Production de bio-intrants à base de micro-organismes autochtones bénéfiques à Cuba

Production of bio-inputs based on beneficial indigenous microorganisms in Cuba

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RÉSUMÉ. Cette étude analyse le développement des bio-intrants à base de micro-organismes autochtones bénéfiques (MAB) à Cuba. L'approche mobilise le cadre d'analyse du système d'innovation sectoriel et des ateliers participatifs dans cinq provinces pour cartographier l'écosystème des parties prenantes. Les résultats montrent que le secteur technologique s'organise autour de deux chaînes : une chaîne industrielle étatique et une chaîne paysanne décentralisée d'autoproduction. Trois obstacles freinent la généralisation : une pénurie d'intrants (mélasse, emballages) ; des procédures de certification conçues pour les unités de production industrielle plutôt que pour les unités d'autoproduction ; ainsi que des dysfonctionnements commerciaux et une pénurie de main-d'œuvre. Les résultats concluent que la généralisation basée sur une trajectoire d'autoproduction repose sur une restructuration institutionnelle des normes techniques et de certification reconnaissant l'hétérogénéité de la production décentralisée.

ABSTRACT. This study analyses the development of bio-inputs based on beneficial indigenous microorganisms (BIM) in Cuba. The approach utilises the sectoral innovation system analysis framework and participatory workshops in five provinces to map the ecosystem of stakeholders. The results show that the technological sector structured by this innovation is organised around two chains: a state-run industrial chain and a decentralised peasant self-production chain. Three obstacles hinder widespread adoption: a shortage of inputs (molasses, packaging); certification procedures designed for industrial production units rather than self-production units; and labour shortages and commercial dysfunctions (quality, distribution). The findings conclude that widespread adoption based on a self-production trajectory relies on an institutional restructuring of technical and certification standards that recognises the heterogeneity of decentralised production.

MOTS-CLÉS. Autoproduction d'intrants, trajectoire sociotechnique, micro-organismes autochtones bénéfiques, système d'innovation, agroécologie

KEYWORDS. Self-production of inputs, socio-technical trajectory, beneficial indigenous microorganisms, innovation system, agroecology

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Introduction

The production and use of bio-inputs in agriculture and food as an alternative to chemical fertilisation are being promoted worldwide. These bio-inputs can reduce agriculture's dependence on the chemical industry and fossil fuels. They could help mitigate the impacts of climate change, reduce chemical pollution and enhance the biodiversity necessary for agroecological transitions. Finally, they are credited with a socio-political role in reducing the technological and political vulnerabilities arising from dependence on international markets, thereby improving food sovereignty [BAV 24]; [KUM 24].

Over the last five years, the market for bio-inputs has continued to grow across different continents [AZE 25], particularly in the Americas [BUL 23]. This growth accompanies and shapes public and private investment in the emergence of bio-factories [MES 24], [GOU 24]. These bio-factories respond to a wide variety of situations — from producers with traditional agroecological experience contributing ancestral knowledge, to small farmers organised into communities, and large-scale farms applying conservation agriculture practices to reduce their costs.

In the Cuban context, these bio-factories are also underpinned by public policies and investment in research centres, universities and state-owned enterprises [MIN 21]; [CAL 23]; [DAN 24]. These policies, launched in the 1980s, focus on the agroecological transformation of agriculture to reduce the country's dependence on imports of inputs blocked by the United States. The recent tightening of the US blockade and the growing instability of the chemical fertiliser market make it urgent to scale up bio-fertiliser production and empower producers to ensure the country's agricultural and food production [TEM 26].

The Cuban bio-inputs sector is structured around two technological pathways. On the one hand, an industrial infrastructure financed by public investment: strain standardisation and investment in bio-factories. This infrastructure faces difficulties in adapting to the reduction in public resources inherent in the current multiple crisis [BEL 26]. On the other hand, there is decentralised self-production through networks of small farmers coordinated by various collective structures: local formulations and the use of indigenous resources. These two trajectories interact through the combination of state-led innovation and peasant expertise in different regional and local contexts.

Based on the results of a collaborative research project between Cuban and international agricultural research institutions, we examine how the current state of the bio-inputs production technology sector in Cuban agriculture allows us to identify the main obstacles to the widespread adoption of production and use.

1. A methodological framework for analysing the bio-inputs innovation system

From a conceptual standpoint, we have utilised the general framework for analysing the innovation system as applied to the study of sectoral technological dynamics related to bio-inputs [TOU 15]. Subsequently, at the methodological level, we have employed various tools [CAN 20], notably the characterisation of the ecosystem of actors and a participatory research approach [BOR 99] to identify the different categories of barriers — technical-productive, economic, social and political — that hinder the widespread adoption of bio-input production based on beneficial indigenous microorganisms (BIM/MABs).

