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Prospective 2035 for the dairy agroindustrial chain: using the Delphi approach and scenario methodology

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The objective of this article is to identify and prioritize technologies, innovations and new businesses related to the dairy agro-industrial chain that are expected to emerge by 2035. To do so, the two-round Delphi method was used and questionnaires were applied to 27 national and international experts. A technology tree was built with Python codes and libraries, consisting of 174 topics. Additionally, 39 variables were generated for scenarios in the Good Livestock Practices BPG; Research, Development and Innovation R&D&I; Sustainable Livestock and Agroindustry groups, as well as four hypotheses and a bet scenario, with the future objectives of sustainable specialization of forage production and mass production and standardization in collection centers. This can be achieved through projects on technologies and innovations prioritized in the Delphi method, including ultrasound, pulsed combustion drying, dairy-derived medicinal products, bioethanol produced from whey, artificial intelligence and selection assisted by molecular markers, electromembrane filtration technologies, whey protein concentrates, life cycle assessment, blockchain, neural networks and smart assays, among others. The opportunity that actors in the Science, Technology and Innovation system have in the chain for the development of programs, plans, public policies and open innovation challenges in the prioritized technologies is highlighted.

KEYWORDS

scenarios, Delphi method, agribusiness, converging technologies, dairy

Introduction

The Colombian dairy sector is renowned for its considerable export potential, particularly in regard to value-added products. It is regarded as a strategic, economically, socially, and food security-wise asset for the Colombian population, as well as a catalyst for local, regional, and national development (República de Colombia-Departamento Nacional de Planeación, 2010).

Consequently, it is one of the sectors prioritized by Colombian public policy (República de Colombia-Departamento Nacional de Planeación, 2010).

According to the National Department of Statistics (hereafter DANE), Colombia will produce 7.5 billion liters of cow's milk per year by 2022. This represents 12% of the agricultural GDP. In addition, milk consumption is approximately 156 L per person per year.

The dairy sector averages a share of 1.5% of the national GDP; 1.1% originated in primary milk production and the remaining 0.4% in the processing of dairy products. The dairy industry in Colombia is an activity that moves more than $12 billion per year, according to sales recorded during 2022 (Departamento Nacional de Estadísticas-DANE, 2024).

Nevertheless, an examination of the sector revealed a number of challenges impeding global and national productivity. Among the most significant challenges to address is the low productivity that falls below the global benchmark, as highlighted by the Ministry of Agriculture and Rural Development (Ministerio de Agricultura y Desarrollo Rural-MADR, 2020).

According to the National Association of Industrialists-ANDI (2020), productivity is low and is not comparable with that of the main players in the world. We are between 50 and 75% of the world average, depending on the source of information. However, there is evidence of slow technical change, revealed by productivity growth according to the International Fact-Checking Network (IFCN) and the projections of the OECD and the FAO. Likewise, and as the productivity base is low (1.5–2.0 tons/animal), doubling it would take 40 years at the current rate and one of the biggest problems in the chain is that there are no official statistics on the evolution of herd size and its characterization (pasture, stable, semi-stable, etc.).

The price trend is favorable for milk and dairy products, motivated by the dynamism of emerging markets. However, in this agro-industrial chain, no major changes are forecast at the level of dairy by-products, except for whey, and the world has made progress in dismantling supports and subsidies that distorted trade, and Colombia has done so at a faster rate. According to the OECD and FAO (cited by ANDI, 2020), Colombia is competitive in terms of prices and Colombian producers are at the level of New Zealand. Colombia has improved its competitive position in terms of costs, moving from high-cost to intermediate-cost countries, and can improve competitiveness if spraying costs, which were close to US$700, are reduced.

Global consumption of dairy products has been and will continue to be more dynamic, and Colombia is also moving in that direction. However, it is at the lower limit of the minimum recommended consumption, despite the potential of 25 kg per person. Therefore, changes in consumption habits for nutrition or sustainability affect the chain (vegetable drinks, vegan products, zero deforestation, animal welfare, etc.) and Colombia is not an active player in international trade (ANDI, 2020).

