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ARTICLE

Beyond the fields: EMBRAPA'S sustainable technological prospects for Brazilian agribusiness

Além dos campos: as prospecções tecnológicas sustentáveis da EMBRAPA para o agronegócio brasileiro

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Abstract: This research aimed to understand the future of sustainable agricultural innovations, analyzing the technologies developed by EMBRAPA, in the conceptual light of innovation, sustainable economic development, and the entrepreneurial state. An exploratory and qualitative methodology was used to chronologically organize 1188 technological solutions, 363 patents and, 2043 cultivars. The method guided the application of a prospective scenario questionnaire adapted to the Likert-type SERVQUAL Scale. Based on the obtained results, a tendency to invest in improved water catchment systems, intelligent irrigation, heat and drought tolerant varieties, soil management technologies, biological pest control, use of renewable raw materials, and genetic improvement was observed. Finally, investments in methodologies, processes, and expansion of EMBRAPA services were also prioritized, as well as the celebration of partnerships with agricultural groups, companies, and institutes. Based on all the information presented in this study, it is evident that EMBRAPA has already established technologies. However, it is more urgent and imperative than ever to invest and drive sustainable innovation, making it accessible to all Brazilian producers, and providing a prosperous future for production and conservation in the sector.

Keywords: economic development, innovation, sustainable technologies, agribusiness, scenario prospecting, technological change.

Resumo: O objetivo deste estudo consistiu em compreender o futuro das inovações agropecuárias sustentáveis, analisando as tecnologias desenvolvidas pela EMBRAPA, à luz conceitual da inovação, do desenvolvimento econômico sustentável e do Estado empreendedor. Utilizou-se uma metodologia exploratória e qualitativa para organizar cronologicamente 1188 soluções tecnológicas, 363 patentes e 2043 cultivares. O método guiou a aplicação de questionário prospectivo de cenários adaptado à Escala SERVQUAL do tipo Likert. A partir dos resultados obtidos observou-se uma tendência de investimentos em sistemas aprimorados de captação de água, irrigação inteligente, variedades tolerantes ao calor e seca, tecnologias de manejo de solo, controle biológico de pragas, uso de matérias-primas renováveis e melhoramento genético. Por fim, priorizaram-se também investimentos em metodologias, processos e ampliação de serviços da EMBRAPA, bem como a celebração de parcerias com grupos agropecuários, empresas e institutos. Com base em todas as informações apresentadas neste trabalho, é evidente que a EMBRAPA já possui tecnologias estabelecidas. Contudo, é mais urgente e imperativo do que nunca investir e impulsionar a inovação sustentável, tornando-a acessível a todos os produtores brasileiros, garantindo um futuro próspero de produção e conservação do setor.

Palavras-chave: desenvolvimento econômico, inovação, tecnologias sustentáveis, agronegócio, prospecção de cenários, mudança tecnológica.

INTRODUCTION

The Brazilian agricultural sector invested in research on tropical ecosystems, guided by technology and knowledge, as well as applied technological strategies for production systems and renewable energy, making it an international reference in producing and exporting food products (Silva et al., 2020).

Despite the agricultural sector occupying a prominent position in the economy due to the achieved increase in productivity, Brazil faces a huge challenge in terms of innovation, given the risk of dependence on imported inputs and technologies used in the production of agricultural commodities. Furthermore, there are global-scale challenges that go beyond issues related to hunger, the environment, and the increasing demand for food and energy (Buainain et al., 2015).

This context reinforces the importance of technology, knowledge, and innovation as distinctive factors between developed and underdeveloped countries. However, it is necessary to recognize that fostering innovation in the economy is not an easy task, as it is intrinsically linked to the dynamism of growth, as evidenced by traditional theories such as Solow (1956) neoclassical growth model, Schumpeter's (1988) cyclical view of creative destruction, and neo-Schumpeterian evolutionary ideas.

In this context, it becomes crucial to understand the concepts of innovation from the perspective of economic development, which have been able to contribute to the creation of an innovation system in the country. This has resulted in the establishment of the National Agricultural Research System (SNPA), coordinated by EMBRAPA, which has the noble mission of developing research, technology, and innovation in this sector.

Furthermore, it is important to understand the technological fields developed by these components, specifically by EMBRAPA, as it is the main public company involved in deposits of new patents, cultivar registrations, and research in the agricultural sector in Brazil.

Thus, the importance of this study lies in the recognition that the Brazilian state plays an entrepreneurial role, acting as an innovative agent by investing in science, technology, and innovation. This is evidenced by the chronological mapping of 1188 technological solutions, 2043 cultivars, and 363 patents developed by EMBRAPA (Mazzucato, 2014). These achievements have provided a solid foundation to conduct a prospective questionnaire with experts to identify future technological trends for sustainable agricultural development in Brazil.

THEORETICAL FOUNDATION

The challenges of the Brazilian agricultural sector.

Nowadays, in the economic era and knowledge society, characterized by highly rapid technological, market, and institutional changes, the Brazilian agricultural sector was forced to achieve specific knowledge to make it possible to transform it into competitive factors for individuals, companies, and institutions (Lemos, 1999).

Agricultural technological innovations become especially critical in this context, particularly when linked to sustainability, considering global challenges such as hunger, governance, the environment, and the increasing energy demand (Crestana & Mori apud Buainain et al., 2015).