This analytical framework leads us to specify different methodological options and to characterise the information-gathering mechanism that structures the results.

The first option focuses the analysis of the innovation process on a specific technology for the production of bio-inputs related to MABs [BLA 16]. This technology develops, adapts and adopts Teruo Higa's Effective Microorganisms (EM) technology within the Cuban context, introduced by the Indio Hatuey Pasture and Forage Experimental Station (EEPFIH) in 2006.

The second methodological approach documents the analysis of the conditions for the implementation and use of MABs in bio-input production across different regions within five provinces. This regional diversity translates into institutional, business and economic heterogeneity among the projects and value chains linked to these regions. The five provinces selected for their importance in the field of bioproducts and microorganisms were: Mayabeque, Artemisa, Matanzas, Cienfuegos, Sancti Spíritus and Ciego de Ávila (Figure 1).

The third methodological approach involves characterising the ecosystem of key stakeholders — scientific institutions, universities, companies, production units — involved in the design, investment, production and use of MAB-based bio-inputs.

The final methodological approach involves gathering information through the organisation and facilitation of participatory workshops with multiple stakeholders. The aim is to share and identify the main constraints to increasing the production of bio-inputs related to MABs. At each workshop, a discussion was organised between the different stakeholder groups, namely: public researchers (institutes and universities), experimental farmers, public enterprises and public support services.

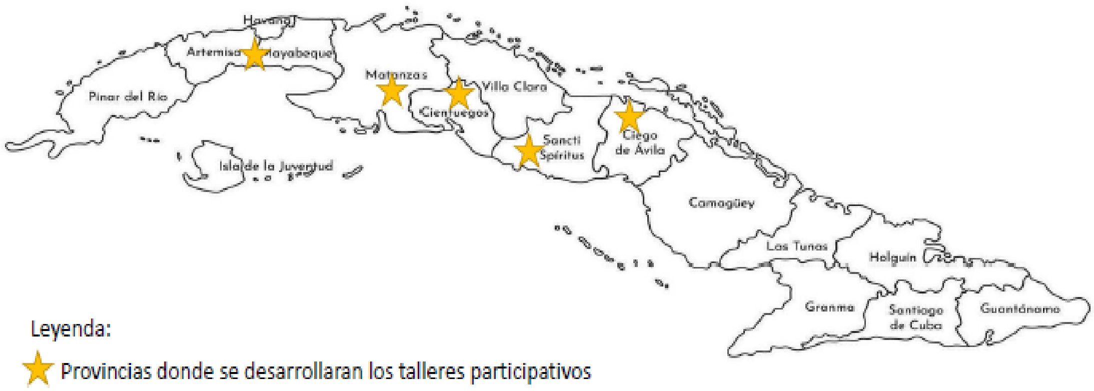

Figure 1. *Distribution of workshops by province, Cuba*

The initial collection of information in the workshops was supplemented by an analysis of the scientific literature on the implementation of MABs globally, in Latin America and in Cuba.

2. Results

2.1. *Characterisation of the MAB-based productive innovation process*

The innovation processes for the production of MABs in the manufacture of bio-inputs can be divided into three production phases: preparation of the solid mother culture, preparation of the liquid mother culture, and activation of the product for application or use [PEN 21].

Experiments into its use have been extended to various agricultural sectors. For example, its use in fertilising potatoes, cucumbers and maize stands out for achieving yields similar to those of conventional cultivation [PEÑ 16]; [MES 16]. The inoculation of rhizobia and the commercial bioproducts ME-50® (effective microorganisms: beneficial bacteria and fungi) and FitoMas E® (amino acids, nitrogenous bases, bioactive saccharides and polysaccharides) increases bean yield by up to 71% compared to the control, with an improvement in grain quality and a reduction in chemical fertilisers [CAL 22]. Similar results have also been obtained in potato and tomato cultivation by applying MABs with *Pseudomonas sp.* and *Trichoderma spp.* [ROJ 23]. Furthermore, their inclusion in biological preparations for animal feed has proven effective in pig rations [OJE 16]; [LOP 16], and in fish farming in association with the California red worm (*Eisenia fetida*) [COR 22].