On the other hand, and according to the Ministry of Agriculture and Rural Development, there are about 155 cluster initiatives registered in the Colombia Cluster Network, some of which are related to the dairy sector. A report on the dairy cluster (2023), and after consultation with technical secretaries from the departments of Colombia, the following actions were identified: 1. Department of Cundinamarca: an initiative led by the Chamber of Commerce of Bogotá is being worked on, called "Bogotá Region Dairy Cluster Initiative," which has an annual strategic plan and four pillars: business strengthening, promotion and marketing, R&D&I, and human capital. 2. Department of Caldas: approaches are being made between entrepreneurs and the Chamber of Commerce to start as a cluster initiative. This topic will be prioritized for 2018. 3. Department of Caquetá: this Department is not focused as an initiative for the formation of a dairy cluster. However, actions have been taken to strengthen processing issues (rural cheese factory), marketing, and market (designation of origin, QC collective brand, advertising strategy); 4. Department of Cesar: the Chamber of Commerce of Valledupar is finalizing a project where eight companies were strengthened. These companies have been given support according to their needs, in relation to procedures, equipment adaptation and infrastructure. Once this project is completed, another one called FOCAL (Strengthening of the Dairy Chain) is on the way. 5. Department of Antioquia: the governance committee of the competitive route for dairy derivatives was activated, in which topics such as: Context of the Competitive Route for Dairy Derivatives, Integration of entrepreneurs from eastern Antioquia into the chain, Formation of the Governance Model of the Route and representatives of the productive sector are being worked on (Ministerio de Agricultura y Desarrollo Rural-Minagricultura, 2023).

In light of the pivotal role of this agroindustrial sector, this article aims to facilitate more informed decision-making by identifying and anticipating prospective avenues for enhancing the scientific, technological, innovative, and competency management of the dairy agroindustrial chain in the department of Quindío, Colombia. To this end, scenario-based foresight and MDs are employed. The two methods were comprised of multiple stages, which are also delineated in this article. They were conducted from a perspective that can be extrapolated to other regions, to answer the following question: What variables, innovations, strategies, and priority actors can be identified for the dairy chain in the year 2035?

This article addresses a theoretical framework related to the production chain of the dairy sector in Colombia, in addition to the subject matter of this Introduction. It also presents a list of the materials and the methodological design applied in the research, as well as the results found for the improvement of capacities in Science and Technology (S&T) of the dairy agroindustrial sector for the department of Quindío-Colombia. Furthermore, it includes a discussion and conclusions, as well as a list of references.

Theoretical framework: dairy sector production chains

The Colombian dairy agroindustrial sector is characterized by a production chain comprising a complex system of six interrelated links. The fundamental product in this chain is milk produced from cattle in either specialized or dual-purpose systems.

The links that interact and interrelate in the Colombian dairy chain are as follows: 1. The supply chain comprises six links: suppliers of goods and services, productive units, collection centers, industrialists, intermediaries, and consumers. The final consumer (Mojica et al., 2007).

The concept of a production chain is open to several different interpretations (Mosnier et al., 2017; Rojas et al., 2020; Dernat et al., 2022; Bianchi et al., 2023; Martinelli et al., 2022; de Morais et al., 2021). This article, however, is based on the work of López (2003),

who defines it as a system formed by the harmonious interaction between different participants, directly or indirectly, in the production and consumption of products and services.

The concept of production chain is not equivalent to that of value chain or supply chain; production chain is a concept that began to be used in Latin America in the nineties of the 21st century, to refer to the collaborative work between productive links and the articulation and design of sectoral policies and business support by government agencies (Beckerman and Cataife, 2015). Thus, since the 1990s, production chains have been part of the conceptual framework of competitiveness that characterizes national and regional development policies in Latin America (Jimenez, 2002).

In accordance with Law 811 of June 2023, which amends Law 101 of 1993 and establishes chain organizations in the agricultural, fishing, forestry, and aquaculture sectors, as well as the Agricultural Transformation Companies (SAT) and other pertinent provisions, a chain is defined as the set of activities that are technically and economically linked from the initial processing of an agricultural product to its ultimate marketing (Congreso de la República de Colombia, 2003a,b). The coordination of these organizations is the responsibility of the MADR, with their registration being regulated by Decree 3,800 of 2006 and Resolution 186 of 2008. Furthermore, the strategic framework of these organizations is defined by the competitiveness agreements.

