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ARTICLE

Conditions for developing agro-biotechnology innovation clusters: empirical evidence from Colombia based on critical success factors

Condições para o desenvolvimento de clusters de inovação em agrobiotecnologia: evidências empíricas da Colômbia com base em fatores críticos de sucesso

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Abstract: This study examines the conditions necessary for enhancing emerging agro-biotechnology clusters at the regional level in Colombia. To identify these conditions, the author developed a conceptual model of success factors based on a holistic and sustainable perspective provided by the "Systemic Competitiveness" framework of the German Development Institute. This model emphasizes that competitiveness is built upon and articulated across four economic levels: meta, macro, meso, and micro. It highlights the importance of considering specific success factors at each level. The primary data for this study were collected through an analysis of the agro-biotechnology cluster initiative in Colombia's Valle del Cauca region, with insights derived from interviews with regional industry experts. The findings are further supplemented by a literature review mapping the success factors of innovation clusters. This research offers empirical insights into the development of Colombia's emerging bioeconomy, exploring the capabilities, conditions, and practices necessary for the industry to achieve superior performance in the future. The study underscores that there is no universal blueprint, as each local context is unique. However, by identifying the presence or absence of key components and systemic competitive success factors, the study provides valuable guidance for investing time and resources effectively.

Keywords: cluster of innovation, agro-biotechnology cluster, cluster initiatives, systemic competitiveness.

Resumo: Este estudo analisa as condições necessárias para fortalecer clusters emergentes de agro-biotecnologia em nível regional na Colômbia. Para identificar essas condições, o autor desenvolveu um modelo conceitual de fatores de sucesso, baseado em uma perspectiva holística e sustentável da estrutura de "Competitividade Sistêmica" do Instituto Alemão de Desenvolvimento. Este modelo destaca que a competitividade é construída e articulada em quatro níveis econômicos: meta, macro, meso e micro, enfatizando a importância de considerar fatores específicos em cada nível. Os dados primários foram obtidos por meio de uma análise da iniciativa do cluster de agro-biotecnologia na região do Valle del Cauca, com base em entrevistas com especialistas da indústria local. Os resultados são complementados por uma revisão de literatura que mapeia fatores de sucesso em clusters de inovação. Esta pesquisa fornece evidências empíricas sobre o desenvolvimento da bioeconomia emergente na Colômbia, explorando as capacidades, condições e práticas essenciais para que a indústria alcance um desempenho excepcional no futuro. O estudo ressalta que não existe um modelo único, pois cada contexto local possui características particulares. No entanto, ao identificar a presença ou ausência de componentes-chave e fatores sistêmicos de sucesso competitivo, a pesquisa oferece orientação valiosa para direcionar efetivamente o investimento de tempo e recursos.

Palavras-chave: cluster de inovação, cluster de agro-biotecnologia, iniciativas de cluster, competitividade sistêmica.

1. Introduction

National and international competition, driven by the pursuit of excellence, along with the demand for competitive and innovative sectors across Colombia's regions, has led to the emergence of new forms of competitive advantage. These advantages are realized through alliances between companies, universities, research institutions, and the government, collectively known as clusters.

According to Ablaev (2018) and Engel (2014), creating innovation clusters represents one of the most promising strategies for regional economic development in the current competitive landscape. Innovation clusters stand out by being more specialized, generating significant financial and scientific-technological impacts, and promoting technological advancement. In Colombia, the focus of industrial activities utilizing biotechnology lies in the natural ingredients, cosmetics, pharmaceuticals, and agri-food sectors. With the growing global demand for sustainable natural products, Colombia has the opportunity to establish a strong position in this market, leveraging its rich biodiversity. A key area for the development of biotechnology in Colombia is green biotechnology, particularly in agricultural biotechnology. Despite efforts by various industries, biotechnology clusters in Colombia have not yet established a solid position within the country and remain in the early or emerging stages of development. To advance the goals of regions with nascent innovation clusters in biotechnology, the author's research highlights several key challenges.

First, the literature reveals abundant theoretical and practical studies on high-tech clusters, emphasizing their role as drivers of economic growth for regions. Many of these studies have been conducted in response to the implicit interest of state policies that foster accelerated economic development zones. However, these studies also spark a critical debate: Why are some regions unable to successfully establish a cluster, despite meeting various economic and structural prerequisites?

Second, technology clusters in the biotech industry are both well-developed and widely distributed. The formation of these technological structures is crucial to regional economic development (Huggins & Johnston, 2010). Research can provide valuable insights into how these clusters evolve by examining the progression of different types of innovation networks within them. A cluster initiative is "an organized effort to increase the growth and competitiveness of a cluster within a region, involving cluster firms, government, and/or the research community" (Sölvell et al., 2003). Cluster initiatives can significantly enhance the performance of emerging clusters by strengthening connections and facilitating collective actions aimed at improving the cluster-specific business environment (Meier Zu Koecker et al., 2016). However, there is still much to understand about the emergence and growth of knowledge-based cluster initiatives, such as those in the biotechnology industry. Key questions remain: What are the success factors at different economic levels throughout the evolutionary process, particularly in the context of the necessary conditions for the development of biotechnology innovation clusters in emerging countries? Additionally, how do the local conditions, considering the country's stage of economic development and the support provided by national and regional policies, affect this process?

Third, as Feldman et al. (2005) noted, further research is needed on emergent clusters to better understand how these processes are initiated. Most existing cluster studies focus on clusters that are already established and functioning. Additionally, the literature lacks a comprehensive framework for understanding innovation cluster development during the emergent phase. According to Scur & Garcia (2019, p. 268),

> There is still an underappreciation of the context-specific factors and issues that may influence the long-term development of clusters. Moreover, the macro, meso, and micro dimensions have previously been studied in three independent streams of research, leaving gaps in our understanding of whether and how the various factors have an impact on the evolution of clusters.

As previously mentioned, the processes behind the emergence of clusters remain unclear, highlighting the lack of sufficient methodology for studying emerging innovation clusters during their development stages. This study contributes to understanding the support needed for the growth of such clusters in Colombian regions in three keyways. First, it identifies the success factors crucial for the development of emerging innovation clusters at the regional level. Second, it provides new empirical evidence through a case study of an agro-biotechnology cluster initiative, exploring how the four dimensions of the Systemic Competitive Model contribute to the success of innovation clusters. Finally, it proposes conditions conducive to fostering environments, particularly in emerging countries, that enable effective collaboration between universities and businesses, facilitating knowledge transfer and actions essential for generating competitive innovations in international markets.

2. Theoretical Foundation

2.1 Overview of the Biotechnology and Agro-biotechnology Sectors in Colombia

According to Vasen (2013), developing countries have a wide availability of natural resources that are necessary for economic development based on biological products. Hence, the development of sectors linked to the bioeconomy could enhance local research, development, and innovation (R&D+I) capacities. An ongoing example in Latin America is the development of an agricultural model based on biotechnologies and genetically modified (GM) crops to improve agricultural productivity. The bioeconomy also offers them the potential to modify the profile of their exports, including products with higher value-added. Biotechnology, as a key component of the bioeconomy, represents a strategic objective for Colombia's economic development. It provides a unique opportunity to capitalize on the country's rich biodiversity, fostering advancements in sectors such as biology, agriculture, and technology. This integration accelerates the creation of innovative commercial opportunities on an international scale, leading to job creation and generating resources to fund ongoing research. Such efforts contribute to establishing Colombia's strong position within the global bioeconomy. Given these advantages, biotechnology has become a crucial driver of economic growth in developing countries, particularly in Latin America. The region's robust research infrastructure, scientific expertise, and, above all, its abundant natural resources make it well-positioned to lead in this field (Cerón Rincón, 2009).