Finally, the application of AMF in the treatment of stagnant water and in sanitation for the control of ammonia emissions from the litter of commercial laying hens has been mentioned [COL 20]. However, these positive results are essentially based on research experiments or production situations linked to research facilities. This leads us to recall the distinction between two main groups of MABs:

- Certified MABs are developed by research institutes with official registration — for example IHPLUS®BF, which is versatile and multifunctional and has been successfully integrated into other bioproducts (biochar).

- Non-certified MABs are produced by local farmers with or without institutional technical support. They are not officially registered but perform similar functions, adapted to locally available inputs incorporating medicinal plants, minerals and other effective microorganisms from local forest litter.

2.2. *Characterisation of the ecosystem of stakeholders in MAB-based bio-input innovation*

Mapping the stakeholders reveals that MAB producers are integrated into the technological innovation system for bioproducts through three complementary profiles that perform distinct functions within the agroecological chain.

- Key experimental actors are farmers in the private sector and in state-run cooperatives (CCS), entrepreneurs belonging to the Self-Employment Scheme (TCP) or Micro, Small and Medium-sized Enterprises (MSMEs), business managers (EES), university lecturers and researchers from Science and Technology Units (UCT). All of them play a key role in the generation, validation and transfer of knowledge that facilitates the adoption of new practices and technologies; they are described and illustrated below, according to the types of actors.

- Producers and entrepreneurs: farms and business in Artemisa, Matanzas, Cienfuegos, Santi Spíritus and Ciego de Ávila (for example, farms: La Magela, La Excelencia, San Juan Bautista, Merceditas, Australia, Punta la Cueva, Casa Blanca, Del Medio, Los Capuchas, Rincón Los Hondones, and business: Primicia Natural)

- With regard to production units, a diversity of experiences can be observed. Some farms, such as San Juan Bautista and Merceditas, rely on commercial products such as IHPLUS®BF, the efficacy of which they validate through institutional training. Others, such as La Excelencia and José Martí, have evolved towards the self-production of bio-inputs, creating their own brands and marketing significant volumes of MAB. In the case of La Magela, Punta la Cueva and Del Medio, these constitute demonstration centres for the artisanal production of effective microorganisms, integrating composting, biochar and empirical practices to rehabilitate degraded soils with the aim of achieving the agroecological transition of production systems.

- At the institutional level, key players such as the EEPFIH, the IIHLD, the Bioplants Centre, the universities of Matanzas and Cienfuegos, and the business group of the Biopharmaceutical Laboratory (LABIOFAM) provide training and promote technology transfer and the industrial production of bio-inputs such as LEBAME, Nerea and Fertimang. They carry out projects such as BioFas and training courses in permaculture, which have enabled producers to learn about international experiences, thereby reinforcing the adoption of agroecological practices.

- Representatives and managers of state-owned enterprises: Ceballos Agro-industrial Enterprise; Enterprise for the Production and Marketing of Glucose, Starch and Maize Derivatives (GYDEMA); 5 de Septiembre Municipal Agro-industrial Enterprise; MINAG Logistics Business Group (GELMA); AZCUBA Business Group (sugar cane); and the Cienfuegos Biopharmaceutical Laboratory (LABIOFAM) business group, part of MINSAP.

- Lecturers and researchers: Agricultural University of Havana (UNAH); National Centre for Agricultural Health (CENSA); Liliana Dimitrova Horticultural Research Institute (IIHLD); Camilo Cienfuegos University of Matanzas (UMCC); EEPFIH/University of Matanzas (UMCC); Faculty of Agricultural Sciences (FCA)/UMCC; University of Cienfuegos (UCF); FCA/UCF; University of Ciego de Ávila (UNICA); Bioplants Centre/UNICA.

- Ministry officials: CITMA regional offices in Matanzas and Cienfuegos; Regional agriculture office linked to the National Association of Small Farmers (ANAP) in Cienfuegos.

Type of actor	Organisation	Role
Producers	CCS and TCP	Primary production: supply of food, raw materials and expertise; at the heart of agricultural innovation and regional sustainability.
Business representatives	EES	Responsible for the production chain: link production with industry, ensure processing and distribution of products, provide infrastructure and logistics.
Lecturers – Researchers	Universities and UCTs	Knowledge generation and technology transfer: conduct research, train professionals and transfer innovations to producers and businesses.
Civil servants	MINAG; CITMA; MES	Regulators and facilitators of public policy: design, oversee and enforce regulations; promote sustainable development programmes; link local actors with national policies.