As posited by Simanca et al. (2016), the notion of a production chain is not synonymous with that of a value chain or supply chain. The term 'production chain' was first employed in Latin America during the 1990s to describe collaborative endeavors between production links and the formulation and implementation of sectoral policies and business support initiatives by government agencies.

Delphi method

According to Sossa et al. (2015), the Delphi method (hereinafter MD) consists of a structured, anonymous and iterative consultation with experts, with the aim of identifying options, obtaining consensus and validating results. The literature on the method also indicates that there are two types of elements to identify the future: 1. Exploratory, which seeks to identify future scenarios and 2. Normative studies, which are aimed at prioritizing a list of generic topics or technologies, with the possibility of adding topics or technologies to those initially proposed, and others that the expert considers may be missing.

MD is one of the most widely recognized and used methods at the business and academic level, and its application seeks to help reduce uncertainty in decision-making. For Nazarko et al. (2015), MD consists of the selection of a group of experts who are asked their opinion on issues related to future events. The quality of the results depends on the care taken in preparing the questionnaire and in choosing the experts consulted (Andersen et al., 2004). The experts' estimates are made in successive rounds, anonymously, in order to achieve consensus, but respecting the opinion and autonomy of the participants (Gnatzy et al., 2011). MD allows for group judgments after successive rounds that provide aspects and justifications that are more effective than if individual judgments were held (Santos et al., 2017). Furthermore, feedback is given to the responses in each round, in order to provide sufficient information for the next round. In addition, the responses are analyzed with descriptive statistical procedures, in order to reach a consensus (Gómez Paz et al., 2015).

According to Reguant-Álvarez and Torrado-Fonseca (2016), this method presents quantitative and qualitative characteristics, where one of the first works carried out was the one developed at the Rand Corporation in the late 1950s, as an effective means of collecting and synthesizing expert judgments. Since the first Rand study was published in 1964, the technique has been used very frequently in a wide spectrum of topics.

Cuhls (2001) and Celiktas and Kocar (2010) emphasize that the application of MD worldwide has largely concentrated in the area of strategic management of large organizations. According to Abend (2002), "the MD proposes a question and invites an opinion or solution from a group of highly qualified experts," although in the classical approach, this method allows efficient communication of the group of experts who remain anonymous among themselves, in order to solve a complex problem (Nazarko et al., 2015).

For his part, Steurer (2011), indicates that opinions, beliefs and judgments are collected and organized in a systematic way that focuses mainly on consensus, but also on dissenting opinions. Therefore, the MD is the most used by organizations, its ease of use and applicability make it a method that can be feasible to complement with others (Figueroa et al., 2012).

However, the techniques for applying MD have been refined in recent years, from the use of conventional descriptive statistics to techniques such as the number of justifications or comments between rounds, a coefficient to quantify the competence or degree of expertise of the participants, measures of the expert's perception of the usefulness of the feedback presented, graphs of the number of arguments according to the number of questions, Wilcoxon ranked pair test, Kolmogorov–Smirnov test and the Mann–Whitney U test (Zartha et al., 2019).

Currently, there are different studies that carry out their research under MD, such as Agyemang et al. (2022), Bootz et al. (2022), DeSouza et al. (2022), Fehr et al. (2022), García-Herrero et al. (2022), Haan et al. (2022), Lente and Peters (2022), Neumann et al. (2022), Lu et al. (2022), Luoma et al. (2022), Spaniol and Rowland (2022), Tamanni et al. (2022) and Westland et al. (2022), among others.

Regarding new Delphi studies, the research by Iqbal et al. (2021) in Pakistan stands out in order to identify the barriers to the adoption of energy management practices in the construction sector. Initially, the barriers are filtered using the fuzzy MD. The most important barriers identified were the lack of support and interest from senior management in energy management issues, lack of conditions for the implementation of energy management practices on the construction site, lack of financing schemes to implement energy management technology, lack of communication and collaboration between project stakeholders, and attitudinal, cultural, and behavioral resistance to the adoption of energy management practices.

