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Experience of good practices

Innovation strategy with bioproducts for the Agricultural Supply Company in Artemisa, Cuba

Estrategia de innovación con bioproductos para la Empresa de Suministros Agropecuarios en Artemisa, Cuba

Estratégia de inovação com bioprodutos para a Companhia de Abastecimento Agrícola em Artemisa, Cuba

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ABSTRACT

The Agricultural Supply Company in Artemisa faces constraints due to the scarcity and high cost of imported chemical fertilizers, coupled with soil degradation issues. The objective of this research was to design an innovation strategy based on bioproducts and biofertilizers for the Agricultural Supply Company, aligned with national food sovereignty policies. The strategy was developed using a

methodological approach that integrated a literature review, mixed-methods assessment (analysis of reports, interviews, and workshops), and triangulation of sources. A comprehensive approach is proposed that includes: research and development of biofertilizers adapted to local conditions; training for producers; and optimization of marketing. The expected results for 2026, based on projections validated by documented international experiences, include a 30% increase in the adoption of local biofertilizers, a 50% reduction in the use of agrochemicals, and the creation of 120 local jobs. The strategy would contribute to agricultural sustainability, food security, and climate resilience in Artemisa, serving as a scalable model for the Cuban agricultural sector.

Keywords: bioproducts; biofertilizers; agricultural innovation; sustainability; food security; technological transition.

RESUMEN

La Empresa de Suministros Agropecuarios en Artemisa enfrenta limitaciones por la escasez y alto costo de fertilizantes químicos importados, unido a problemas de degradación de suelos. Esta investigación tuvo como objetivo diseñar una estrategia de innovación basada en bioproductos y biofertilizantes para la Empresa de Suministros Agropecuarios, alineada con las políticas nacionales de soberanía alimentaria. La estrategia se desarrolló mediante un enfoque metodológico que integró revisión documental, diagnóstico con técnicas mixtas (análisis de informes, entrevistas y talleres), y triangulación de fuentes. Se propone un enfoque integral que incluye: investigación y desarrollo de biofertilizantes adaptados a condiciones locales; capacitación a productores; y optimización de la comercialización. Los resultados esperados para 2026, basados en proyecciones validadas con experiencias internacionales documentadas, incluyen un aumento del 30% en la adopción de biofertilizantes locales, una reducción del 50% en el uso de agroquímicos, y la creación de 120 empleos locales. La estrategia contribuiría a la sostenibilidad agrícola, la seguridad alimentaria y la resiliencia climática en Artemisa, constituyendo un referente escalable para el sector agropecuario cubano.

Palabras clave: bioproductos; biofertilizantes; innovación agrícola; sostenibilidad; seguridad alimentaria; transición tecnológica.

RESUMO

A Companhia de Abastecimento Agrícola de Artemisa enfrenta limitações devido à escassez e ao alto custo dos fertilizantes químicos importados, além de problemas de degradação do solo. Esta pesquisa teve como objetivo desenvolver uma estratégia de inovação baseada em bioprodutos e biofertilizantes para a Companhia de Abastecimento Agrícola, alinhada às políticas nacionais de soberania alimentar. A estratégia foi desenvolvida utilizando uma abordagem metodológica que integrou revisão documental, diagnóstico com técnicas mistas (análise de relatórios, entrevistas e oficinas) e triangulação de fontes. Propõe-se uma abordagem abrangente que inclui: pesquisa e desenvolvimento de biofertilizantes adaptados às condições locais; capacitação de produtores; e otimização de marketing. Os resultados esperados para 2026, com base em projeções validadas por experiências internacionais documentadas, incluem um aumento de 30% na adoção de biofertilizantes locais, uma redução de 50% no uso de agroquímicos e a criação de 120 empregos locais. A estratégia contribuiria para a sustentabilidade agrícola, a segurança alimentar e a resiliência climática em Artemisa, servindo como um modelo escalável para o setor agrícola cubano.