Table 1. *Key stakeholders in MAB management. Note: CCS = Credit and Cooperative Services; TCP = Self-Employment; EES = State-Owned Enterprises; UCT = Scientific-Technical Unit; MINAG = Ministry of Agriculture; CITMA = Ministry of Science, Technology and the Environment; MES = Ministry of Higher Education*

The mapping of stakeholders reveals a diverse ecosystem comprising private producers, cooperatives, universities, research centres and public enterprises. These stakeholders form a network that links research, promotion and production, within which other key stakeholders operate: company representatives and managers, teachers and researchers, as well as ministry officials. These elements, discussed during the decentralised workshops in the five regions studied, allow us to distinguish two production chains for the implementation of MABs: the state production chain and the smallholder production chain.

2.3. *Differentiation of bio-input production chains based on MABs*

2.3.1. *State production chain*

The state production chain generates bio-inputs at the enterprise level, covering the entire national territory. It is represented by LABIOFAM, the FINLAY Institute, and the National Centre for the Production of Laboratory Animals (CENPALAB). According to MINAG, as of 2021, Cuba had 229 facilities dedicated to the production of bio-inputs [MIN 21]. Of these, 12 were industrial fermentation bio-factories, with an installed capacity of 45,810 litres and an annual production potential of 3,685,000 litres to which was added the production of 40 tonnes of EcoMic®, 8 kg of Biobras 16® and 2,000,000 litres of Fitomas E®. The remaining 217 facilities were Centres for the Reproduction of Entomophages and Entomopathogens (CREE).

In 2021, the pilot plant for the IHPLUS®BF bio-fertiliser was inaugurated, based on MAB obtained in the Ciénaga de Zapata region, in Matanzas, which has a potential capacity of 1,000,000 litres per year. Subsequently, the following industrial bio-factories were established: UEB Bio-productos Cuba 10, specialising in the mixed microbial cultures Lebame®, obtained through controlled fermentation from strains developed using biotechnology (Bacillus subtilis, *Lactobacillus bulgaricum* and *Saccharomyces cerevisiae*); and Labiofam, with the ME-50 bio-fertiliser based on MAB from the Ciego de Ávila region. Table 2 presents the main commercial bioproducts developed in the regions studied.

Product	Base microorganism / active ingredient	Main function	Developing institution
IHPLUS®BF	Consortium of bacteria, yeasts and fungi	Biofertiliser, biostimulant, agro-environmental	EEPFIH
Azofert®	*Rhizobium leguminosarum* and *Bradyrhizobium elkanii*	Biofertiliser, biological control and biostimulant	INCA
Biobras-16®	Brassinoids (plant hormones)	Biostimulant	INICA, ICDCA, INCA
Fitomas-E®	Mineral salts, organic extracts and amino acids	Biostimulant	ICIDCA
EcoMic®	Arbuscular mycorrhizal fungus (AMF)	Biofertiliser	INCA
ME-50®	Consortium of lactic acid bacteria, yeasts, fermentative and photosynthetic bacteria	Biofertiliser, biostimulant	LABIOFAM
Lebame	*Bacillus subtilis, Lactobacillus bulgaricum, Saccharomyces cerevisiae*	Biofertiliser, biostimulant	ICIDCA, UEB Bioprocesses Cuba 10
Fosforina	*Bacillus, Pseudomonas, Aspergillus* and *Penicillium*	Biofertiliser	Soil Institute
Nerea	Natural zeolites	Fertiliser	IMRE, University of Havana
Fertimang	Concentrated aqueous extract of *Mangifera indica* L.	Organic fertiliser	LABIOFAM

Table 2. *Main commercial bioproducts developed in the laboratory and used in the regions studied. Note: EEPFIH = Indio Hatuey Pasture and Forage Experimental Station; INCA = National Institute of Agricultural Sciences; INICA = National Institute of Sugar Cane Research; ICDCA = Cuban Institute of Sugar Cane Derivatives; LABIOFAM = Biopharmaceutical Laboratories; UEB = Grassroots Business Unit; IMRE = Institute of Materials Science and Technology.*

These bio-plantations sell their products directly at the production site, which limits access for farmers, many of whom are located a considerable distance away. In fact, they must arrange transport, the costs of which, linked to energy prices, are constantly rising. The lack of decentralised distribution networks is linked to infrastructure and transport constraints, but also to the difficulty of ensuring and guaranteeing the storage and preservation conditions for biological inputs, as well as to the deterioration of infrastructure (falling public investment) in relation to soil and plant health laboratories, and CREEs. The limited capacity of accredited laboratories to cope with the decline in public funding also makes it difficult to obtain biosafety licences.