In a new study in Pakistan Iqbal et al. (2021) empirically analyzed the promotion strategies for the adoption of energy efficient technologies in developing countries using a methodology that combined Fuzzy Delphi, MICMAC—Multiplication Cross Impact Matrix applied to a Classification, and Interpretive Structural Modeling, the authors found that the most important promotion strategies that could accelerate the adoption of energy efficient technologies in Pakistani construction projects are: tax incentives and financial schemes related to energy efficient technologies, organizing international conferences and workshops to support the adoption of

energy efficient technologies, learning from developed countries' energy policies and government regulations and standards.

Another study in the same country aimed to assess the factors that drive energy management practices in the construction sector by using a methodology that combined Fuzzy Delphi using interpretive structural modeling and MICMAC. Iqbal et al. (2022), the authors identify factors such as increasing taxation of construction companies for energy usage and contribution to pollution, promotion of subsidies for investment in energy efficiency technologies, and increasing enforcement of government rules and regulations regarding energy management practices in the workplace, as contributing to the adoption of energy management practices in the construction sector in Pakistan.

Another study that combines not only Delphi but MICMAC and other techniques is the research by Iqbal et al. (2024) on critical success factors for energy management in the construction sector of Pakistan, in this study the authors integrate the MD with the MICMAC methodology and Interpretive Structural Modeling, the authors found that variables such as top management support, international pressure and pressure from environmental policies are the most important factors in the adoption of an energy efficient supply chain, the same author conducted another study in 2024 related to green supply chain in post-COVID-19 times in China applying not only the Fuzzy Delphi but also the MICMAC methodology. Iqbal et al. (2024), in this case the authors found that lack of trust between companies and supply chain partners and the difficulty of transforming positive environmental attitudes into actions are the most important challenges for the implementation of green supply chain management.

Meanwhile, and citing Godet (2007), one of the most representative authors of prospective studies, this is a management discipline that allows us to reflect on the future, what could be and what should be, with a view to guiding human action, individual or collective, in the present, through a whole conceptual and methodological infrastructure applicable to problems in different fields and areas.

In Colombia, several prospective studies have been carried out, which have had as their objective the identification of future needs of human resources that will arise from the impact of technological advances and organizational trends between 5 and 10 years (Zartha-Sossa et al., 2017).

Materials and methods

The methodology delineates the phases of each method, elucidating the outcomes in exhaustive detail, and underscoring the examination of pivotal variable scenarios through the lenses of Matrix Multiplication Applied to a Classification (MICMAC) and Matrix of Alliances and Conflicts, Tactics, Objectives, and Recommendations (MACTOR). This approach generates scenarios in accordance with their probability of occurrence.

The MICMAC analysis identifies the key or most dependent variables of the original cross-impact matrix (MIC) that are rated by experts or stakeholders on a scale of 0, 1, 2, or 3. The MACTOR analysis aimed to estimate the correlation of forces among the actors and to examine their convergences and divergences with respect to specific challenges and associated objectives (Zartha et al., 2023).

This study employed two analytical techniques: the prospective scenario analysis method, comprising its constituent stages, and the MD, applied in two rounds.

Techniques such as MICMAC, MACTOR and SMIC Probexpert have been used in the foresight of other agro-industrial sectors in Colombia, such as (Zartha et al., 2012; Sossa et al., 2019; Sossa, 2020). The Delphi method has also been used in the foresight of other agro-industrial sectors, such as Fishing sector (Montes Hincapié et al., 2017); Cocoa (Meza-Sepulveda et al., 2020); Mora (Suárez et al., 2021) and Coconut (Grass Ramírez et al., 2023), among others.

The variables used in the scenario methodology that are inputs for the MICMAC matrix of 39 variables were obtained through a Forms survey of stakeholders in the dairy chain of the department of Quindío-Colombia, considering the PESTAL matrix approach (Mendez Penagos et al., 2024), that is, respondents answered the main problems of the dairy chain from political, economic, social, technological, environmental and legal contexts. Subsequently, the project monitoring team extracted the variables of the problems mentioned by the chain actors, these variables were validated with experts in several workshops with the chain actors in the Chamber of Commerce of the region. Therefore, we have attached this explanatory paragraph in the methodology.

The technologies and innovations variables allowed the construction of the MD thematic/technological tree with 164 items and these, in turn, were obtained from a scientific and technological surveillance study with critical surveillance factors related to the dairy value chain and other focuses related to ICTs and genetics.