Buainain et al. (2015), also, point out that the growing demand for food raises challenges not only to production and availability but also to effective logistics aspects such as quantity and quality accordingly, pricing, and social politics. Governance should play a primary role in building, reforming, and rebuilding organizations and institutions so that they can operate with practical and efficient solutions.

It is truly necessary to improve the concept of sustainable development, disseminated at the United Nations Conference on Environment and Development, Rio-92. This review should drive the formulation and implementation of innovative sustainable development policies, rethinking the relationship between humans and the environment(da Silva et al., 2021).

Sachs (2017) proposes a robust framework for sustainable development, supported by four fundamental pillars: economic prosperity, social inclusion and cohesion, environmental sustainability, and good governance. The latter requires active and responsible participation from all relevant social actors, including both governments and businesses.

Bourgon (2011) emphasizes the social vision that a government should have, describing governance not only in terms of vertical authority but also encompassing the horizontal dimension of collective knowledge and power derived from society.

When analyzing the agricultural sphere in the light of sustainability, Frankelius et al. (2019) highlight the complex task scientists face in balancing the expansion of biological production with technical, economic, and environmental issues, demanding significant changes in land use and attention to sustainability pillars.

Thus, there is a significant challenge in the agricultural sector, given the trend of natural resource scarcity, making them more expensive and scarce, as well as the sustainability of production processes, conservation, and environmental preservation in agricultural activities as well as in land use (Crestana; Mori apud Buainain et al., 2015).

Agricultural innovation in the light of economic development and the entrepreneurial State

Innovations in the agricultural sector distinguish themselves from other sectors, as do their ecosystems. They operate under constant environmental risks, such as biotic stresses (like pests and diseases) and abiotic stresses (including weather conditions, soil characteristics, and water availability). Furthermore, the location of agricultural production is often determined by these environmental factors rather than just economic or logistical considerations. (Triguero et al., 2013).

Dosi et al. (1990) characterize technological innovation as a complex activity, embedded in a process or discovery in development or experimentation whose outcomes generate new products and/or productive processes. Under this neo-Schumpeterian reasoning, Reardon et al. (2019) argue that investigations focused on agricultural innovation have the potential to generate fundamental knowledge and insights that can catalyze the development of robust and effective value chains in the sector.

In the current global economy, technological innovation has the power to alter the equilibrium state of the economic system deeply. This can occur through the introduction of a new product, a new method of production, the opening of a new market, or the establishment of a new organization (Schumpeter, 1988). In this dynamic context, the State plays a fundamental role as an entrepreneur, not only facilitating but also actively driving the introduction of innovations (Mazzucato, 2014).

In this context, the choice of EMBRAPA as the object of study is justified by its status as the leading reference in agricultural research in Brazil, playing a decisive role in the incorporation and dissemination of new technologies across various segments of the agricultural production chain (Swinnen & Kuijpers, 2019). Furthermore, EMBRAPA stands out for its ability to foster the creation and access to new markets, whether through local or global value chains, thus strengthening the dynamism and competitiveness of the Brazilian agribusiness (Feyaerts et al., 2020).

EMBRAPA, through its continuous commitment to research and development (R&D), clearly embodies the concept of innovation proposed by Johannessen et al. (2001), by introducing new products, services, and production methods, as well as paving the way for new markets and organizing itself in innovative ways. This scenario also aligns with the definition of innovation proposed by the OECD (Organization for Economic Cooperation and Development), which recognizes innovation as the implementation of a new or significantly improved product (good or service), process, marketing method, or organizational method in business practices, workplace organization, or external relations (Instituto Brasileiro de Geografia e Estatística, 2021; Organisation for Economic Co-Operation and Development, 2018). Consequently, EMBRAPA stands out as a concrete example of this conceptualization, with its activities strongly linked to innovation in the agricultural sphere.

It's worth highlighting that EMBRAPA doesn't have the responsibility to insert its technological assets into the productive and social environment in isolation, as its institutional competence is to promote, stimulate, coordinate research, development, and innovation activities, and transfer knowledge and technologies, as stated in Article 4 of its statute (Empresa Brasileira de Pesquisa Agropecuária, 2020b).

From a micro perspective, the institution's premise is to provide scientific and technological support to agricultural producers and companies to promote economic and social development (Empresa Brasileira de Pesquisa Agropecuária, 2020a), through targeted investments in research and development of new products/services to maintain the competitiveness of sector companies by attracting new consumers (Fagerberg et al., 2013). This strategy, according to Fossas-Olalla et al. (2015), prompts organizations aiming to maintain competitiveness to make room for innovation.

From this perspective, EMBRAPA promotes, stimulates, and transfers its technologies through different business strategies such as technological cooperation, technology supply, and licensing of rights to patents and cultivars, among others (Empresa Brasileira de Pesquisa Agropecuária, 2020a).

It is noteworthy that since the 1990s, Brazilian agriculture has undergone significant technological innovation, with substantial changes in production methods and, especially, the adoption of new techniques, transforming Brazilian agribusiness into a highly competitive and efficient production system, reflected in the Gross Domestic Product (GDP) value.

In this aspect, Wang & Chien (2007) emphasize the significant role of technology in economic growth, stating that agribusiness companies, faced with international competitive challenges, require constant technological progress to maintain their position in the market.