Palavras-chave: bioprodutos; biofertilizantes; inovação agrícola; sustentabilidade; segurança alimentar; transição tecnológica.

INTRODUCTION

Agriculture in Cuba faces the challenge of maintaining productivity amid critical input shortages, soil degradation, and the effects of climate change. According to FAO monitoring (2023), cereal production in Cuba decreased by nearly 50% compared to the five-year average during 2023, due to persistent shortages of agricultural inputs and limited access to credit for producers. This crisis is reflected in the drastic reduction in available chemical fertilizers, which, according to recent reports from the U.S. Department of Agriculture (Zahniser et al., 2024), have covered less than 10% of national requirements, forcing farmers to turn to biofertilizers in the absence of chemical alternatives.

Recent meta-analyses, based on more than 1,800 field trials, demonstrate that biofertilizers significantly increase yields in 21 of 23 crops evaluated, with average increases of 12-25% depending on crop type and soil quality (Pei et al., 2025; Schütz et al., 2018). Specifically, in semi-arid conditions, biofertilizers based on *Bacillus* spp. and arbuscular mycorrhizae have been shown to

increase water stress tolerance in wheat, improving water use efficiency by up to 53% under water-deficient conditions (Ikan et al., 2024).

In Cuba, the use of bioproducts has been promoted through the Farmer-to-Farmer agroecological movement of the National Association of Small Farmers, which since the 1990s has demonstrated the viability of sustainable production without dependence on imported chemical inputs, contributing significantly to food sovereignty and laying the groundwork for the transition toward resilient agricultural models (Betto, 2021; Rosset et al., 2011). This movement has validated participatory research methodologies that integrate peasant knowledge with agroecological science, creating the conditions for the transition toward more sustainable agriculture.

The Agricultural Supplies Company (GELMA) has initiated promising experiments using local byproducts such as tobacco (*Nicotiana tabacum*) for pest control, demonstrating the potential of these alternatives under the specific conditions of Artemisa. These initiatives are part of circular economy models where agro-industrial waste is repurposed as sustainable inputs, reducing production costs by up to 40% and decreasing pollution from synthetic agrochemicals (Gaitan Angulo et al., 2024). However, these initiatives lack systemic integration that would allow for their scaling up and widespread adoption across the province, requiring a comprehensive strategy that integrates production, training, and marketing.

Therefore, the objective of this research was to design an innovation strategy with bioproducts and biofertilizers for GELMA in Artemisa, contributing to agricultural sustainability and food sovereignty. The proposed strategy seeks to capitalize on existing experiences and enhance them through a systemic approach that considers the agroecological and socioeconomic particularities of the territory.

MATERIALS AND METHODS

The research was conducted using a mixed-methods approach (qualitative-quantitative), through a descriptive-propositional case study of the Agricultural Supply Company in the province of Artemisa, Cuba (2023-2024). The methodological design was based on the triangulation of sources (documentary, interviews, workshops) and methods (analytical- -descriptive, and participatory) to ensure the internal validity and reliability of the results (Hernández Sampieri et al., 2014).

Phase 1: Literature review and context analysis

A systematic review of scientific literature was conducted in the Scopus, SciELO, and Google Scholar databases and in Cuban institutional repositories (2020-2024), using controlled descriptors: "biofertilizers," "agricultural bioproducts," "sustainable agriculture in Cuba," "circular economy," and "agroecological transition." The following inclusion criteria were applied: (a) publications from 2020-2024, (b) language: Spanish/English, (c) full-text access.

Concurrently, 15 internal technical reports from GELMA (2019-2023) were analyzed, selected through purposive sampling based on thematic relevance and document availability, including: supply management reports (n=6), agrochemical import reports (n=5), and evaluations of input use by crop (n=4). The documents were analyzed using documentary content analysis (Bardin, 2016) (Appendix 1: Technical Report Analysis Matrix).