The Colombian government wants to harness the potential of the bioeconomic sector. According to the *Misión Internacional de Sabios* (Minciencias, 2019, p.207), the government has the following vision:

> "In 2030, the bioeconomy will represent 10% of GDP and the creative economy will represent 8%, doubling the value of its exports and creating 100,000 new jobs through a strong public-private partnership that will allow Colombia to know and value the extension of its natural and cultural megadiversity, conserve it, protect it, and understand its importance to transform the economic activities related to the agri-food, cosmetic, chemical, textile, pharmaceutical, cultural, forestry, artistic, energy, and health sectors, among others".

Agricultural biotechnology holds significant promise in Colombia, offering more precision and efficiency in enhancing the traits of plants used as inputs for the food industry or to streamline processing. Additionally, it plays a vital role in ensuring food availability and safety for consumers by increasing the variety of foods and improving production efficiency. The application of advanced technologies for transferring desirable traits provides a safer alternative to conventional breeding techniques, enhancing the safety of plant-based foods and products (Bonciu & Sarac,

2017). As such, modern agricultural biotechnology is a powerful tool for combating hunger, advancing food security, improving nutrition, and fostering sustainable agriculture.

Efforts in this direction have already been made in Colombia, such as the Genetically Modified (GM) crops of cotton, corn (controlled planting), and blue carnation (Fedearroz, 2008). According to the Association of Agricultural Plant Biotechnology (Agro-Bio, 2020), Colombia began to participate in the use of Genetically Modified (GM) crops in 2002, with the planting of blue carnations. The following year, GM cotton was approved under a controlled planting scheme; likewise, GM corn was approved in 2007, and GM blue flowers were approved in 2009. Figure 1 illustrates the regional volumes of genetically modified crops in Colombia according to the Colombian Agricultural Institute, ICA (Agro-Bio, 2020), therefore Colombia planted a total of 113,965 ha of GM crops in 2020, distributed between 109,128 ha of corn, 4,825 ha of cotton, and 12 ha of blue flowers.

Figure 1. Map of genetically modified crops in Colombia 2020: by region (hectares).
Source: Agricultural Plant Biotechnology Association (Agro-Bio, 2020)

Among the main benefits identified in the application of biotechnology to crops are the increase in productivity due to improvements in yield, greater nutritional value of food, and reduction of food costs. In the study "Genetically modified (GM) crop use in Colombia: farm-level economic and environmental contributions", Brookes (2020) states that since the arrival of the cultivation of cotton (2003) and transgenic corn (2007) in Colombia, the results of the impact on the environment that have left transgenic crops are favorable.

The explained results of the GM application were achieved through the common work of researchers and product developers in multiple processes. Biotechnology research was started in 1997 by the institution COLCIENCIAS (the former Administrative Department of Science, Technology, and Innovation of the Colombian Government) with a program called the National

Biotechnology Program (NBP) to encourage cooperation between universities, researchers, companies, and the government. The main areas of activity of the NBP are the union of the biotechnology sector in Colombia, the development and production of environmentally sustainable biofuels, and an urge to develop knowledge, improve protection, and use Colombian biodiversity sustainably.

A research study of the governmental institution Innpulsa confirms the existing obstacles and weaknesses in the development of Colombia's biotechnology sector in the areas of social, research/technology transfer, economic/financial, political/regulatory, and commercial/investments (Innpulsa, 2013). Table 1 presents a summary of some of the weaknesses in these areas.

Table 1. Weaknesses of the organizational environment for the development of biotechnology in Colombia.

Area	Weakness
Social	• The biotechnology sector in Colombia has a bad image due to its excessive association with "genetic manipulation".
	• Excessive risk aversion in society in general and of investors in particular.
Research/technology transfer	• Quality research needs a higher level of development (prototypes, proximity to the market).
	• Fragmentation of the groups and dispersion of the research centers that generate knowledge in biotechnology.
	• Lack of experience and knowledge of researchers in the biotechnology transfer process.
Economic/Financial	• Only a few specialized private investors are interested in investing in life sciences in general and biotechnology in particular.
	• Unattractive business models to attract international investors.
	• Public seed capital funds do not cover the specific needs of the sector.
Political/regulatory	• Institutional inefficiency and lack of coordination between the key agents for the development of the biotechnology and life sciences industry in Colombia.
	• No efficient framework regulatory environment
	• Absence of a clear coordination mechanism for R&D support programs of the government.
Commercial/investments	• Need to communicate the benefits of biotechnological and life sciences applications in traditional sectors.
	• There are areas of technological demand not covered by academic institutions (search for international partners).
	• Difficulty in identifying the right collaborators in the academic environment.

Source: created by the author based on Innpulsa (2013)

The results of the Innpulsa study in Colombia highlight several common challenges faced by developing countries, which are influenced by historical, cultural, and economic contexts. When it comes to cluster development, developing countries are characterized by the dominance of small and medium-sized enterprises (SMEs), often lacking the critical mass of established companies, particularly in high-innovation sectors. Additionally, organizational structures tend to be more informal, and networks are generally weaker compared to those in developed countries. In recent years, however, the agricultural sector in developing countries has made strides in producing higher-value products and services, as well as expanding into international market networks (Galvez-Nogales, 2010). Historically, the focus was more on production rather than research.

2.2 Conditions for the emergence of an innovation cluster

In recent decades, significant attention has been devoted to the territorial agglomeration of industries and its role in driving economic development in emerging countries and regions. For high-tech industries, the focus has largely been on the creation and growth of so-called innovation clusters. Ablaev (2018) argues that establishing innovation clusters presents one of the most promising avenues for regional economic development, particularly in the context of the current competitive landscape.

Kuhlmann & Arnold (2001) proposed a framework for understanding innovation clusters, presented in Figure 2. This framework highlights the significance of knowledge sharing among cluster members and the dynamics of cooperation within the network, providing valuable insights into the cluster's development and growth potential. Within innovation clusters, technological knowledge for innovation development, market, and management expertise are exchanged. The strength of these networks has a positive impact on the acquisition, adoption, and utilization of technology (Pan et al., 2019), which in turn enhances innovation capabilities (Tseng et al., 2016). Xue (2018) emphasizes that the exchange of various types of knowledge between organizations, facilitated through both formal and informal connections, generates diverse knowledge flows, leading to the formation of distinct types of networks.