Faced with these international challenges and the pursuit of continuous technological development, EMBRAPA has been practicing open science since its creation, by entering into international cooperation agreements with other institutions, based on a knowledge production model called open science. This model is characterized by expanding collaboration levels in solving scientific problems, using external sources to enhance competitiveness in generating new technologies, as well as in commercializing ideas that do not align with the organization's business model (Tapscott & Williams, 2007).

Consequently, EMBRAPA's macro innovation process is structured on the mature open innovation model focused on generating and providing knowledge, information, and technologies to the productive sector for the benefit of agriculture sustainability and food security (Empresa Brasileira de Pesquisa Agropecuária, 2020a).

The company holds the know-how, assets, and technologies that can easily move at the boundary between the company and the market, in both directions. The path of this movement is clearly represented by a funnel as shown in Figure 1, where the input represents various propositions of technological assets originating from the ideation process, and the outer area of its output represents the finished technological assets reaching the market (Empresa Brasileira de Pesquisa Agropecuária, 2020a).

In Figure 1, it can be observed that the stages of research, development, and validation of technological assets reach various maturity levels along this path.

According to the Manual on the Use of the TRL/MRL Scale by Empresa Brasileira de Pesquisa Agropecuária (2020a), the outer side of the "input" funnel in Figure 1 is categorized as pre-technological assets, encompassing pre-technological products, biological collections, technical-scientific methodology, databases, information, and analyses, which are at TRL/MRL levels 1 and 2. These levels comprise the stages of state-of-the-art discovery, understanding, and concept. When these assets enter the funnel, they are incorporated as components of technological assets, progressing through TRL/MRL levels 3 to 5, which involve the phases of adaptation and development. For example, a gene (pre-technological asset) that is incorporated into a cultivar (technological asset), or a database (pre-technological asset) that is integrated into software (technological asset) (Empresa Brasileira de Pesquisa Agropecuária, 2020a).

Levels TRL/MRL 7 and 8 are characterized by the validation and refinement phases of the technological asset under development, which may be deemed inapplicable, or other fields of application for the innovation asset may be identified. However, when this asset is validated and refined, it can be transferred by EMBRAPA through licensing, assignment, or technology supply as a spin-off to the sector (Empresa Brasileira de Pesquisa Agropecuária, 2020a).

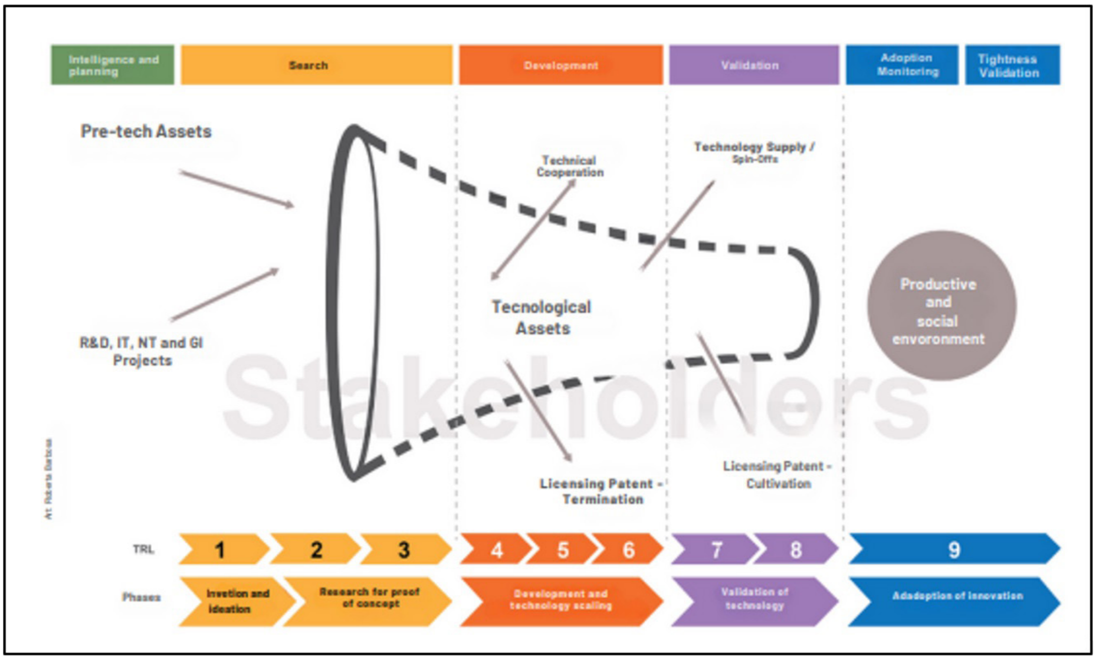

Figure 1. EMBRAPA's innovation macroprocess.
Source: Empresa Brasileira de Pesquisa Agropecuária (2020a)

According to Mazzucato (2014), R&D activities are always accompanied by risk, and in the case of EMBRAPA, many assets may be discontinued along the way, as not all ideas and projects result in new products, processes, or services (Empresa Brasileira de Pesquisa Agropecuária, 2020a).