Phase 2: Primary data collection

Semi-structured interviews: Eight interviews were conducted with key informants from GELMA: executives (n=3: president, vice president of finance, director of production) and technical specialists (n=5: regional agronomists with 5 or more years of experience). Selection was based on institutional experience and direct knowledge of the subject of study. The interviews were structured around four dimensions: (a) input management and dependence on imports, (b) previous experiences with bioproducts, (c) technical and infrastructure capacities, (d) perceptions regarding agroecological transition. The interview guide was validated by three experts in agricultural management (Content Validity Coefficient: CVI=0.92) and pilot-tested (n=2) prior to its final application (Appendix 2: Semi-structured interview guide and validation certification).

The interviews were conducted between January and February 2024, with an average duration of 45 minutes, at GELMA's facilities. Informed consent was obtained from all participants, and confidentiality was ensured through alphanumeric coding (E1-E8). The interviews were audio-recorded (with permission) and verbatim transcribed for analysis.

Participatory validation workshops: Two workshops were held with 25 agricultural producers (Alquízar municipality, n=13; Guanímar municipality, n=12), selected based on their membership in credit and service cooperatives (CCS) affiliated with GELMA, their cultivation of various crops (staple foods, vegetables, tobacco), and their willingness to participate. The workshops lasted 4 hours each

(March 2024) and were structured in three phases: (i) presentation of preliminary results of the SWOT analysis by the research team, (ii) focus groups by crop type (3 groups of 8-9 producers), identifying barriers and potential for the adoption of bioproducts, (iii) a participatory validation session of proposed strategies using a weighted voting technique and collective development of adjustments.

Workshop minutes were prepared, including photographic records, signed attendance lists, and consensus matrices (Appendix 3: Workshop minutes and photographic evidence). The information was systematized through thematic content analysis (Bardin, 2016).

Phase 3: Data analysis and strategy development

Documentary and primary data were processed through categorical content analysis, using NVivo 12 software for qualitative data management. Predefined categories from the SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) and subcategories emerging from inductive analysis were established. Methodological triangulation was performed by cross-checking: (a) documentary evidence (technical reports), (b) interview testimonies (managers and technicians), and (c) workshop consensus (producers). The Inter-Source Agreement Coefficient was calculated (≥0.80 was considered acceptable).

To develop the strategy, the participatory projection method (simplified Delphi) was used, validating goals through trend analysis of documented experiences (Schütz et al., 2018) and projections based on GELMA's installed capacity. Quantitative projections for 2026 were calculated using scenario analysis: (a) conservative scenario (gradual adoption, 20% reduction in agrochemicals), (b) moderate scenario (accelerated adoption, 50% reduction), (c) optimistic scenario (massive adoption, 70% reduction). The moderate scenario was selected as a feasible target, with 95% confidence intervals.

RESULTS AND DISCUSSION

Diagnosis of GELMA's current situation

The comprehensive diagnosis of GELMA in Artemisa revealed a complex scenario characterized by strategic strengths and structural limitations. Among the main strengths identified are its consolidated position in the provincial agricultural supply chain (covering 85% of cooperatives), its

established logistics network, and its emerging experiences with bioproducts, particularly the use of tobacco (*Nicotiana tabacum*) as a biopesticide in vegetable crops. These initiatives, developed since 2021, demonstrate internal capacities for innovation and technological adaptation, constituting a solid foundation for productive transformation processes.

The following critical weaknesses were identified: (a) high dependence on imported inputs, accounting for 92% of the fertilizers used in the province; (b) limited infrastructure for local production of bioproducts (no in-house quality control laboratory); (c) a shortage of specialized technical training in bio-input management (only 2 technicians with specific training); and (d) centralized distribution systems that hinder timely access for producers. These constraints align with reports by the FAO (2023) and the U.S. Department of Agriculture (Zahniser et al., 2024) regarding Cuba, where dependence on agricultural input imports constitutes a critical vulnerability factor for food systems.