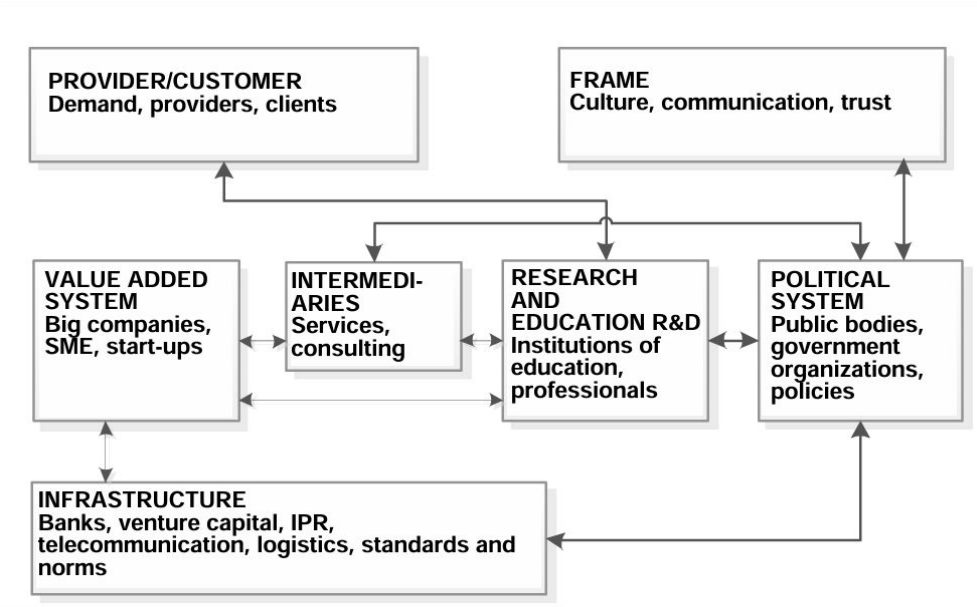

Figure 2. Structure of an innovation cluster system.
Source: Kuhlmann & Arnold (2001)

Emerging clusters are often described as a developmental process based on the analysis of established, mature clusters. The developing steps are then applied to those regions claiming to have emerging clusters, without considering specific regional factors such as industry profiles, social capital, and national institutions. This oversight often leads to policy misinterpretations, which have been criticized by many scholars (Martin & Sunley, 2003; Maskell, 2001). Two points of consensus are clear: first, there are significant differences between the processes and factors that drive cluster formation and those that define a cluster's functioning; and second, while new industries may be established across many regions, clusters only emerge in a subset of those regions (Romanelli & Feldmann, 2006; Storper & Walker, 1989).

Brenner (2004) proposed a cluster emergence design in which the specific mechanisms that influence the timing and location of cluster emergence are classified. The main factors of this model are as follows:

Conditions of the location: The attractiveness of the region (in combination with the market position) must be sufficiently high to exceed a certain critical value (the first critical mass). For example, geographic location, regional and national politics, and the educational system, including the existence of universities, research, and the culture of the area, are all important when evaluating the success of the emergence of clusters.

Conditions for agglomeration: The population of local companies must exceed a critical value (second critical mass) during the initial phase. For example, the institutional density, specific characteristics of the local market, attitude towards entrepreneurship, specialization in the value chain of the sectors, existence of related industries, and history of the region are all factors to be evaluated.

Associativity conditions: Local self-augmenting processes must be present. For example, the attitude toward cooperation, the governance structure in the region, and the attitude of the population toward technological development are criteria that affect the conditions of associativity.

In Brenner's model, exogenous externalities play a crucial role, as they must undergo specific conditions to become catalysts for the development of local industrial clusters. Furthermore, for an innovation cluster to emerge, a solid foundation of technological infrastructure comprising skills, knowledge, institutions, and specialized resources is essential to establish a geographic hub of innovation. The presence of companies is also vital for the generation and diffusion of knowledge, as these companies provide technical expertise and serve as potential suppliers and users of innovation. These factors are all fundamental to the emergence and consolidation of innovation clusters. To explore the conditions necessary for enhancing emerging agro-biotechnology clusters at the regional level in Colombia, the author selected the Systemic Competitiveness Model, which allows for the integration of these elements across different levels of the country's environments.

2.3 The Systemic Competitiveness Model as the Conceptual Framework

Drawing on insights from emerging innovation clusters, this research adopts a conceptual framework rooted in the holistic perspective of the Systemic Competitiveness model. This model emphasizes that competitiveness is shaped by measurable factors within a region, articulated across four analytical levels: meta, macro, meso, and micro (Esser et al., 1996; Morales Rubiano & Castellanos Domínguez, 2007). Beyond the traditional macro and micro perspectives, the model incorporates factors such as social integration and strategic capacity at the meta and meso levels, alongside the design of an environment that promotes, complements, and amplifies corporate-level efforts.

Systemic Competitiveness aims to capture both the political and economic determinants of successful industrial development. A country cannot arbitrarily select individual policies or aspects of competitiveness from the broader set of Systemic Competitiveness determinants. Competitive countries feature meta level structures that foster competitiveness, while macro level pressures push for improved firm performance. The meso level involves state and social actors who implement targeted policies that support structural development and social learning

processes. At the micro level, firms focus on enhancing efficiency, quality, flexibility, and customer orientation, often integrating these efforts into broader networks (Esser et al., 1996, 2013).

The key areas of industrial development in each dimension in successful developing countries are demonstrated in Figure 3: at the meta level, governance and industrial competitiveness; the macro level includes the link between economic stabilization and liberalization, with the capacity for transformation; the meso level gives support to the efforts of the companies, formed by specific policies and institutions to shape industries and their environment; and finally, the micro level refers to the technological and institutional requirements (Esser et al., 1996, 2013; Morales Rubiano & Castellanos Domínguez, 2007).

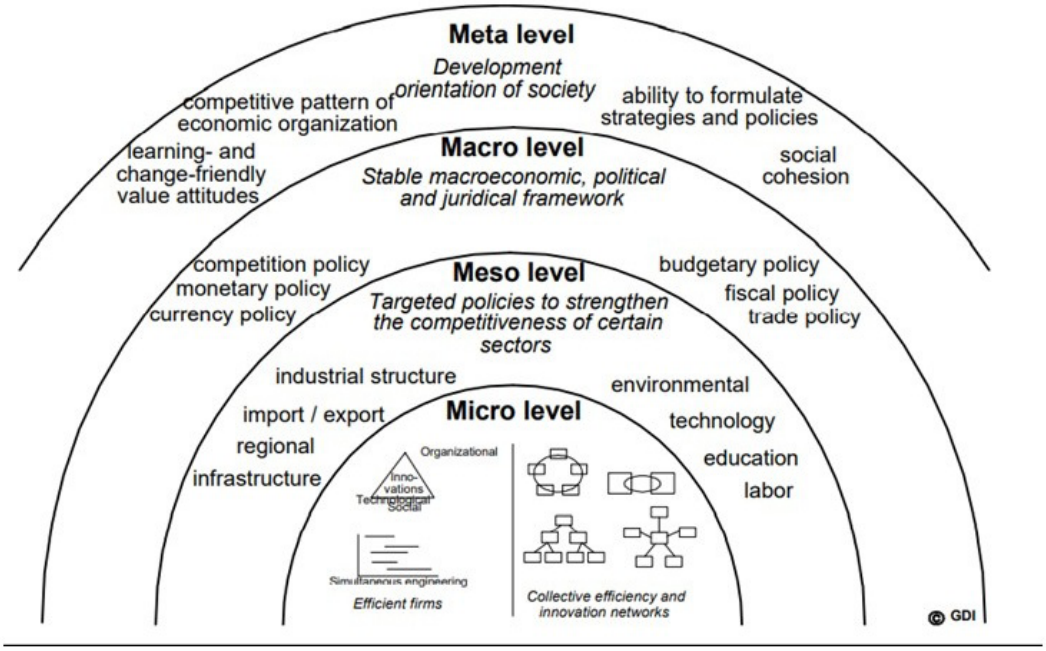

Figure 3. Determinants of Systemic Competitiveness.
Source: Altenburg et al. (1998)

3. Methodology

The research approach for this study is qualitative, following an exploratory and descriptive design (Denzin & Lincoln, 2005; Yin, 2009). This study examines the emergence and development of cluster initiatives by leveraging existing technological foundations in specific geographic areas. The analysis is conducted in two phases: the first phase involves a comprehensive literature review to identify the "critical success factors" of innovative clusters, as outlined in scientific research. The second phase consists of administering a questionnaire to local experts in a particular region of Colombia, focusing on the dimensions of the Systemic Competitiveness Model, which serves as the theoretical and analytical framework for this study.