Although the innovative model is contemporary, EMBRAPA has a record of an Entrepreneurial State, as outlined by Mazzucato (2014), due to Brazil's significant investment in agricultural R&D. This commitment is evidenced by the robust team composed of 2,290 analysts, 2,123 assistants, 1,293 technicians, and 2,196 researchers who, until 2022, developed impressive 1,188 technological solutions, 363 patents, and 2,043 cultivars. These results, stemming from both incremental and radical research, emerge from an extensive maturation process and are aligned with the current and future demands of society and the market. Additionally, EMBRAPA remains in tune with global factors shaping the agricultural sphere, encompassing technological trends, market restructuring, and competitive and regulatory transitions, all contributing to an uncertain scenario (Empresa Brasileira de Pesquisa Agropecuária, 2018). This description illustrates how the institution and its researchers perceive themselves and their work within a broader context, using the third person to contextualize their contribution to the field of agricultural innovation.

METHODOLOGY

To achieve the research objectives, methodological triangulation was adopted in a single case study, utilizing both quantitative and qualitative methods. Primary data on all company innovations were collected through EMBRAPA, MAPA, and Espacenet website, complemented with an intensive analysis of secondary information from various sources. Search terms were defined based on the name of the depositor EMBRAPA and its variations, using boolean operators on the Espacenet and CultivarWeb platforms, respecting the specificities of each.

Regarding data exportation, it is important to clarify that the CSV (Comma Separated Values) format is available from Espacenet, and Excel format from CultivarWeb. These data were organized chronologically in Excel spreadsheets to develop dynamic reports with groups of data for the construction of visual dashboards.

It is worth noting that the dissemination of EMBRAPA's innovations is challenged by access difficulties, such as the need to gather information from multiple platforms into a unified chronological spreadsheet, as demonstrated in this research. It highlights data fragmentation as a significant barrier to continuous and effective access to developed technologies.

Based on the identification of innovations developed by EMBRAPA, it has been decided to apply a questionnaire in scenario planning, following Porter's (1985) guidance, which proposes constructing alternative scenarios to understand and anticipate emerging trends.

Considering that technological progress is influenced by market dynamics, environmental impacts, financial resources, and the institutional political environment, it has been developed a structured questionnaire around three possible scenarios - optimistic, realistic, and pessimistic. This tool allowed respondents to evaluate and select, among various options, the areas that should be prioritized in terms of investment to foster the sustainable future development of the Brazilian agricultural sector.

It's worth highlighting that the technology alternatives provided to the participants were confined to EMBRAPA's extensive technological collection until 2022. This decision was taken to balance the company's investments in Science, Technology, and Innovation (ST&I), given the vast diversity and number of cultivars and patents generated by the company.

Following Porter's (1985) guidelines for scenario planning: environment, technological trends, political changes, social transformations, and economic instability have been considered. Additionally, it has been evaluated the competitive landscape based on Porter's five forces: the threat of new entrants, the threat of substitutes, the bargaining power of buyers, the bargaining power of suppliers, and competitive rivalry. Based on the questionnaire proposed to experts, three possible scenarios for the future of Brazilian agribusiness are outlined:

- The optimistic scenario, where economic strengthening prevails in emerging countries, driven by significant public investments in science and technology, along with efficient resource management and the transition to renewable energies.
- The realistic scenario, is characterized by global social and economic instability, reduced purchasing power in emerging societies, environmental pressure on production, and budgetary constraints affecting the advancement of science and technology.
- The pessimistic scenario, where a global setback is outlined, with a reduction in purchasing power, dependence on external inputs, scarcity of vital resources, emergence of a new pandemic, long periods of conflicts, and insufficient public investment in science and technology.

Faced with these scenarios, six questions were elaborated regarding technological solutions, focusing on the main aspects of sustainability, especially those relevant to water supply, CO2 emissions, animal protein exports, investments and partnerships external to the company, and EMBRAPA's technologies.

The information gathered from specialists and researchers connected to these technologies, through the application of prospective questionnaires, was adapted to the Likert 5-point SERVQUAL scale (Table 1).

Table 1 – Likert Scale

Priority Degree	Meaning
0	No priority
1	Low priority
2	Low priority
3	Medium priority
4	High priority
5	Very high priority

Source: The Author

Data analysis was conducted using the RStudio software, allowing manipulation and analysis of variables representing respondents' characteristics. The program was also used to create graphs and tables, facilitating comparison and understanding of variables of interest. Additionally, statistical measures such as mean, mode, median, and standard deviation for each technology were calculated and added using the system *Overleaf* por *LaTeX.*

RESULTS AND DISCUSSION

Innovations developed by EMBRAPA from 1975 to 2022

The evolution of innovative knowledge in the Brazilian agricultural sector is progressing at an accelerated pace, making it essential to incorporate sustainable technologies into the production process, as well as to examine technological trends that the sector currently presents from various perspectives.

Through a conceptual evolutionary analysis of innovation and its implications from the perspective of economic development, 1188 technological solutions, 363 patents, and 2043 cultivars developed by EMBRAPA were mapped, as presented in Table 2.

Table 2 - Innovations developed by EMBRAPA between 1975 and 2022

TECHNOLOGIC SOLUTIONS		PATENTS		CULTIVARS	
1975 to 2022		1983 to 2021		1998 to 2022	
Methodology	110	Electricity	3	Forestry	88
Agricultural Practice	354	Engineering	8	Forage	79
Process	64	Execution of operations; Transport	23	Fruitful	401
Product	582	Physical	42	Great Cultures	1163
Service	14	Measurement	1	Vegetable crops	177
Agricultural System	64	Human needs	209	Ornamental	8
		Chemical	75	Others	127
		Textile	2		
TOTAL	**1188**		**363**		**2043**

Source: The author, based in Barbosa (2022)[1].