The environmental analysis identified significant opportunities: (a) the existence of a consolidated peasant movement with experience in agroecology (Rosset et al., 2011); (b) the availability of research centers with proven capabilities (University of Artemisa, Labiofam, AzCuba); (c) the existence of valuable local byproducts (tabaquina, sugarcane waste, poultry manure); (d) growing demand for organic food in local markets. Recent research confirms that partnerships between companies and research centers accelerate innovation and technological adaptation in the agricultural sector (Liu et al., 2023).

Among the most significant threats are: (a) volatility in the international fertilizer market (200-400% price increases post-pandemic); (b) impacts of climate change (prolonged droughts, hurricanes); (c) cultural resistance among producers to changing established practices; (d) unfair competition from smuggled imported agrochemicals. These external factors underscore the urgency of implementing adaptation strategies based on local resources (Ikan et al., 2024).

GELMA's experience with tabaquina aligns with the principles of the circular economy by valorizing a waste product from the local tobacco industry (provincial production: ~1,200 tons/year of waste) that previously represented an environmental liability. Recent studies confirm that such initiatives not only reduce production costs by up to 40% but also contribute to soil health and reduce pollution from synthetic agrochemicals (Gaitan Angulo et al., 2024).

The scientific literature corroborates the potential of bioproducts in agricultural contexts with input constraints. Schütz et al. (2018) demonstrated in a global meta-analysis that biofertilizers increase crop yields by 12-25% depending on the specific crop. Specifically, recent experimental studies in *Frontiers in Microbiology* demonstrate that consortia of phosphate-solubilizing *Pseudomonas* spp. and *Bacillus* spp. increase phosphorus availability in tomato plants through the production of organic acids (gluconic, malic, and citric), reaching solubilization concentrations of up to 195.42 μgmL^{-1}, and reduce the incidence of bacterial diseases such as bacterial canker by 75% (Bakki et al., 2024). Meanwhile, global meta-analyses confirmed that biofertilizers significantly improve soil health, increasing organic matter by 16.64% and suppressing pathogens by 51.81% (Pei et al., 2025), validating their effectiveness under real field conditions. Additionally, it has been demonstrated that microbial consortia inoculated into living soils perform significantly better than individual strains, increasing plant growth by 48% versus 29% for isolated strains (Liu et al., 2023).

Proposed innovation strategy

Component 1: Research and Development (R&D)

The R&D strategy is based on establishing strategic partnerships with academic institutions and research centers. We propose the creation of a Bio-Inputs Innovation Unit within GELMA, in collaboration with the "Julio Díaz González" University of Artemisa and the Labiofam Biopharmaceutical Research Center. This unit would have three lines of work: (a) formulation of nitrogen and phosphate biofertilizers adapted to the province's brown and red ferralitic soils; (b) industrial scaling of biopesticides derived from tabaquina and other local byproducts; (c) standardized field trials for efficacy validation.

The program will prioritize the development of biofertilizer formulations based on arbuscular mycorrhizae (*Glomus* spp.) and legume-specific rhizobia, adapted to the soil and climate conditions of Artemisa. Recent meta-analyses demonstrate that microbial consortia can increase nutrient use efficiency by up to 48% compared to individual strains, particularly in strategic crops such as tobacco, beans, and vegetables (Liu et al., 2023; Schütz et al., 2018). The sustainability of the R&D component requires the establishment of a basic quality control laboratory (microbiology, soil biochemistry) within the GELMA structure, with an estimated investment of $25,000 in initial equipment.

Component 2: Training and Technology Transfer

The training program will be designed using a participatory approach that integrates farmers' traditional knowledge with technical and scientific advances, following the Farmer-to-Farmer methodology validated in Cuba (Rosset et al., 2011). It will be structured as a tiered training system: (a) basic level (management and application of bio-inputs), (b) intermediate level (artisanal production of biofertilizers), (c) advanced level (quality monitoring and problem-solving). The methodologies will include theoretical-practical workshops, monthly field days, demonstration plots in 5 pilot cooperatives, and educational materials adapted to the local context (booklets, short videos).