The author chose the case study methodology because it enables the investigation of contemporary issues in real-world contexts, where the variables under study extend beyond the available information. This approach requires the use of multiple sources of evidence and the development of a theoretical framework to guide data collection in the field and inform

the analysis (Bergen & While, 2000). The case study is particularly well-suited for examining aspects of management, organization, and strategy within a business context, to establish causal relationships, create profiles, and propose theories from either an exploratory or explanatory perspective (Villarreal Larrinaga & Landeta Rodríguez, 2010). This research used the case study definition proposed by Creswell et al. (2007), which views a case study as a qualitative approach in which the researcher examines a specific system (a case) or multiple systems (cases) over time. This involves a detailed, in-depth data collection process using various sources of information (e.g., observations, interviews, audiovisual materials, documents, and reports) to provide a comprehensive description of key topics related to the case.

As a case, this research focuses on the biotechnology cluster initiative in the Valle del Cauca region of Colombia, specifically the Regional Biotechnology Innovation System for Agriculture, Agroindustry, and Bioindustry (SRIB). According to Procolombia (2013), the country is divided into five regional biotechnology development zones: Bogotá-Cundinamarca, Bucaramanga-Santander, Caldas-Risaralda-Quindío, Cali-Valle del Cauca, and Medellín-Antioquia. There have been notable improvements in the organizational environment, driven by government policies such as CONPES 3697 (2011), aimed at advancing biotechnology in Colombia. Valle del Cauca stands out as the most advanced region in green biotechnology, particularly with the development of the SRIB, making it the ideal setting for studying the conditions surrounding the emergence of this cluster (Chapter 4.1).

The analysis aims to validate the proposed conceptual model of success factors, as outlined in the Systemic Competitiveness model (Figure 3), by comparing these factors with those identified in the case study and the insights gathered from expert opinions. The empirical data collected for this study was enriched through bibliographic research, documentary analysis, and semi-structured interviews with key stakeholders in the regional cluster.

3.1 Secondary data collection

Integration in a cluster economy means that companies generate specific capacities that allow the development of competitive advantages and opportunities to penetrate new markets. This is the result of greater specialization induced by strong competition and access to new resources (Porter, 2003). According to Ketels (2003), clusters generate benefits that directly impact their members and public policy managers according to their interests, for the former, the maximization of profits, and for the latter, ensuring the long-term sustainability of the regions. Given the importance of clusters, the author identified some factors that promote the emergence of clusters in high-tech sectors, especially those that contribute to the successful development of innovation. In this regard, there are numerous contributions from different authors, as listed in Table 2.

Another source for identifying success factors is the analysis of the failure to develop Italy's largest emerging biotechnology cluster in Lombardy (Breschi et al., 2001). This case explores why no significant innovative or commercial activities in biotechnology emerged in what was initially considered a promising region for the industry's growth in Italy and examines the factors that led to the stagnation of its development. The analysis offers valuable lessons on the regional conditions necessary for fostering innovation clusters and the key success factors of agglomeration processes.

The concentration of innovative activities in Lombardy could be attributed to Milan's high concentration of research laboratories, both academic (particularly in medicine and biology) and industrial, as well as its role as Italy's primary financial center. While the region possessed the

conditions to support the emergence of a biotechnology cluster, the dynamics were insufficient to sustain successful activities when compared to other European regions. The main reasons for the failure of the biotechnology cluster in Lombardy can be summarized as follows: The region lacked a robust scientific foundation in advanced technologies, its industrial base was weak, and there was minimal interaction between industry and universities. Furthermore, financial and regulatory constraints likely hindered the development of biotechnology. Figure 4 illustrates the situation and highlights the key lessons learned.

Table 2. Success factors for high-tech clusters.

Success Factors	Main Contributors
Sophisticated buyers, specialized suppliers, support between companies, and rivalry between competitors.	Porter (1998, 1999)
Trust, rivalry, proximity, and extensive outsourcing agreements.	Khan & Ghani (2004)
Spillovers (effects of the relationship between foreign companies and local companies), local labor market, and cooperation.	Brenner & Greif (2006)
Proximity (generation of trust, shared language, and habits) contributes to creating semi-formalized networks. Company specialization.	Muscio (2006)
Strong integration of people and knowledge from different entities.	Tracey & Clark (2003)
Frequent and intensive exchanges of personnel between customers and suppliers and cooperation between competitors.	Markusen (1996)
Learning processes are facilitated by local or intra-regional networks.	Eraydin & Armatli-Köroğlu (2005)
Interactive learning to promote systemic innovation (business mentoring, technological knowledge transfer processes).	Cooke et al. (1997) Audretsch (1998)
The labor market and labor mobility (as channels of sources of knowledge and ideas).	Power & Lundmark (2004)
Demand for specialized products and services (search for routines and new or improved capabilities) promotes the emergence of new companies or the reconversion of some existing companies.	Caniëls & Romijn (2003)
Infrastructural categories (public and private financing, competent local authorities (investment in infrastructure and university-industry integration), and superstructural (institutional aspects, organizational aspects in the company, and organizational aspects in the field of politics).	Cooke (2001)

Source: created by the author based on Becerra Rodríguez & Serna Gómez (2012)

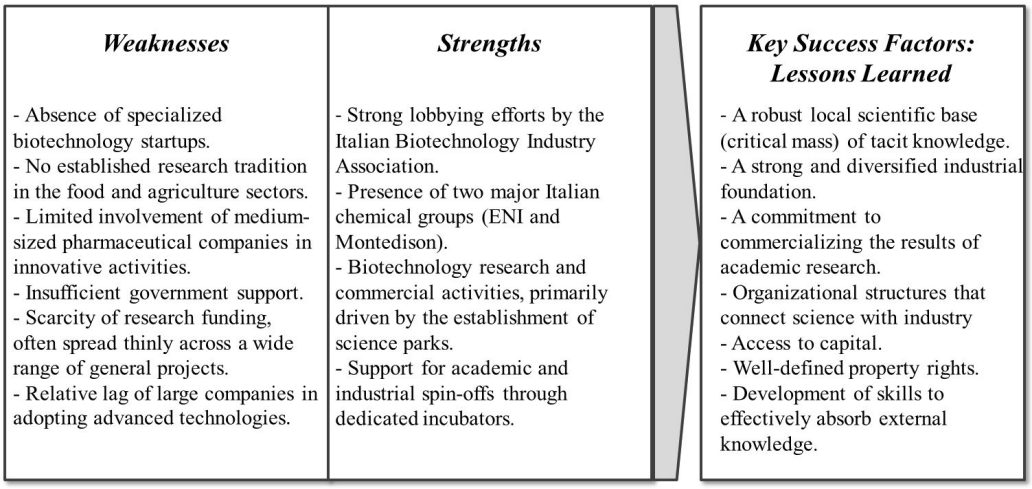

Figure 4. The situation of the biotechnology cluster in Lombardy.
Source: created by the author based on Breschi et al. (2001)

Building upon the analysis of success factors identified in the literature, the innovation cluster framework, and the conceptual model of critical success factors for information and communication technology clusters developed by Tavassoli & Tsagdis (2014), the author has designed a customized model of success factors specifically for agro-biotechnology clusters. Figure 5 illustrates the proposed model and highlights the internal success factors within each cluster component, as well as the interrelationships between these components and the success factors identified.