2.3.2. *Smallholder production chain*

Self-production of MABs has developed progressively since 2006, thanks to small-scale artisanal facilities located on farms. The process involves collecting indigenous strains from forest litter, propagating them through fermentation in solid substrates or liquid media, activating and enriching them in carriers (water, molasses, compost or clay), and preserving them. This involves carrying out microbiological quality controls to ensure the presence of MABs and the absence of pathogens.

Artisanal self-production is usually practised by ‘pioneering’ farmers for the local marketing and distribution of bioproducts amongst themselves. In 2020, up to 98 bioproduct production centres were recorded on multi-purpose smallholder farms [COL 20]. The production of MABs through artisanal processes does not follow a fixed manufacturing standard. There are, therefore, various processes that vary depending on the raw materials used, the microbial inoculants, the type of fermentation and the duration of the process. All of this influences the nutritional composition, microbial diversity, final quality, intended use and application rates of the products resulting from these processes [DIA 21]. In these contexts, quality controls are sometimes carried out to check pH, microbial composition and the absence of pathogens.

This self-production is the setting for various innovations, often effective, but which remain conditioned by the circumstances in which they arise. Thus, for example, one of the producers, a pioneer of this technology, the agricultural chemical engineer Fernando Donis, improved the technology by proposing a new natural organic fertiliser, ‘DonisFer’, based on rock flour, charcoal and MAB. Another pioneering inventor [ARM 22] has designed the natural organo-mineral fertiliser ‘FertiBiol–Combi’, which combines a mixture of rock flour, wood ash, charcoal, vermicompost, MAB, organo-minerals and commercial bio-fertilisers (Fosforina and Dimargon, *Bacillus thuringiensis* strain LBT-3, *Trichoderma harzianum* strain A-34 and entomopathogenic nematodes).

Product	Main function
Worm castings	Organic soil amendment that improves soil structure, water retention and nutrient retention; source of beneficial microorganisms.
Vermicompost leachate	Liquid fertiliser rich in nutrients and microorganisms; for foliar application and irrigation.
Bioproducts	Plant extracts, ferments and microorganisms for integrated management: bioproducts, biopesticides and biostimulants.

Table 3. *Main bioproducts produced on smallholder farms in addition to MAB.*

Product	Main function
Ash slurry	Foliar fertiliser and disinfectant; source of potassium and calcium; repellent and cleaner.
Sulphur-lime solution	Mineral fungicide and acaricide (sulphur + lime); also supplies S and Ca to the crop.
Biochar	A mineral-carbon amendment that improves soil structure, increases water and nutrient retention, and promotes microbial activity.
Crushed rocks	A slow-release, natural source of minerals and trace elements; improves soil fertility and provides essential micronutrients.

Table 4. *Main mineral bioproducts produced on smallholder farms*

The use and adoption of MABs to produce bio-inputs used by farmers manifests itself in two ways. On the one hand, large-scale production and storage in commercial enterprises or state research centres. This is currently facing difficulties, as it has been destabilised by the macroeconomic crisis inherent in the embargo and its intensification. On the other hand, self-production using biological preparations, based on practical experience and peasant empiricism, the knowledge of which continues to be contextualised within the identified empirical situations.

3. Analysis of the obstacles to bio-input production using MABs

The participatory forums held in five provinces brought together the main actors in the innovation ecosystem. The aim of these workshops was to identify and characterise the obstacles to increasing MAB production. Three levels were identified: (1) technical-productive, (2) institutional, and (3) economic. The nature of these barriers has proved to be cross-cutting or redundant across the five regions and the two production technology chains that have been characterised (state and smallholder). However, their prioritisation varies according to regional contexts and the nature of the technology chains. The participatory methodological approach has not allowed for the reliability of the prioritisation exercises that have been attempted with heterogeneous stakeholder configurations.

3.1. *Technical and production-related obstacles linked to the availability of inputs and energy*

The availability of quality primary inputs (sugar cane molasses, fibrous plant residues such as rice straw and sugar cane bagasse, whey, forest litter and packaging) is an indispensable element for the production, preservation, marketing and consumption of MABs. Irregularities in the availability and quality of these inputs affect the continuity of production processes and the consistent quality of the final product. Under the 2023 National Bioproducts Programme [IPS 24], measures implemented achieved only 35% of their targets due to a shortage of packaging and raw materials. This significant difficulty was confirmed in the workshops and described as follows.