An innovative aspect will be the prioritization of young people (ages 18-35) and women (≥40% of participants) through specific modules that address their particular needs and potential. Recent studies show that the inclusion of these social groups not only strengthens equity in the agricultural sector but also accelerates the adoption of sustainable technologies (FAO, 2023). Flexible schedules (weekends) and teaching methodologies that address knowledge access gaps (digital literacy, inclusive language) will be established.

Impact evaluation will be conducted using the following indicators: (a) number of trained producers, (b) technology adoption rate (6- and 12-month follow-up), (c) changes in management practices (structured surveys), (d) satisfaction with training (Likert scale). According to the FAO (2023), agricultural extension programs that incorporate robust monitoring mechanisms achieve technology adoption rates up to 40% higher than conventional programs.

Component 3: Marketing and Market Access

Optimizing the supply chain requires reengineering logistics processes. A decentralized distribution system will be implemented with: (a) 3 regional collection centers with refrigerated storage capacity for bio-inputs, (b) 15 points of sale in cooperatives (mobile stores), (c) a telephone and digital ordering system (mobile app). This will facilitate timely access for farmers, reducing wait times from 15-20 days to 3-5 days.

Marketing strategies will incorporate: (a) multimedia outreach campaigns (local radio, social media, brochures) communicating economic and environmental benefits, (b) testimonials from pioneering producers who have successfully implemented these technologies, (c) a quality assurance system

with efficacy certification and crop-specific application protocols, (d) the territorial brand "BioGELMA-Artemisa" associated with the province's agricultural identity, adding commercial value. Previous studies highlight that social validation through successful peer experiences significantly increases trust and willingness to adopt technological change (Gaitan Angulo et al., 2024).

Flexible financing mechanisms will be established: credit sales (post-harvest payment), cross-subsidies (larger-scale producers support small-scale ones), and partnerships with credit unions for preferential loans. This will address the liquidity barrier that frequently limits the adoption of innovations in the current Cuban context (Rosset et al., 2011).

Expected impact of the strategy (2026 projections)

The comprehensive implementation of the strategy could generate transformative impacts across multiple dimensions:

Economic dimension: 40% reduction in fertilizer costs (replacing imports with local production), freeing up an estimated $450,000 annually for other productive investments. Creation of 120 local jobs (direct and indirect): 25 in bio-input production, 15 in quality control and distribution, 40 in technical assistance, and 40 in marketing. A 25% increase in net income for adopting producers, due to reduced input costs and access to differentiated markets (organic).

Environmental dimension: 50% reduction in the use of synthetic agrochemicals (conservative projection: 35% by 2024, 50% by 2026), reducing soil and aquifer contamination. Estimated annual increase of 0.8-1.2% in soil organic matter, improving water retention and climate resilience. 30% reduction in the carbon footprint associated with the transport of imported inputs.

Social dimension: Direct training of 500 producers and technicians (2024-2026), strengthening territorial management and innovation capacities. Participation of 40% women and 35% youth in training and entrepreneurship programs. Stabilization of provincial agricultural production, contributing to local food security.

The projections are based on: (a) analysis of documented previous experiences (Ikan et al., 2024; Pei et al., 2025; Schütz et al., 2018), (b) models of technology adoption in agriculture (diffusion of innovations), (c) GELMA's current and potential installed capacity. Scenario analysis with 95%

confidence intervals was used, selecting targets from the moderate scenario (accelerated but realistic adoption).

The proposed strategy represents a viable path for the agroecological transition of GELMA in Artemisa, integrating technological innovation, institutional strengthening, and social participation. However, its implementation will face challenges that must be proactively addressed.

The study's limitations include: (a) the availability of up-to-date data on the province's actual bioproduct production capacity (internal reports with a 6- to 12-month lag); (b) the need to adjust implementation timelines based on the availability of external funding (international cooperation); (c) dependence on the establishment of formal inter-institutional partnerships (university-business agreements). These limitations were mitigated through triangulation of sources and participatory validation, but require monitoring during the implementation phase.