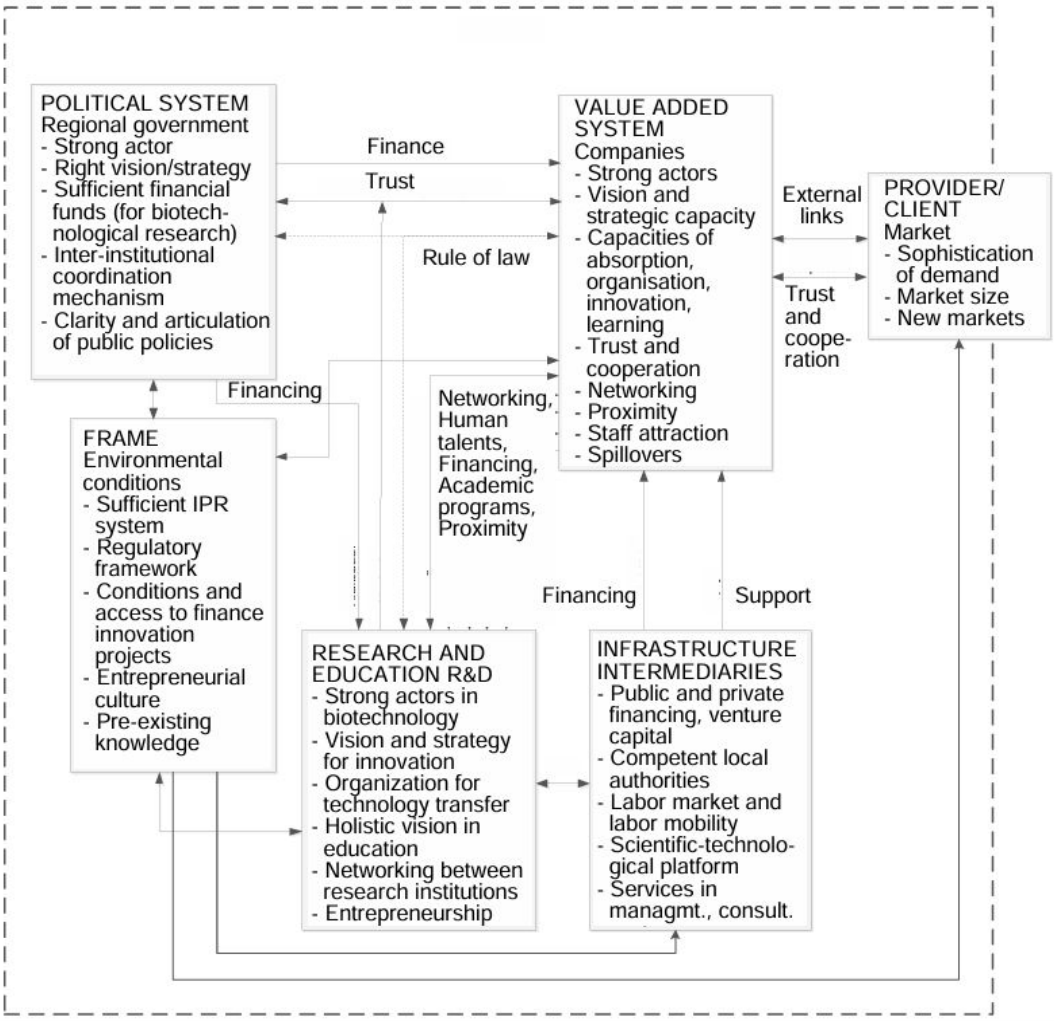

Figure 5. Model of Success Factors for Agro-biotechnology Clusters.
Source: created by the author based on Tavassoli & Tsagdis (2014) and Kuhlmann & Arnold (2001)

3.2 Primary data collection

The developed model of success factors for agro-biotechnology clusters serves as the foundation for linking these factors to their corresponding propositions within the meta, macro, meso, and micro dimensions of the Systemic Competitiveness Model, as illustrated in Table 3 below. These four dimensions provide a structured framework for categorizing success factors and constructs, facilitating the systematic collection of key information. The Systemic Competitiveness

Model enables the identification of both exogenous and endogenous success factors that influence the establishment and development of biotechnology clusters. Furthermore, the model incorporates regional (territorial) success factors, offering a comprehensive perspective on the elements that drive or hinder cluster formation.

Table 3. Linking success factors with their corresponding propositions.

Dimension	Construct	Success Factor	Proposition
Meta	Public Policy Societal context	· Policy-based on innovation systems · Innovation policy · Clarity and articulation of public policies · Shared vision and values	· **Public politics** The clarity and articulation of biotechnological and agricultural innovation and development policies are fundamental for the selection of cluster initiatives. · **The right vision and strategy** The coordination of key players in the cluster under a shared vision and values is essential for the cluster's success.
Macro	Characteristics of the territory Macroeconomic context	· Pre-existing agroecological and biotechnology knowledge and capacities · Physical infrastructure · Culture of innovation · Culture of entrepreneurship · Territorial attractions · Industries/sectors related to biotechnology. · Labor market and attraction of personnel · Recognition of the region (branding)	· **Pre-existing knowledge** The pre-existing knowledge of the region (technologies and other forms of knowledge) is an important seed for a cluster initiative. · **Physical infrastructure** An inadequate physical infrastructure (Internet, transport, ICTs, etc.) in the region is an obstacle to the development of clusters. · **Entrepreneurial culture** A weak entrepreneurial culture (start-ups, spin-offs, installation of foreign companies) in the cluster prevents it from growing. · **Labor market** The presence of skilled experts and workers (technicians) has an important effect on the successful development of companies in the cluster. · **Quality of life** The attractiveness of the region, where the cluster is located, attracts human talents and contributes to the success of the business.
Meso	Core competencies and interactions	· Political system · Research and Education · Value creation system · Philosophy of collaboration and collective ownership · External links · Networking	· **Academic education programs** Communication and cooperation between the business and educational sectors have allowed the adaptation and/or creation of new academic programs. · **Quality of education** The quality of graduates from educational institutions meets the requirements of the cluster companies. · **Culture of collaboration (associativity)** The relationship between the cluster companies has allowed the creation of an environment of collaboration and competition (rivalry). · **External links (interregional and international)** Cluster companies need to link and interact with global markets and value chains to develop "spillovers". · **Trust (quality of relationships in the network)**

Source: The author, developed from their research data (Bruszies, 2020, pp. 234-237)

Table 3. Continued...

Dimension	Construct	Success Factor	Proposition
Meso	Core competencies and interactions	· Political system · Research and Education · Value creation system · Philosophy of collaboration and collective ownership · External links · Networking	Trust between members of the cluster (public-private) has facilitated the formation of alliances, agreements, arrangements, etc. · **Geographic proximity** The proximity between companies and research institutions has promoted technology transfer and the development of innovations.
	Infrastructure and framework conditions	· Financing, conditions, and requirements for access to financing for innovation projects · Scientific-technological platform · Service infrastructure · Facilitator or director	· **Financing** Insufficient sources of funding and government support are barriers to the development of innovation projects. · **Scientific-technological platform** Successful technology transfer requires a scientific-technological platform that stimulates research and the implementation of tests by entrepreneurs. · **Service infrastructure** The services of marketing agencies, patent attorneys, and consulting for entrepreneurs significantly impact the development of the cluster. · **Cluster management and services** The cohesion and development of the cluster require a facilitator who acts as director, administrator, and mediator between different entities.
Micro	The strategy of research and entrepreneurship	· Organizational resources and capabilities · Research orientation · Market formation	· **Strong actors with competitiveness and core competencies** The sustainability of the cluster depends on its ability to attract, engage, and retain strong actors. · **Innovation capacity (R&D)** The actors in the cluster are characterized by a high degree of openness toward new ideas, technologies, etc. · **Demand for specialized products and services** The markets currently served by the cluster companies have a low level of sophistication.
	Development and dissemination of knowledge	· Knowledge development · Dissemination of knowledge · Intellectual property protection system	· **Technology-based networks** Policies and the participation of government entities are required for the creation of technology-based SME networks. · **Protection of intellectual property** The lack of experience in intellectual property protection processes has led to the loss of business opportunities.
	Activation of resources	· Creating legitimacy · Regulatory framework · Attracting competitive actors	· **Regulatory framework** A harmonious and comprehensive regulatory framework (e.g., access to the commercialization of genetic resources) is essential for the development of a successful biotechnology network. · **Sustainable growth** The cluster promotes the entry of new companies, the strengthening of existing ones, and cooperation with related clusters.

