), and bugs (*Horcias nobilellus* and *Lygus* sp.).

The cotton boll weevil is native to Mexico and Central America and is currently distributed throughout most cotton-producing countries in Latin America. It is considered the most important pest, as its control can account for up to 40% of production costs and may cause yield losses of up to 100%.

Figure-1. *Helicoverpa armigera*

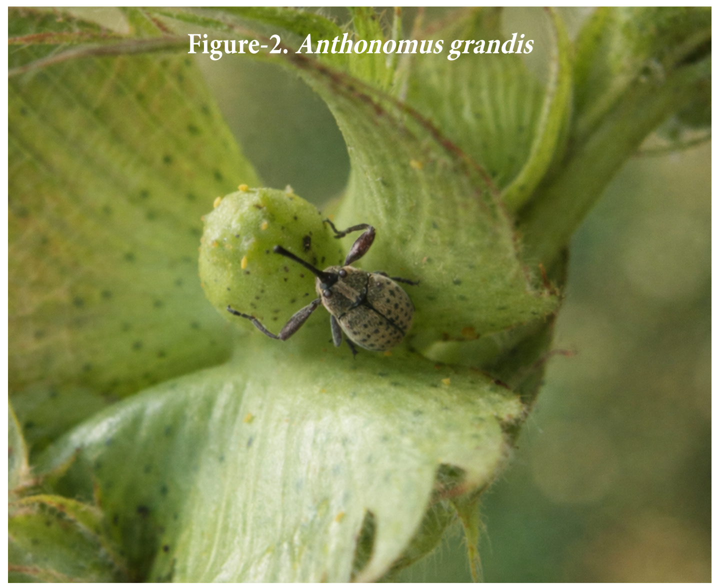

Figure-2. *Anthonomus grandis*

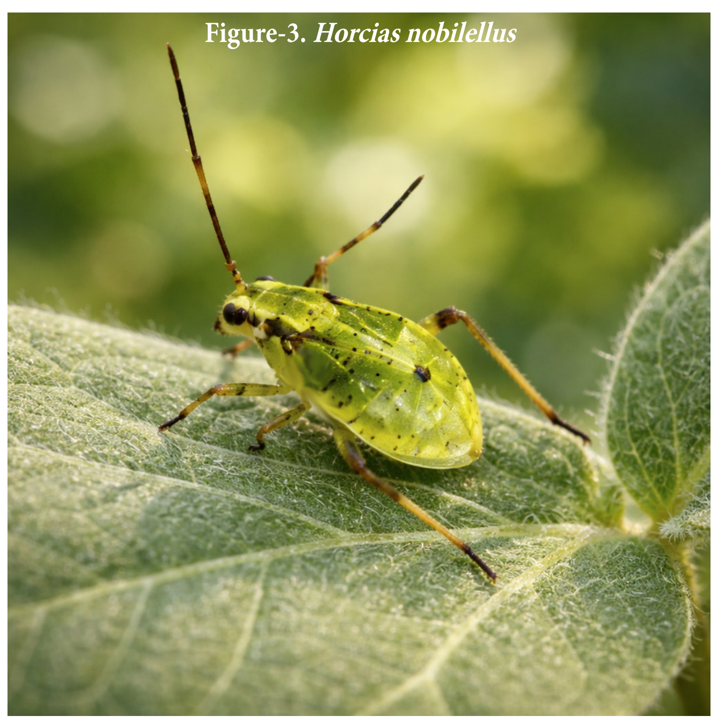

Figure-3. *Horcias nobilellus*

Figure-4. *Pectinophora gossypiella*

Figure-5. *Aphis gossypii*

Figure-6. *Bemisia tabaci*

Integrated Pest Management

According to FAO, Integrated Pest Management (IPM) is a pest management system that, within the context of the environment and pest population dynamics, uses all appropriate and compatible techniques and methods to maintain pest populations below levels that cause economic damage.