GELMA's experience with bioproducts, particularly the valorization of tabaquina, serves as a scalable model for other companies in the Cuban agricultural system. The strategy demonstrates the viability of transitioning toward more sovereign, sustainable, and resilient agricultural models, contributing to the Sustainable Development Goals (SDG 2: Zero Hunger, SDG 12: Responsible Consumption and Production, SDG 13: Climate Action).

It is recommended to establish a monitoring and evaluation system with quarterly indicators: (a) volume of bio-input production, (b) number of trained producers and adopters, (c) reduction in agrochemical imports, (d) user satisfaction. This will allow for timely adjustments and the documentation of lessons learned for replication in other regions.

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APPENDICES

Appendix 1. Analysis Matrix of GELMA Technical Reports (2019-2023)

Code	Document type	Year	Relevant content	SWOT Categories
IT-01	Supply Management Report	2019	94% Dependence on Imports	Weakness
IT-02	Supply Management Report	2020	Shortage of NPK fertilizers	Threat
...	...	...	...	...
IT-15	Assessment of input use	2023	Experience with tobacco	Strength

Appendix 2. Semi-structured interview guide and validation

INTERVIEW GUIDE FOR GELMA MANAGERS AND TECHNICIANS

General Information: Date: ___ Code: ___ Position: ___ Years in Position: ___

Section A. Input management and dependence on imports

1. What is the current percentage of imported versus domestic fertilizers sold by GELMA?
2. How has the input crisis affected the company's operations over the past 3 years?
3. What strategies has GELMA implemented to mitigate the shortage of agrochemicals?

Section B. Experience with bioproducts

4. Has GELMA gained any experience with biofertilizers or biopesticides? Please, describe.
5. What are the main obstacles to the production/marketing of bioproducts?
6. What potential do you see in local byproducts (tobacco waste, organic waste)?

Section C. Capacities and innovation

7. Does GELMA have infrastructure for a laboratory and quality control of bio-inputs?
8. Has GELMA established partnerships with research centers (universities, Labiofam)?

Section D. Perceptions of agroecological transition

9. How do you assess producers' willingness to adopt bioproducts?
10. What institutional support would GELMA require to lead this transition?

CONTENT VALIDATION CERTIFICATION

Expert	Specialty	Item 1	Item 2	...	Item 10	CVI
E1	Agricultural Management	4	4	...	3	0.90
E2	Agroecology	4	4	...	4	1.00
E3	Agricultural Extension	4	3	...	4	0.90
Total						**0.93**

Scale: 1 = Not relevant, 2 = Slightly relevant, 3 = Relevant, 4 = Very relevant.

CVI ≥ 0.80 is acceptable

Appendix 3. Minutes of participatory workshops

Workshop minutes No. 1

Date: March 15, 2024

Location: CCS Camilo Cienfuegos, Alquízar

Participants: 13 producers (8 men, 5 women)

Procedure

1. Presentation of SWOT analysis results (45 min)
2. Focus groups by crop: root vegetables (4), vegetables (5), tobacco (4) (60 min)
3. Validation of strategies and weighted voting (45 min)

Consensus reached

- Prioritize nitrogen biofertilizers for corn and beans
- Need for field demonstrations prior to widespread adoption
- Request for flexible financing (short-term credit)

Photo record: [Attach 5-8 photos with participants' permission]

Facilitators: [Signatures] **CCS President:** [Signature]

(Similar format for Workshop No. 2, Guanímar, March 22, 2024)

Conflict of interest

Authors declare that they have no conflicts of interest.

Authors' contribution

Efraín Díaz Arias and Alexander Chile Bocourt designed the study, analyzed the data, and prepared the draft.

Mariol Morejón García was involved in data collection, analysis, and interpretation.

Adrián Martínez García participated in primary data collection and coordinated participatory workshops with producers.

All the authors reviewed the writing of the manuscript and approve the version finally submitted.

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