Source: The author, developed from their research data (Bruszies, 2020, pp. 234-237)

Using the structure and definitions of the Systemic Competitiveness model, face-to-face interviews were conducted with experts from the biotechnology cluster in Valle del Cauca to validate the success factors identified in the literature review. Between 2019 and 2020, six experts participated in these interviews, during which a structured questionnaire was used to gather their insights. The experts, whose professional profiles are detailed in Table 4, provided in-depth feedback on the status of each success factor within the region's biotechnology cluster. Their responses were carefully documented and analyzed, with the results presented in Chapter 4.3.

Table 4. Profiles of the interviewed experts.

Areas	Description
Entity	Corporación Biotec
Position	Director
Education	Advanced training in biotechnology business at Duke University, a master's degree from the *Ecole Polytechnique Federale De Lausanne*, France, and an advanced program at Harvard Business School and London University.
Experience	Emeritus Researcher
Entity	Universidad Javeriana de Cali, Colombia
Position	University teacher and researcher
Education	Ph.D. from the University of Brighton (CENTRIM, Innovation Management), England. Master's degree from the University of Sussex (SPRU). Innovation and Sector Analysis. Business Administrator.
Experience	Researcher and teacher, participating in the Biotec Corporation
Entity	BIOS Manizales
Position	Director of Science
Education	Agronomist and Ph.D. in biological sciences with an emphasis in molecular biology (University of Brasilia, Brazil)
Experience	He worked at CENICAFE (coffee research center), in public and private universities in Colombia and Brazil, and at the Center for Genetic Resources and Biotechnology (EMBRAPA).
Entity	FLAR (Association: Latin American Fund for Irrigated Rice)
Position	Researcher CIAT-FLAR (The International Center for Tropical Agriculture), Colombia
Education	Ph.D.
Experience	Genetic engineering of rice seeds
Entity	Government of the department Valle de Cauca
Position	Expert in CTI (strategic planning in regional science, technology, and innovation)
Education	Industrial Engineer, Advanced studies in computer science, Master's degree in Entrepreneurship
Experience	Professional in the planning department of the department
Entity	Government of the department Valle de Cauca
Position	Coordination of the licensing process in the department
Education	Master of Science in Organization

Source: The author, developed from their research data (Bruszies, 2020, p. 278)

The survey instrument as demonstrated in Table 5 below was designed based on the propositions outlined in Table 3, using categories from a Likert scale. The Likert scale is an ordinal rating system that measures participants' perceptions of their agreement or disagreement with each proposition or statement related to the success factors under study. Success factors where expert opinions align provide a clearer understanding of the critical elements necessary for developing an emerging biotechnology cluster. During fieldwork with the selected experts, only those success factors that could be sufficiently assessed were included, given the limited availability of in-depth information and secondary sources.

Table 5. Questionnaire for the information collection.

Questionnaire for the information collection - Success Factors for Biotechnology Clusters					
Date: _____	Please indicate how much you agree or disagree with each of the following statements concerning the success factors of biotechnology clusters. The response options are:				
Cluster Name: _____	a. Strongly agree b. Agree c. Neutral (neither agree nor disagree) d. Disagree e. Strongly disagree				
Name of person interviewed: _____					
Position in the Cluster: _____	Please mark with an X the answer option that you consider most appropriate.				
Statements	**a. Strongly agree**	**b. Agree**	**c. Neutral**	**d. Disagree**	**e. Strongly disagree**
1. Public Politics The clarity and articulation of biotechnological and agricultural innovation and development policies are fundamental for selecting cluster initiatives.					
2. The right vision and strategy The coordination of key players in the cluster under a shared vision and values is essential for the cluster's success.					
3. Pre-existing knowledge The pre-existing knowledge of the region (technologies and other forms of knowledge) is an important seed for a cluster initiative.					
4. Financing Insufficient sources of funding and government support are barriers to the development of innovation projects.					
5. Physical Infrastructure An inadequate physical infrastructure (Internet, transport, ICTs, etc.) in the region is an obstacle to cluster development.					
6. Service infrastructure The services of marketing agencies, patent attorneys, and consulting for entrepreneurs significantly impact the development of the cluster.					
7. Labor market The presence of skilled experts and workers (technicians) has an important effect on the successful development of companies in the cluster.					
8. Academic education programs Communication and cooperation between the business and educational sectors have allowed the adaptation and/or creation of new academic programs.					
9. Quality of education The quality of graduates from educational institutions meets the requirements of the cluster companies.					
10. Scientific-technological platform Successful technology transfer requires a scientific-technological platform that stimulates research and the implementation of tests by entrepreneurs.					
11. Protection of intellectual property The lack of experience in intellectual property protection processes has led to the loss of business opportunities.					
12. Demand for specialized products and services The markets currently served by the cluster companies have a low level of sophistication.					
13. Entrepreneurial Culture A weak entrepreneurial culture (start-ups, spin-offs, installation of foreign companies) in the cluster prevents it from growing.					
14. Quality of life The attractiveness of the region, where the cluster is located, attracts human talents and contributes to the business success.					

Source: The author developed from their research data (Bruszies, 2020, p. 376)

Table 5. Continued...

Questionnaire for the information collection - Success Factors for Biotechnology Clusters					
Statements	**a. Strongly agree**	**b. Agree**	**c. Neutral**	**d. Disagree**	**e. Strongly disagree**
15. Technology-based networks Policies and the participation of government entities are required for the creation of technology-based SME networks.					
16. Trust (quality of relationships in the network) Trust between members of the cluster (public-private) has facilitated the formation of alliances, agreements, arrangements, etc.					
17. Geographic proximity The proximity between companies and research institutions has promoted technology transfer and the development of innovations.					
18. Regulatory framework A harmonious and comprehensive regulatory framework (e.g., access to the commercialization of genetic resources) is essential for the development of a successful biotechnology network.					
19. Strong actors with competitiveness and core competencies The sustainability of the cluster depends on its ability to attract, engage, and retain strong actors.					
20. Culture of collaboration (associativity) The relationship between the cluster companies has allowed the creation of an environment of collaboration and competition (rivalry).					
21. Innovation capacity (R&D) The actors in the cluster are characterized by a high degree of openness toward new ideas, technologies, etc.					
22. External links (interregional and international) Cluster companies need to link and interact with global markets and value chains to develop "spillovers".					
23. Sustainable growth The cluster promotes the entry of new companies, the strengthening of existing ones, and cooperation with related clusters.					
24. Cluster management and services The cohesion and development of the cluster require a facilitator who acts as director, administrator, and mediator between different entities.					
TOTAL					

Source: The author developed from their research data (Bruszies, 2020, p. 376)

4. Results and Discussion

4.1 Case Study of an Agro-biotechnology Cluster in Colombia: SRIB, Valle del Cauca

The Valle del Cauca department, with its capital city Cali, and the broader western region of Colombia, is renowned for its rich diversity of biological and genetic resources. This has fostered the development of technological and institutional capacities in biotechnology and bioindustry. These capacities are concentrated in key research centers, such as Cenicaña, Ceniuva, Cenicafé, Corporación Biotec, and the International Center for Tropical Agriculture (CIAT), as well as in universities offering academic programs in biotechnology and the agricultural sector, including Universidad del Valle, Universidad Javeriana Cali, Universidad Nacional de Palmira, and Universidad ICESI. In addition, various companies, including Sucroal S.A., Levapan S.A., and Cartón de Colombia S.A. (Smurfit Kappa Cali), are closely involved in these areas (Matta Diaz et al., 2004). Since 2000, significant efforts have been made to consolidate these biotechnology capabilities into an organized network, with the collaboration of the aforementioned regional actors, culminating in the creation of the Bioindustrial Cluster of Western Colombia (CBOC).