3.1.1. *Availability of raw materials*

Sugar cane molasses, due to its high sugar and mineral content, is an essential input in the technological process of MAB production. The shortage of sugarcane molasses, attributable to the collapse of the sugar sector, thus limits the widespread production of bio-inputs. With national sugarcane production below 200,000 tonnes per year, the availability of molasses for agricultural bio-inputs has been considerably reduced. This use now competes with other forms of economic utilisation of molasses, whether by large industrial consumers, such as the Habana Club rum companies (which absorb most of the available supply), or through opportunities for use in animal feed. The opacity of molasses prices, which vary according to quality, location and purchasing conditions; the difficulty of relating this ‘price’ to its actual cost; the shortage of molasses supply to bio-factories; and the problems of transporting it to bio-factories are bottleneck factors cited in the workshops.

Although alternatives such as fresh sugarcane juice [DON 14] or pineapple juice are considered technical alternatives, their use remains marginal and sporadic. Firstly, due to the lack of technical data on the performance of these alternatives. Secondly, and above all, due to their economic cost, which is higher than that of molasses.

As for other organic waste generated in rural areas, such as waste from agricultural markets, crops, livestock and forestry, the prospects for energy recovery—highly sought after during a period of disruption to fossil fuel supplies—compete with its use as a raw material for the production of MAB. However, some studies [VAZ 17] and [VAZ 25] point to the potential abundance of forestry waste linked to the agricultural crisis (Marabú forests – *Dichrostachys cinerea*) which could offer recovery prospects worth exploring.

3.1.2. *The shortage of containers*

Access to ‘containers’ constitutes another major constraint on the production and marketing of MABs. This shortage affects both fermentation (which requires clean, airtight barrels) and distribution (containers ranging from 1 to 20 litres for transport and sale). Since the COVID-19 crisis, the shortage of these basic inputs has worsened.

These shortages also affect the preservation of processed foods, leading to competition for reusable containers between organic products and higher-value foods. In economic terms, the cost of the packaging far exceeds that of the contents: a 1-litre container costs 80 CUP compared to 8 CUP per litre for MAB, and a 20-litre container costs 500 CUP, of which 340 CUP is for the container alone. This situation drives up production costs and limits the growth of bioproducts. It is true that in some urban and semi-urban agricultural ventures, materials derived from equipment and tools are recycled and marketed, as documented on some farms.

3.1.3. *Energy supply and storage conditions*

Bio-inputs based on centralised MABs are subject to storage and transport restrictions that affect their storage and marketing costs. The conditions for their performance require production systems linked to stable distribution logistics networks that can be subject to technical and hygiene inspections, as well as maintenance and quality control services. This sometimes involves the supply of water, electricity and other consumables. These distribution networks differ from those for chemical inputs, which are stable, thereby generating additional distribution costs for bio-inputs. In this regard, frequent power cuts are an obstacle to the prolonged and continuous storage of bioproducts. These cuts would explain a loss of efficacy and quality in the bioproducts of companies such as LABIOFAM, as well as a loss of confidence among farmers due to the loss of quality in their use.

However, a key product for MABs is the ‘solid mother’, whose shelf life is comparable to that of chemical products. The creation of a stable market for solid matrices would be an alternative for structuring networks of decentralised bio-factories and exchange networks between bio-factories and farms. Two successful examples have been identified. Firstly, the production of a biological preparation by CENPALAB using the solid mother supplied by the EEPFIH bio-factory and used for the remediation of water bodies. Secondly, the technological chain between the producer ‘Rincon Los Hondones’ and the MSME ‘Carnes D’Tres’, in Ciego de Ávila, applied to intensive pig farming [DUA 25]. This second experiment has made it possible to extend the estimated shelf life of MABs produced by the bio-factories from six months to over 30 months without altering their functionality (appropriate reactivation processes under strict anaerobic conditions at the ‘La Vigía’ and ‘Punta La Cueva’ farms). The implementation of a system for the production and supply of solid MAB starter cultures still needs to be consolidated. It constitutes a reliable lever for the mass production of MAB-based bioproducts that should be explored, but it faces the limitation of the absence of clear and documented guidelines on the shelf life of MAB-based bioproducts, bearing in mind that the establishment of these guidelines depends on the evolution of the chemical and biological composition, which would need to be stabilised. There are differences in the shelf life of bioproducts from artisanal production compared to standardised products from biorefineries. For example, in smallholder self-production, electricity is not required for the production and preservation of bio-inputs. These differences highlight the need to gather further information through future research projects.

The widespread shortage of inputs in terms of raw materials, packaging and energy has reduced the operational production capacity of existing bio-factories. According to stakeholders in the sector, this would explain why current ‘bio-factories’ are operating at only 10% to 20% of their potential.