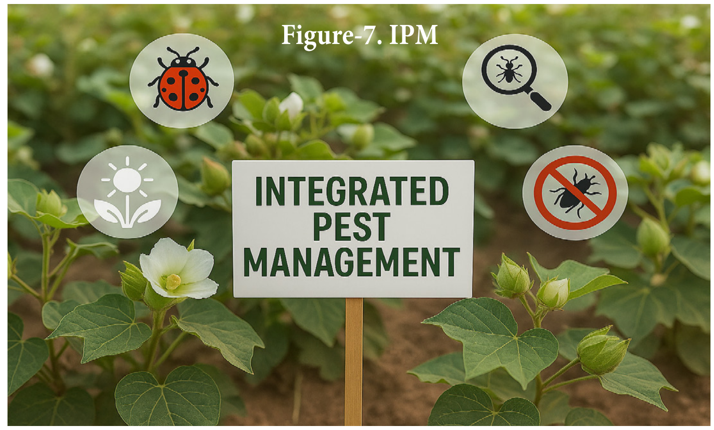

Figure-7. IPM

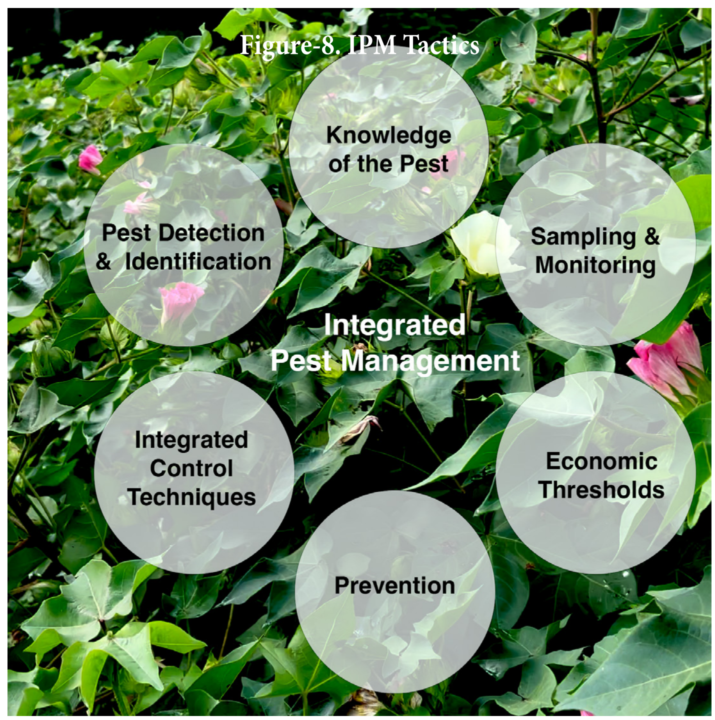

Figure-8. IPM Tactics

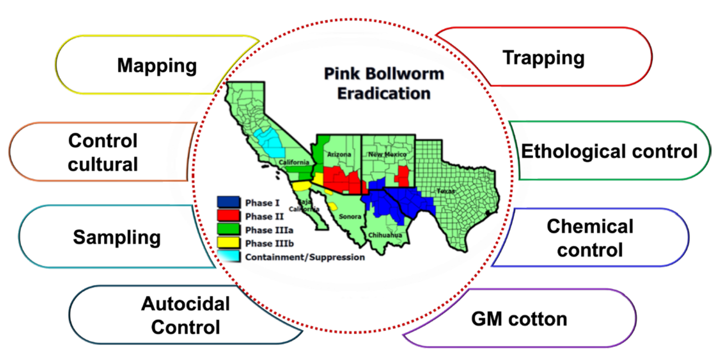

Figure-9. Pink bollworm eradication strategies

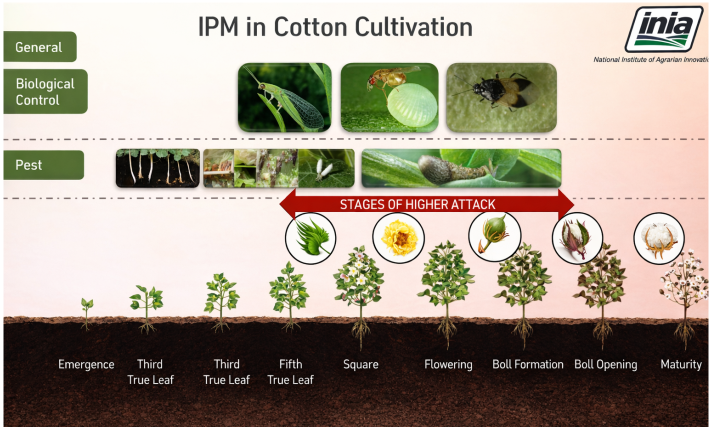

Figure-10. Cotton crop phenological stages

IPM has several basic components, including the identification and understanding of the biology and behavior of the target pest, monitoring and detection, economic thresholds, preventive measures, and control tactics (Figure 8). In addition, in the case of cotton, it is essential to understand each of the crop's phenological stages (Figure 10).