Building on the progress made, the Prospective Agenda for Science, Technology, and Innovation of Valle del Cauca was developed in 2004, and the Valle del Cauca Bioregion strategy was established as a key development initiative for the department. A bioregion is defined as a development and competitiveness strategy focused on the sustainable use of biodiversity, bioindustrial resources, and capacities, along with their intersectoral integration. It serves as a driving force for regional development, supported by the technological innovation system, and aims to address the critical needs and opportunities of society (Arboleda et al., 2007). The findings from this effort highlighted the need to create the right conditions for the development and application of biotechnology and life sciences as tools for the region's growth and prosperity. In this context, the Biotec Corporation, in 2009, presented a proposal to COLCIENCIAS (the former Administrative Department of Science, Technology, and Innovation of the Colombian Government) titled "Regional Biotechnology Innovation System for the Agricultural, Agro-industrial, and Bio-industrial Reconversion of Western Colombia: Contribution to its Consolidation". The primary objective of this initiative is to "promote an associative technological platform for the region, supporting the Regional Biotechnology Innovation System (SRIB) that connects, enhances, and optimizes existing and future resources, bringing together academic and research centers, government entities, companies, and national and international collaborators" (Sánchez-Mejia & Gutiérrez-Teran 2013, p. 261). In the SRIB framework, Sánchez-Mejía and Gutiérrez-Terán described sectors with competitive potential in the territory based on biotechnology: "The sector of sugarcane and its derivatives is, together with coffee and its development in the coffee plantation area, the sector with the most advanced technological and institutional productive development in Valle del Cauca. Some of these sectors, from the point of view of their scientific, technological, and innovation developments, are linked as world-class sectors to international networks and commerce, specifically in biotechnological developments, such as the sugar cane, forestry, and yeast sectors" (Sánchez-Mejia & Gutiérrez-Teran, 2013, p. 262).

Currently, the vision of competitiveness, science, technology, and innovation for the year 2032 determines that "Valle del Cauca will be a department with high levels of equity, competitiveness, and sustainability in Colombia, through science, technology, and innovation, for its productive and social transformation with regional articulation and a global perspective with a focus on biodiversity, agricultural-agroindustrial, services-logistics, health, energy, tourism, and education" (Valle del Cauca, 2016, p. 30). The SRIB, as an innovation cluster initiative, can leverage its scientific-technological platform and service infrastructure to foster high-tech entrepreneurship and facilitate the creation of university spin-offs. In conclusion, there remains a need to strengthen the conditions and establish more formalized networks to effectively develop and apply biotechnology and life sciences as drivers of regional growth and prosperity.

4.2 Success factors identified from the literature review

The Systemic Competitiveness model, as a framework for the development of biotechnology cluster initiatives, organizes and categorizes the success factors into four environmental dimensions: meta, macro, meso, and micro. As a summary, the characteristics of each dimension and the main areas of success factors according to Table 3 are described below.

1. The **meta level** represents governance and industrial competitiveness. The emphasis is on government policies; for example, developing a vision for the biotechnology sector considering the specific conditions of the regions in which the cluster initiatives are located. Success factors cover political and social affairs.

- **Public politics:** the development of a policy based on innovation systems, a shared vision of the development of the biotechnology sector, innovation policy, regulatory framework, intellectual protection system, and clarity and articulation of public policies.
- **Society context:** The most important social issues are shared values and social cohesion, attitudes to support the biotechnology sectors and clusters, and efforts to change and learn.

2. The **macro level** includes the link between stable economic conditions and attitudes toward change and transformation. Macroeconomic success factors are concentrated on sufficient infrastructure and resources (e.g., capabilities to develop innovative products) for companies and actors in the biotechnology cluster initiative.
   - **Territorial conditions:** The business environment that affects cluster development includes pre-existing agroecological and biotechnology knowledge and capacities, physical infrastructure, the culture of innovation and entrepreneurship, attraction of personnel (opportunities for a pleasant lifestyle), the existence of industries/sectors related to biotechnology, and the labor market.
   - **Macroeconomic context:** economic performance, financing capacities, production rates, imports, and export regulations.

3. The **meso level** includes the specific policies of the business environment and actors (local government, service companies, entrepreneurs, universities and research institutes, seed investors) that support the creation of competitive advantages for cluster companies. The areas of success factors cover territorial issues, interactions of the actors, providers of specialized products and services, infrastructure, and framework conditions that govern the conduct of the sector.
   - **Core competencies and interactions**. The success factors that promote interaction between actors are the philosophy of collaboration and collective ownership (common vision), sufficiency of the productive value chain, proximity, attraction of actors and trust (business culture and rivalry), external links, and networking.
   - **Infrastructure and framework conditions**. The success factors for service infrastructure are access to financing of innovation and entrepreneurship projects (e.g., venture capital and public programs), a scientific-technological platform, service companies (e.g., consulting in legal affairs, TICs, and marketing), and cluster management (e.g., a facilitator or director who coordinates and integrates the cluster actors and represents the cluster).

4. The **micro level** refers to actors' capacity and resources for innovation management. The success factors are the functions that must be carried out throughout the life cycle of innovations, from the development of knowledge and markets to the creation of legitimacy of the innovations.
   - **Strategy of research and entrepreneurship**. This refers to the choice and emphasis of technological programs, the development of products and business plans, and the formation of markets, organizational resources, and capabilities.
   - **Development and dissemination of knowledge**. According to the knowledge management cycle, the steps are the knowledge acquisition of internal and external partners (e.g., spillovers), knowledge distribution in the organization, and knowledge adaption and transformation of new business models and market offers.
   - **Activation of resources**. For the development of biotechnology clusters, intangible resources are core competencies, such as the work of technological experts, their interchange (Open innovation) between universities, research institutes, and companies (especially in start-ups) in the cluster, and the diversity of skills and experience.

4.3 Results and discussion of the success factors by the experts described in Table 4

The experts' responses to the survey propositions are presented in Figure 6, based on the following rating scale: (a) Strongly Agree, (b) Agree, (c) Neutral, (d) Disagree, and (e) Strongly Disagree. Given the exploratory and descriptive nature of this research, the experts' opinions should be viewed as supplementary and validating the findings from the documentary review. These responses should not be interpreted as universally applicable to the case under study.