According to Nascimento & Castro (2020), by the late 1990s, Brazil was already recognized as an international leader in tropical agriculture. During this time, EMBRAPA was influenced by the SIAC approach, which resulted in the development of 118 technological solutions from 1974 to 2000. These solutions predominantly focused on practices for soil fertilization and fertilization management, along with the development of conventional cultivars and machinery, implements, and equipment. Additionally, 70 patents were granted, predominantly classified in the categories of human needs, execution of operations, transportation, and physics.

It's important to highlight that in 2002, ten years after the influence of the SIAC approach, EMBRAPA underwent a new restructuring of its institutional model directed towards the third approach proposed by the World Bank, in 2006, the Agricultural Innovation System (SIA).

Based on the foundations of the SIA approach, EMBRAPA establishes the EMBRAPA Management System (SEG), which values the capabilities and processes emphasized by the National Agricultural Research System (SNPA) and the Information System and Agricultural Knowledge (SIAC). Furthermore, it recognizes the importance of actors involved in the innovation process, such as the private sector along the production chain, creative adaptation processes, and innovation financing policies (Empresa Brasileira de Pesquisa Agropecuária, 2012).

This new restructuring resulted in 271 granted patents, mainly in the development of areas related to physics, human needs, and chemistry. Additionally, it led to 1016 technological solutions delivered to society relating to management practices, production systems, software products, and new conventional and transgenic cultivars, among other technical-scientific methodologies (Empresa Brasileira de Pesquisa Agropecuária, 2012).

According to Empresa Brasileira de Pesquisa Agropecuária (2011), SEG is the model that best aligns with the innovation system (SI) approach, whose goal is to plan and coordinate research and development activities, technology transfer, communication, and institutional development of the company itself and the entire SNPA.

In line with the interactive innovation model, the R&D process of EMBRAPA and the National Agricultural Research System (SNPA) begins with the identification of demand, which generates knowledge and technical information through the development and adaptation of technologies. These technologies result in prototypes to be validated, which, in turn, give rise to finished products and processes. Once new products and processes are originated, EMBRAPA´s second basic activity takes place, which is technology transfer, following its statute (Empresa Brasileira de Pesquisa Agropecuária, 1999).

[1] The data presented in Table 2 were extracted from Appendices 1, 2, and 3 of BARBOSA Vivian's Dissertation (2022).

With the help of Figure 1 and Table 2, it is evident that EMBRAPA has achieved a high level of maturity in recent years. They have developed 1188 technological solutions, 363 patents, and 2043 cultivars through an extensive Research, Development, and Innovation (RDI) process that is consistently aligned with market demands and environmental considerations.

Prospective Scenario Questionnaire

Based on the technological survey, it was possible to create an outline of the innovative products and processes developed by the company and, consequently, glimpse sustainable technological trends that will be priorities for development and implementation shortly, through the application of a prospective scenario questionnaire.

Faced with the technologies proposed in the questionnaire, the respondents prioritized future investments for each problem presented.

The questionnaire addressed the water problem based on studies by Hernandez & Szigethy (2019), which identified that excessive industrial and agricultural uses, population growth, and poor water management cause water scarcity affecting over 40% of the global population. The objective was to assess the investment priority in sustainable technologies by EMBRAPA to mitigate this crisis, considering optimistic, realistic, and pessimistic scenarios.

It is observed in Table 3 that respondents prioritized investment in improved water harvesting systems, smart irrigation, and local practices (Option 1), as well as the development of varieties tolerant to abiotic stresses to address areas of severe water stress (Option 6), aligning with trends identified by Crestana and Mori (cited in Buainain et al., 2015). This suggests that key technologies for water problems may include alternatives that ensure stable production, such as resistant cultivars, bio-inputs, no-tillage farming, crop-livestock integration, and sub-optimal irrigation.

Table 3 - Investment priority for water sanitation in production, from the perspective of three scenarios, according to respondents

Question 2			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Technological Options					
Option 1	Improvement of water harvesting systems, smart irrigation, and practices adapted to local conditions.	Average	4.19	3.73	3.18
		Deviation	1.09	1.14	1.62
		Median	5	4	3
		Mode	5	4	5
Option 2	Development of functions and ecosystem services related to soil and water in rural areas.	Average	3.39	2.94	2.55
		Deviation	1.34	1.22	1.50
		Median	4	3	2
		Mode	4	3	2
Option 3	Agroforestry systems that incorporate plant diversity with agricultural, fruit-bearing, and forestry species.	Average	3.68	3.23	2.60
		Deviation	1.31	1.27	1.49
		Median	4	3	3
		Mode	4	3	3
Option 4	Crop-Livestock-Forest Integration (CLFI), promotes the recovery of degraded pastures, intensification, and diversification of production.	Average	3.94	3.64	3.00
		Deviation	1.15	1.07	1.50
		Median	4	4	3
		Mode	5	3	5

Source: Own elaboration based on respondents' data

Table 3 - Continued...