3.2. *Institutional barriers through regulations and technical standards*

3.2.1. *Registration and certification of MABs*

The regulatory framework for the management of bioproducts in Cuba is overseen by MINAG, which, through the National Directorate of Soils and Fertilisers and the National Bioproducts Programme, is responsible for the application and official registration of these products. CITMA, responsible for regulatory provisions and environmental impact assessments, as well as MINSAP, in charge of monitoring toxicological and health risks, also participate in the design and evaluation of standards.

The certification and quality control system is based on technical standards aligned with international standards and on registration, assessment and monitoring procedures. The Register requires technical documentation, samples and tests for efficacy, toxicity and environmental compatibility; accredited laboratories carry out analyses to ensure safety and traceability. Companies such as BioCen and LABIOFAM hold international certifications.

Despite the robustness of the regulatory framework, the registration process suffers from significant delays that slow down the commercialisation of new bioproducts. Discussions held during the participatory assessments highlight bureaucratic hurdles and shortcomings in the certification bodies for the reagents, instruments and devices needed for the required analyses and tests. Faced with these limitations, many producers resort to rudimentary but functional checks (pH strips, organoleptic assessment, germination tests) to verify microbial viability and efficacy in the field.

Legal developments have strengthened the institutional framework: MINAG Resolution No. 140/2018 established the initial requirements regarding efficacy, quality and safety for registration; and Decree 76/2022 [GAC 23] has elaborated on registration procedures, testing, deadlines and the required documentation, thereby consolidating the legal instruments for the regulation and control of bioproducts in the country.

3.2.2. *Deficiencies in technical certification standards for self-production channels*

The restriction on the marketing of uncertified MABs produced on smallholder farms nevertheless constitutes an obstacle to income generation and to incentives for the mass production of these products. Although their internal use on farms is authorised, their sale or distribution to third parties is restricted due to health risks arising from the absence of microbiological controls to guarantee product safety and, in general, the lack of registration in accordance with predefined certification standards.

The current certification system imposes complex and costly technical requirements, such as a detailed description of the manufacturing process, the product's composition and multiple agronomic tests. The process is inaccessible to producers, which keeps their MABs confined to self-production or informal local exchange networks within existing collective organisations, but rarely between these organisations, with no possibility of legally expanding their use for commercial transactions.

The new Agroecological Agriculture Act [GAC 25], which establishes the implementation of a participatory guarantee certification scheme for bio-inputs, represents a significant institutional innovation that could remove this obstacle. Globally, this is the first time such a certification scheme has been introduced for bio-inputs. However, the specific conditions for implementing these SPGs must be consolidated and put into practice in the coming years.

3.3. *Economic barriers in the pre- and post-bio-factory phases*

On the one hand, in the current context of a growing number of 'bio-factories' driven by the self-production initiatives launched by farmers, labour shortages represent an obstacle to the widespread adoption of bio-input production technology based on MAB processes. Indeed, as regards labour availability, the migration of younger generations to cities or abroad reduces the labour pool in a context where the workload is already high on mixed-cropping farms (various activities) that practise complex crop association and rotation systems. This shortage of available labour is compounded by the increased additional workload involved in the production of bio-inputs. This additional workload manifests itself on two levels. On the one hand, the working time required for new investments in infrastructure and specific logistical capacities to collect and centralise raw materials. On the other hand, the labour time involved in preparing MAB on farms, collecting and transporting the organic matter used as a substrate, as well as supervising the production and storage process. This constraint tests the capacity to innovate in the mechanisation of the technological process and the sharing of the necessary infrastructure for small bio-factories amongst several farms, leading some of them to specialise partly as producers of bio-inputs as their main function.

In the post-harvest phase, the marketing of final agricultural and food products, and even of the bio-inputs themselves, has become uncertain and risky against a backdrop of dysfunctional marketing structures, exacerbated in part by energy shortages. According to statements gathered during workshops held in several provinces, paradoxically, post-harvest losses in the countryside have increased due to logistical breakdowns, whilst cities' supply needs are growing in line with the deterioration of food security indicators [TEM 26]. According to producers, this situation constitutes a major obstacle, as it discourages the intensification of production by failing to guarantee minimum marketing conditions and failing to make use of the surpluses obtained.

3.4. *An institutional and policy framework conducive to the widespread adoption of bio-inputs*

Workshops on the characterisation of the ecosystem of actors involved in technological innovation processes highlight an institutional and political environment inherent to the policy supporting agroecology that intentionally favours the widespread adoption of MAB-based bio-input production technology. As the characterisation of this framework is explored in greater depth in other complementary works, only a few key elements of the framework's functionality will be illustrated here in relation to opportunities for activating levers that can eliminate the main limiting factors that have been identified.