For monitoring and detection of cotton pests, traps and species-specific pheromones are used, in addition to field sampling. Depending on the pest, available control tactics include biological control, behavioral (ethological) control, autocidal control or the Sterile Insect Technique (SIT), genetic control, chemical control, legal control, and cultural control. The latter is one of the most important, as the establishment of planting periods and the destruction of stalks or crop residues have a strong impact on reducing populations of cotton boll weevil and pink bollworm.

The most commonly used biological control agents for cotton pests include *Trichogramma* spp., *Chrysoperla* spp., *Orius insidiosus, Bacillus thuringiensis*, and *Beauveria bassiana*. For chemical control, pyrethroid insecticides (deltamethrin and cypermethrin), organophosphates (malathion and mercaptothion), neonicotinoids (imidacloprid and thiamethoxam), sulfoximines (sulfoxaflor), and avermectins (abamectin) are applied. The use of these products should preferably be carried out under the recommendation of a specialized technical advisor.

In 2002, the Binational Mexico–United States Program for the eradication of pink bollworm and cotton boll weevil was implemented in the state of Chihuahua. For pink bollworm eradication, the program included an area-wide integrated pest management scheme with actions such as trapping, sampling, cultural control, behavioral control, autocidal control or the Sterile Insect Technique (SIT), genetic control (genetically modified cotton), and chemical control. After 16 consecutive years of work, eradication was achieved in all cotton-producing areas infested by the pest in Mexico and the United States of America. This represents a strong example of the effectiveness and benefits of Integrated Pest Management.

Main Pest Concerns in Latin American Cotton

- During the last two cotton seasons, failures have been observed in genetically modified cotton for pink bollworm control in Argentina, along with increases in pest populations and damage in organic cotton-producing areas and in the semiarid regions of Brazil. Mondino (2024) reported this issue in Argentina and described the available control methods for pink bollworm management.
- Resistance breakdown of stacked genetically modified cotton technologies (BG + VIP3, TwinLink + VIP3, WS + VIP3) to *Spodoptera frugiperda* and *Helicoverpa armigera* has also been observed in Brazil.

These two events should alert the cotton sector, since lepidopteran pest control over the last 30 years has been largely based on the planting of genetically modified cotton. Losing this important management tool would imply a return to intensive pesticide use, with high environmental and public health impacts.

Main Challenges for Cotton IPM in Latin America

Based on the review conducted by the Working Group in Mexico, Argentina, Brazil, and Peru, the following challenges were identified:

- Management of tolerance or resistance of *Pectinophora gossypiella*, *Spodoptera frugiperda*, and *Helicoverpa armigera* to *Bt* proteins. One of the most important measures to manage tolerance or resistance is to respect the planting ratio of genetically modified *Bt* cotton, with a maximum of 96% of the area planted with Bt cotton and 4% planted with conventional cotton as refuge. The use of certified seed also plays an important role, as planting seed of uncertain origin ("pirate" seed) does not ensure genetic vigor and accelerates the development of pest tolerance. Compliance with established legislation on these issues is essential.
- Training of new researchers, extension agents, and technical advisors to prepare for generational renewal. There are few young professionals entering this field in most cotton-producing countries in Latin America; therefore, encouraging and supporting them is a priority in the short term.
- Promotion and strengthening of IPM research, as some countries lack specific research programs. In this context, public–private partnerships are necessary to finance projects. Local and federal governments, along with the seed and pesticide industries, must work closely together to develop solutions to the current challenges affecting cotton production.

References

Mondino, M. H. (2024). Pink bollworm of cotton: the return of an old problem to the crop. Santiago del Estero Agricultural Experiment Station.