Question 2 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 5	Conservationist no-tillage system that promotes carbon accumulation in the soil, fostering biological improvements in the soil and reducing erosion and sedimentation of water resources.	Average	3.87	3.61	2.98
		Deviation	1.18	1.22	1.48
		Median	4	4	3
		Mode	5	3	2
Option 6	Development of improved varieties with heat tolerance, drought tolerance, and other abiotic stress tolerance.	Average	4.10	3.63	3.22
		Deviation	1.17	1.16	1.47
		Median	5	4	3
		Mode	5	4	5

Source: Own elaboration based on respondents' data

Given the concern about Brazil's dependence on foreign fertilizers, which is impacted by external events such as pandemics and wars affecting global supply, supply chain disruptions, and rising food costs and prices, the level of priority to invest in sustainable technologies from EMBRAPA that could reduce external input dependence was questioned, considering three scenarios.

Among the technological options presented, respondents prioritized investments in the development of inputs for biological control of pests and diseases using renewable raw materials (Option 4) and the facilitation of methods for biological nitrogen fixation in a greater number of species (Option 6), according to data from Table 4.

This result reveals that the trend towards the use of technologies in the future encompasses the mapping of the real needs of arable soils in the country through the use of precision technology; development of machinery, equipment, and automation processes for small and medium-scale enterprises, with special emphasis on increasing efficiency in the use of fertilizers (Buainain et al., 2015); use of technologies for plant nutrition such as the use of microorganisms; integrated management and biological control of pests and diseases (Bettiol & Campanhola, 2003).

Table 4 - Investment priority for mitigating fertilizer use, from the perspective of three scenarios, according to respondents.

Question 3 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 1	Development of national production systems for phosphate fertilizers.	Average	4.12	3.64	3.00
		Deviation	1.08	10.77	1.55
		Median	4	4	3
		Mode	5	4	2
Option 2	Development of new plants producing nitrogenous fertilizers and expansion of areas using biological nitrogen fixation to recover degraded areas, reduce greenhouse gas emissions, and decrease contamination risks.	Average	3.52	3.14	2.48
		Deviation	1.30	11.02	1.38
		Median	4	3	2
		Mode	5	3	3
Option 3	The expansion of no-tillage farming enables greater efficiency in mechanized operations, allowing fuel savings and consequent reduction of CO2 emissions.	Average	2.85	2.33	2.01
		Deviation	1.36	12.28	1.36
		Median	3	2	2
		Mode	3	2	2

Source: Own elaboration based on respondents' data

Table 4 - Continued...

Question 3 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 4	Improvement of integrated management in crop protection against diseases, insects, and weeds.	Average	4.17	3.60	3.07
		Deviation	1.20	12.31	1.60
		Median	5	4	3
		Mode	5	4	5
Option 5	Improvement in agroecological and organic production systems, considering the non-use of pesticides, chemical fertilizers, antibiotics, or genetically modified organisms.	Average	3.48	3.09	2.47
		Deviation	1.62	13.23	1.50
		Median	4	3	3
		Mode	5	3	3
Option 6	Facilitation of methods for biological nitrogen fixation in a greater number of species.	Average	3.94	3.61	3.11
		Deviation	1.23	9.59	1.32
		Median	4	4	3
		Mode	5	4	3

Source: Own elaboration based on respondents' data

About mitigating greenhouse gas (GHG) emissions, since 2009, Brazil has instituted the National Policy on Climate Change, creating the ABC Plan, currently referred to as the "Sectoral Plan for Climate Change Adaptation and Low Carbon Emission in Agriculture" (ABC+ Plan). In this context, the degree of investment priority in sustainable technologies from EMBRAPA that could mitigate or reduce emissions of these gases was questioned, from the perspective of three scenarios.

According to the data in Table 5, respondents prioritized investments in improving integrated management for crop protection against diseases, insects, and weeds (Option 4), reflecting a strong trend toward the use of technologies in the recovery of degraded pastures, Crop-Livestock-Forest Integration (CLFI), agroforestry systems (AFS), no-tillage farming systems (NTFS), biological nitrogen fixation (BNF), widely promoted by EMBRAPA, as well as the implementation of planted forests, treatment of animal waste, and increasing the adaptive capacity and resilience of production systems to climate change (Silva et al., 2021).

Table 5 - Investment priority for greenhouse gas (GHG) emission mitigation, from the perspective of three scenarios, according to respondents.

Question 4 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 1	Development of national production systems for phosphate fertilizers.	Average	2.85	3.03	3.39
		Deviation	1.63	1.32	1.40
		Median	3	3	4
		Mode	5	4	5
Option 2	Development of new plants producing nitrogenous fertilizers and expansion of areas using biological nitrogen fixation to recover degraded areas, reduce greenhouse gas emissions, and decrease contamination risks	Average	3.03	3.27	3.41
		Deviation	1.58	1.22	1.49
		Median	3	3	4
		Mode	5	3	5

Source: Own elaboration based on respondents' data

Table 5 - Continued...

Question 4 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 3	The expansion of no-tillage farming enables greater efficiency in mechanized operations, allowing fuel savings and consequent reduction of CO2 emissions.	Average	3.12	3.39	3.46
		Deviation	1.27	1.05	1.33
		Median	3	3	4
		Mode	2	4	4
Option 4	Improvement of integrated management in crop protection against diseases, insects, and weeds.	Average	3.28	3.56	3.67
		Deviation	1.48	1.06	1.32
		Median	4	4	4
		Mode	5	4	5

Source: Own elaboration based on respondents' data

Regarding the possibility of commercial embargoes on Brazilian meat due to discussions about the growing population demand, consumers becoming more aware of quality and production processes increases in greenhouse gas emissions and climate change, the degree of investment priority in sustainable technologies from EMBRAPA capable of reducing environmental and market impacts on animal protein production was questioned from the perspective of an optimistic, realistic, and pessimistic scenario.