3.4.1. *Effective integration of scientific training with technical support services*

The integration between universities, scientific centres, public services linked to previous investments in public bio-input production infrastructure, as well as networks of experimental producers, remains functional, effective and active despite the current macroeconomic difficulties. Some research centres continue to produce bioproducts in pilot plants, whilst collaborating with cooperatives and small-scale producers to continue innovating and adapting the technological conditions of design, production and use to the identified limiting factors and to the need to strengthen the short technological chain of self-production, which takes on greater importance in the objective of generalising the production of bio-inputs based on MABs.

At another level, universities and Municipal University Centres (CUMs) offer technical vocational training, but also provide spaces for experimentation that allow students to carry out diagnostics and test solutions. The relevant technical skills are present.

The EEPFIH production chain, established with IHPLUS®BF, for example, in numerous projects sometimes supported by international cooperation, continues its activities in the design and technology transfer in relation to other agroecological practices, integrating research, production and training to consolidate their adoption.

Pilot farms undergoing 'agroecological transition' continue to offer services as experimentation and demonstration centres (for example, the Finca Punta la Cueva in the province of Cienfuegos). By partnering with universities and research centres, they dedicate their own resources to testing and presenting agroecological practices that demonstrate their technological autonomy in the face of dependence on imported chemical inputs. They document on actual plots and generate observable evidence that allows for the adjustment of dosages and the definition of protocols to contextualise technical usage standards according to the diversity of MAB-based bio-inputs resulting from the heterogeneity of production conditions and accompanying the dynamics of production decentralisation linked to self-production. The difficulty and challenge lie in accepting this decentralisation, which is a source of mass production, but also in being able to frame it through adapted technical standards that guarantee the effectiveness of the technological process. This effectiveness is based on the appropriate alignment between the biochemical composition of a bio-input, its preservation, and the nature of the functions for which it is used, depending on the cropping system, soils or uses. Therefore, a lever for scaling up consists of reducing the risks of premature technology transfer, ensuring the combination of good practices and compatible products [PEN 21].

Public recognition of successful experimental results reinforces the multiplier effect, providing prestige and visibility that facilitate the legitimisation of good practices [JES 22].

Finally, local networks of farmers who share their experiences and good practices are also a means of accelerating adoption. The main socio-technical network is based on partnerships within municipalities between agroecology organisations such as ANAP, the Cuban Association of Agricultural and Forestry Technicians (ACTAF) and the Cuban Association of Animal Production (ACPA) (Table 4), which culminate in the creation of conditions for the adoption of new agricultural technologies [MES 20]; [VAZ 25].

Conclusion

The innovation and experimentation undertaken by Cuban farmers have facilitated the transition towards resilient agricultural systems, in which producers play a central role in promoting food security and sovereignty. The adoption of Beneficial Indigenous Microorganisms (BIM) is a strategy for the agroecological transformation of agricultural systems in Cuba. Production takes place within the framework of two production chains, with both local and national impact. The long chain generates bioproducts at the level of state-owned enterprises, whilst the short chain comprises smallholder farmers who are leaders in self-production or artisanal production intended for local exchange. Macroeconomic budgetary difficulties, along with intensification and energy disruptions, have destabilised the centralised technological chain’s capacity to achieve mass adoption. Current infrastructure is underutilised due to disruptions in the supply of inputs, which have been characterised by limiting factors in multi-stakeholder workshops.

An initial analysis might consider this to be a temporary situation. The partial or total lifting of the blockade in the future could restore functional supply conditions for this technological chain, which is potentially ‘in a dormant state’.

A second analysis suggests that instabilities in the external supply of energy and other inputs will remain structural. Furthermore, the dysfunctions of the centralised ‘ ’ technology chain are not only related to supply disruptions, but also to the need to contextualise the decentralisation of MAB self-production so that this technology enables food chains to be truly competitive against those based on chemical input technologies. In this second approach, the widespread adoption of bio-input production based on MABs depends on the ability to establish technical standards for bio-input production adapted to the needs of their inherent heterogeneity, which is characteristic of decentralised self-production. The recently adopted decree-law on agroecology, which recognises Participatory Guarantee Systems (PGS) as a mechanism for certifying bio-inputs, constitutes in itself an opportunity to be explored in the coming years to contribute to widespread adoption based on self-production.

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