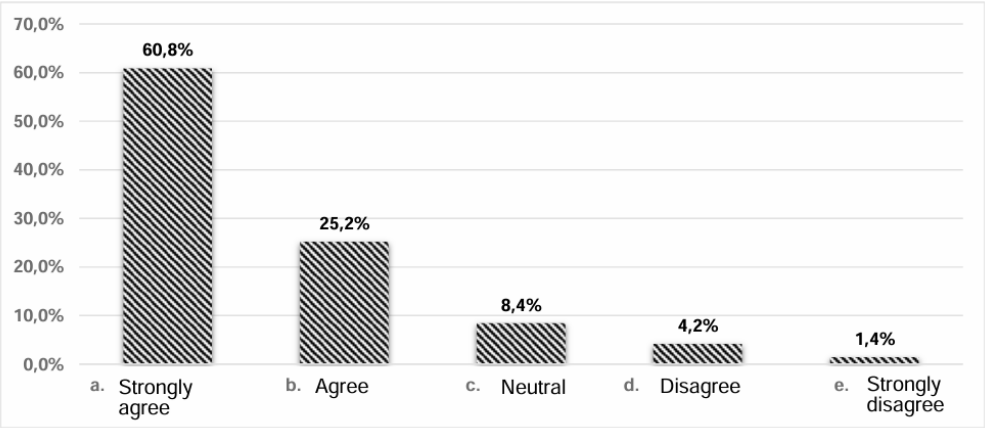

Figure 6. Consolidated relative frequency.
Source: survey results (2020)

More than sixty percent of experts "strongly agree" that the conditions outlined in the propositions are crucial for fostering a biotechnology cluster that drives innovation in SMEs, or that they closely reflect the region's current reality. The success factors with which all experts "strongly agree" include the labor market, scientific-technological platform, and pre-existing knowledge. Experts unanimously emphasize the importance of a skilled workforce for the successful development of SMEs within the cluster. Additionally, the region's existing knowledge base, encompassing technologies and other forms of expertise, serves as a critical foundation for cluster initiatives. It is also important to highlight that effective technology transfer depends on a robust scientific-technological platform that encourages research and experimentation by entrepreneurs. In conclusion, the success factors in which the experts agreed to promote the sustainable use of biotechnology and life sciences as mechanisms for the development and prosperity of the region are public policies, a regulatory framework, financing, service infrastructure, the labor market, scientific-technological platforms, an entrepreneurship culture, strong actors with competitiveness and core competencies, external links, sustainable growth, and cluster management and services. To achieve a high level of success factors determined by the recommended Systemic Competitiveness model, it is essential to establish policies and instruments aimed at the creation and development of technology-based companies and institutions that promote this type of activity.

According to this model, the **meta level** encompasses the success factors for building a shared vision for the development of biotechnology. At this level, it is essential to establish an ethical culture for the development, commercialization, and sustainable use of technology. This involves understanding local social dynamics, trends, preferences, and the social acceptance of biotechnologies and their biological products (Bezama et al., 2019, p. 1). Experts interviewed for this study emphasized the importance of understanding regional awareness of social acceptance

and the sustainable use of biotechnology. They also highlighted that clear and aligned policies for innovation and development in agriculture and biotechnology are critical for the success of cluster initiatives. However, experts stressed the need for well-defined regulatory standards that apply across the entire biotechnology industry value chain, from access to genetic resources to commercialization.

The **macro level** focuses on the macroeconomic success factors that promote innovation and investment in biotechnology. The experts agree that the existing knowledge and resources within a region must be integrated by companies and other stakeholders to ensure the success of the cluster initiative. Creating favorable macroeconomic conditions for investment in biotechnology and related sectors is essential. Additionally, fostering an entrepreneurial culture within universities is crucial for developing innovation and biotechnological cluster networks. This can be achieved by establishing incubators that provide training for students, professionals, and researchers.

At the **meso level**, the success factors related to the region and the innovation cluster in the biotechnology sector are consolidated. According to Bezama et al. (2019), transforming the educational system is crucial for developing a skilled workforce for the biotechnology sector. The experts unanimously agreed that improving the regional educational system is vital for cultivating the necessary personnel, technicians, and experts to achieve a regional "critical mass" essential for the development of cluster initiatives and networks. In addition, experts emphasized the need for robust physical and service infrastructure, such as a scientific-technological platform, to facilitate technology transfer processes and promote venture capital to support start-up companies. They also highlighted the importance of developing efficient administrative services in areas such as cluster management, consulting, marketing, branding, and the commercialization of biotechnology products and services. To foster stronger relationships between cluster actors, such as research institutes, universities, and companies, experts suggested that the creation of joint research projects is a key strategy for collaboration and innovation.

Finally, the **micro level** focuses on the internal conditions necessary for innovation within biotechnology companies, such as optimizing their capacity for innovation and technology management. The experts agree that companies in this high-tech sector must be integrated into global value chains to foster spillover effects and technological knowledge transfer resulting from interactions between foreign and local companies. However, to ensure sustainable growth, the cluster must simultaneously maintain favorable regional conditions that attract new companies while strengthening the existing ones.

Today, Biotec Corporation (BC), located in the Valle del Cauca region of Colombia, has officially been recognized as a Research Centre by the Ministry of Science, Technology, and Innovation (Minciencias, 2022). As part of Colombia's National and Regional Science, Technology, and Innovation System (STI), BC as a core institution of the emerging agro-biotechnology cluster, is dedicated to advancing BIO frontier research and innovation. Its mission is to drive the transformation of agriculture and accelerate the bioeconomy by fostering sustainable agricultural systems that deliver high-added value for improved quality of life. BC is positioned to become a leading model for a sustainable tropical bioeconomy and has updated its strategic approach for the period from 2016 to 2026 as part of the institutional recognition renewal process. BC defines its value proposition through three key strategies: (1) Ensuring the sustainability of tropical forest and fruit production systems, (2) Enhancing agriculture and health by addressing regional diets and the social determinants of well-being, and (3) Promoting natural ingredients for food and nutrition security, public health, and value-added industries (Corporación Biotec, 2022).

5. Conclusions

This study explores the conditions necessary to strengthen emerging agro-biotechnology clusters at the regional level in Colombia, with a particular focus on the Valle del Cauca department. It examines the capacities, conditions, and practices required for the industry to achieve world-class performance. From this perspective, the Colombian government recognizes that biodiversity offers a comparative advantage for the country's socioeconomic, environmental, and sustainable development.

To achieve a high level of success based on the Systemic Competitiveness model, it is crucial to implement policies and tools that foster the creation and development of technology-based companies and institutions that support such activities. According to this model, the meta-level encompasses the success factors needed to build a shared vision for biotechnology development. The macro-level focuses on the macroeconomic factors that promote biotechnology innovation, while the meso-level addresses the success factors within the region and the biotechnology innovation cluster. Finally, the micro-level considers the internal conditions necessary for innovation within biotechnology companies.

Each country and region must develop its own bioeconomic agenda, tailored to its specific conditions, capacities, and needs, to identify opportunities with the participation of various societal actors. Colombia has embraced this approach, and significant progress has been made in improving the organizational environment through government policies such as CONPES 3697 (2011), which aims to promote biotechnology further. This policy seeks to advance the commercial development of biotechnology-based products derived from biological and genetic resources.

The challenge for both national and regional governments in Colombia is to drive industrial development by shifting from reliance on non-renewable resource exploitation and primary agricultural products toward building a bioeconomy based on advanced technology and a circular economy that is both environmentally and socially sustainable. Additionally, the state must create conducive environments across the four dimensions of the Systemic Competitiveness Model to foster interaction between universities, institutions, and businesses, facilitating knowledge transfer and the actions necessary to generate competitive innovations for international markets.

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