According to the data in Table 6, the priority sustainable technologies for the production of higher quality and more sustainable animal protein, according to respondents, would be investment in genetic improvement through breeding products, breeding stock, or lineages (Option 1) and in enabling biological nitrogen fixation in a greater number of species, especially grasses (Option 2).

These results reflect a trend towards the use of no-tillage farming technologies, biological nitrogen fixation in grain production for animal feed, as well as animal waste treatment (TDA); intensification of integrated systems (CLFI and CLP) as described by Balbino et al. (2012), continuous and non-invasive remote monitoring of animals through computer vision and bioacoustics, genomic development that aids in increasing the animal population with better nutritional quality; improvements in management techniques for soil and water conservation and animal welfare; increased food supplementation (Medeiros et al., 2013).

Table 6 - Investment priority for sustainable animal protein production, from the perspective of three scenarios, according to respondents.

Question 5 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 1	Genetic improvement through breeding products, breeding stock, or lineage.	Average	3.67	3.43	3.03
		Deviation	1.18	1.08	1.39
		Median	4	3	3
		Mode	4	3	3
Option 2	Enabling biological nitrogen fixation in a greater number of species, especially grasses.	Average	3.76	3.41	2.98
		Deviation	1.19	1.03	1.36
		Median	4	3	3
		Mode	5	4	4

Source: Own elaboration based on respondents' data

Table 6 - Continued...

Question 5 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 3	Development of devices for animal traffic identification and monitoring.	Average	3.00	2.60	2.23
		Deviation	1.39	1.28	1.27
		Median	3	3	2
		Mode	3	3	3
Option 4	Improvement in the control of toxic plants in pastures.	Average	2.61	2.32	1.88
		Deviation	1.38	1.24	1.26
		Median	3	2	2
		Mode	3	2	2
Option 5	Development of cultivars for the ILP system.	Average	3.41	3.16	2.74
		Deviation	1.25	1.15	1.39
		Median	4	3	3
		Mode	4	3	2
Option 6	Improvement of grazing management under rotational stocking	Average	3.58	3.27	2.84
		Deviation	1.14	1.07	1.30
		Median	4	3	3
		Mode	4	3	3

Source: Own elaboration based on respondents' data

Given EMBRAPA's commitment to open innovation and the long period of research and development that innovation requires, as well as the possibility of interruptions during this process due to economic, financial, and/or budgetary instability in the country, an evaluation was proposed regarding the best partnership opportunities with other institutions so that the company could develop new sustainable innovations from the perspective of an optimistic, realistic, and pessimistic scenario.

It is observed in Table 7 that respondents consider advantageous the establishment of partnerships for research and technology development through the open innovation model, with agricultural groups, agribusiness companies (Option 5), and science and technology institutes (Option 8).

The prospective exercise led to the prioritization of R&D through the sharing of knowledge in productive clusters such as networks of producers that have relationships with each other, participation of funding institutions that encourage and enable the development of these knowledge networks, whose results enable both technological and economic development as well as social development (Cardoso et al., 2015).

Table 7 - Priority for entering into new partnerships with EMBRAPA, from the perspective of three scenarios, according to respondents.

Question 6 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 1	Investment Funds	Average	3.16	2.61	2.24
		Deviation	1.38	1.19	1.42
		Median	3	3	2.0
		Mode	4	3	2
Option 2	Communication and information technology companies	Average	3.16	2.81	2.39
		Deviation	1.20	1.14	1.37
		Median	3	3	2.0
		Mode	3	3	1

Source: Own elaboration based on respondents' data

Table 7 - Continued...

Question 6 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 3	Food and gastronomy industry	Average	3.41	3.01	2.46
		Deviation	1.04	1.16	1.46
		Median	3	3	2.5
		Mode	4	3	3
Option 4	Innovation ecosystem	Average	3.70	3.31	2.76
		Deviation	1.22	1.07	1.39
		Median	4	3	3.0
		Mode	4	3	3
Option 5	Agricultural groups and agribusiness companies	Average	3.83	3.43	2.86
		Deviation	1.13	1.21	1.58
		Median	4	3	3.0
		Mode	4	3	5
Option 6	State research organizations (OEPAS)	Average	3.07	2.74	2.34
		Deviation	1.25	1.29	1.44
		Median	3	3	2.0
		Mode	3	3	3
Option 7	Representative entities of producer classes	Average	3.32	2.98	2.44
		Deviation	1.20	1.15	1.34
		Median	3	3	2.0
		Mode	4	3	3
Option 8	Institutes of science and technology	Average	3.69	3.21	2.90
		Deviation	1.37	1.17	1.45
		Median	4	3	3.0
		Mode	5	3	3

Source: Own elaboration based on respondents' data

Concluding the analysis, the extensive portfolio of technological solutions from EMBRAPA - which includes products, methodologies, agricultural practices, processes, systems, and services - enabled respondents to understand which categories of EMBRAPA technologies should receive investment priority in optimistic, realistic, and pessimistic scenarios. When evaluating the portfolio, respondents showed a preference for future investments in methodologies (Option 2), process improvement (Option 4), and expansion of services (Option 6), as indicated in Table 8.

These results reflect the institution's tendency to prioritize the enhancement of analysis methods, laboratory procedures, diagnostic techniques, and research methods, as well as the development of new processes for creating new food, chemical, biological, and industrial products, given the maturity of the company and current sector demands.

Table 8 - Investment priority regarding EMBRAPA's technological portfolio, from the perspective of three scenarios, according to respondents.

Question 7 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 1	Development of physical and digital PRODUCTS, such as software, applications, cultivars (seeds and seedlings), animals, machinery, equipment, beverages, fertilizers, and vaccines.	Average	4.18	3.70	3.25
		Deviation	1.07	1.09	1.49
		Median	5	4	3.5
		Mode	5	4	5

Source: Own elaboration based on respondents' data

Table 8 - Continued...

Question 7 Technological Options			Optimistic Scenario	Realistic Scenario	Pessimistic Scenario
Option 2	Increase in METHODOLOGIES aimed at achieving knowledge or results through analysis methods, laboratory procedures, verification and monitoring of socio-environmental profiles, digital soil mapping, diagnostic methods, and research methods.	Average	3.48	3.10	2.62
		Deviation	1.34	1.20	1.45
		Median	4	3	3.0
		Mode	4	4	3
Option 3	Improvement of AGRICULTURAL PRACTICES encompassing production techniques, natural resource management, fertilization, planting, disease and pest control, soil recovery, conservation, and renewal.	Average	4.11	3.77	3.14
		Deviation	1.04	0.95	1.43
		Median	4	4	3.0
		Mode	5	4	3
Option 4	Development of PROCESSES for product generation, such as processes for obtaining packaging, production of pesticides and other chemical and biological products, fertilizers, food and beverages, animal feed, industrial products, machinery, and implements.	Average	3.69	3.31	2.78
		Deviation	1.11	1.22	1.51
		Median	4	3	3.0
		Mode	4	3	3
Option 5	Improvements to animal and plant production management systems, including breeding cultivation, intercropping monoculture, crop rotation, and integrated production SYSTEMS.	Average	4.07	3.59	3.11
		Deviation	0.98	1.03	1.36
		Median	4	4	3.0
		Mode	5	4	3
Option 6	Expansion of SERVICES in research and technology transfer, including the development of analysis, consulting, monitoring, and web services.	Average	3.55	3.26	2.75
		Deviation	1.20	1.12	1.49
		Median	4	3	3.0
		Mode	4	3	2

Source: Own elaboration based on respondents' data

Finally, it is worth noting that the averages in Table 8 reveal optimism in the most favorable scenario for the evaluated technological options, suggesting significant potential under ideal conditions. As a transition to realistic and pessimistic scenarios can be observed, the averages decrease, indicating more reserved expectations. The standard deviation indicates variability in respondents' perceptions, possibly due to uncertainties or diverse interpretations about the future. Median and mode complement the analysis, highlighting an overall positive trend but with notable caution in adverse scenarios. This statistical evaluation may serve as a key indicator for planning and strategic decision-making in the technology sector.

CONCLUSIONS

It can be observed that EMBRAPA plays a central role in Brazil's innovation system, particularly in the agricultural sector, acting as a catalyst for innovation by developing new technologies, practices, processes, and crop varieties that strengthen Brazilian agriculture.

Based on the theoretical framework brought by Mazzucato (2014), it can be affirmed that the Brazilian state, through EMBRAPA, actively acts to direct and stimulate innovation. This means that the institution, through its technological solutions, goes beyond its traditional role as a regulator or mediator of market failures. The public company adopts a risk-investing stance, committing to innovative and uncertain research and development, whereas the private sector may be hesitant to be.

These R&D investments have resulted, up to the year 2022, in 1188 technological solutions, 363 patents, and 2043 developed cultivars, which have a direct and significant impact on the development of innovations that shape both Brazilian and global agriculture. Evidence of this includes the creation of crop varieties adapted to Brazilian peculiarities, such as tropical soybeans, as well as the development of sustainable technologies, such as biological pest control, biological nitrogen fixation, and the production of renewable agricultural inputs.

These sustainable innovations from EMBRAPA not only increase the productivity and competitiveness of the sector but also have the potential, according to Schumpeter's theory (1988), to reshape the structure of the economic system, particularly in the context of the Brazilian agribusiness, since a large part of the agricultural system still relies on non-renewable sources and unsustainable technologies.

The sustainable innovations conducted by EMBRAPA have disruptive potential to modify this scenario, especially in Brazilian agriculture. Predictions indicate that, shortly, the market will demand improvements in these processes and products, which places sustainable innovations in a prominent position. Therefore, the emphasis on sustainable innovations by EMBRAPA, according to the respondents, reflects a trend in the sector to enhance analyses, develop new products and processes, implement sustainable practices, and adapt to climate change. These innovations have transformative potential, with the ability to redefine the current economic landscape.

As a result, this article aims to advance scientific knowledge in its field through reflections and solutions for the improvement of public policies and organizational performance in any institution. The findings and analyses contained in this research not only guide decision-making but also outline a clear organizational strategic roadmap capable of fostering innovation and increasing efficiency in any context. It is expected that this positively will impact both the academic landscape and governmental and corporate spheres, reinforcing the importance of R&D institutions, such as EMBRAPA, in conducting research and development. Such efforts not only drive Brazilian agriculture forward but also shape the sustainable future of the sector on a global scale.

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