In order to ensure the participation of the different stakeholders in the chain, several actions were carried out, including:

1) Questions to experts: who were selected for their knowledge of the dairy agro-industrial chain. Using the structured interview technique and surveys, information was obtained on the innovation processes, as well as determining the barriers and drivers of innovation.
2) Meetings with different stakeholders: several meetings were held with the stakeholders of the chain, in order to obtain data on the challenges and issues for adopting innovative practices.
3) Validation of sources: to validate the data, a triangulation of sources was carried out. For primary sources, for example, direct consultations were made with experts, while for secondary sources a literature review was carried out in specialized databases, such as Scopus and Google Scholar, and for tertiary sources, technical and statistical reports were used, as well as government publications.

An issue that raises concerns and creates gaps for research is related to determining the required number for an expert consultation, and in particular when applying the MD. Although there is no univocality, the consulted literature establishes that a large number of experts is not necessary. Studies such as Gordon and Pease (2006), Kauko and Palmroos (2014) and Liimatainen et al. (2014) agree that a group of between 8 and 25 experts is sufficient. Meanwhile, other authors point out that increasing the size of the expert consultation does not necessarily improve precision. Hence, authors such as Rowe and Wright (2001) and Zartha-Sossa et al. (2017) establish that a range between 5 and 20 is relevant for an analysis. However, there is still no consensus on the optimal number

of participants for Delphi rounds, which highlights a persistent gap in this area of research.

The following section elucidates the aforementioned techniques.

Scenario-based foresight methods

The scenario-based foresight method is a technique that has been employed in a number of studies (Godet, 1995; Godet, 2010; Weng and Lin, 2015; Graham et al., 2015; Bontoux et al., 2016; Botha, 2016; Dugarova et al., 2016; Read et al., 2016). The following studies have employed the scenario-based foresight method: Godet (1995, 2010), Weng and Lin (2015), Graham et al. (2015), Bontoux et al. (2016), Botha (2016), Dugarova et al. (2016), Royuela et al. (2016), Ceriani (2017), De Lattre-Gasquet et al. (2017), Hussain et al. (2017), Barzman et al. (2021), Zackery et al. (2022), Boddenberg et al. (2024), and Muhammad and Sunitiyoso (2024). In 2017, Pospieszny published a study in which he established two groups: a monitoring team and a methodological team. In the following year, Proskuryakova et al. (2018) and Surahman et al. (2019) published studies with similar methodologies.

The use of prospective scenarios has been discussed by companies from different sectors and addressed by different authors and researchers. This is the case of Oliveira et al. (2018), who carried out a detailed literature search on scenario prospecting, allowing different types of analysis and applications. A bibliometric study was carried out in the Scopus database, with the aim of identifying how articles on the term prospective scenarios are presented in the literature. 87 articles on the subject indexed in Scopus were found, corresponding to April 2015 and June 2017. The authors noted that they hope that this work will contribute to the construction of an overview of the existing literature on prospective scenarios, in order to stimulate the interest of more researchers in the subject (Oliveira et al., 2018).

Other authors advance studies on foresight, appealing to methods other than MD, developed in the present research. This is the case of Drei et al. (2023), who developed a research on prospective scenarios for Brazilian tourism post-COVID-19, using the Momentum method. The analysis was limited to the tourism sector, since no Brazilian studies focused on this topic were identified, which provides a novelty. It was presented as a hybrid model, using a prospective view of scenarios. Three prospective scenarios for tourism in Brazil were established, as well as four alternative forms of tourism, directly linked to these scenarios, for multicriteria evaluation. It was possible to establish that both methods determined the same alternatives for adequate tourism in specific scenarios (Drei et al., 2023).

For their part, Mellem et al. (2022), conducted a study in the training and development sector and, by applying the Momentum method, analyzed the demand of a company's clients in the area of corporate training in Brazil, considering different contexts and, based on that, proposing a decision-making process to increase the efficiency and effectiveness of its procedures, prioritizing the courses that present the greatest return and relevance for the organization. The results obtained were satisfactory, providing support for strategic decision-making in the composition of the portfolio of courses offered, resulting in a classification of the same, presenting those that should be prioritized, maintained or discarded by the company's management. It is highlighted that the methodology presented in this work can be applied in other sectors—tactical, operational or strategic—presenting relevance for academia and society (Mellem et al., 2022).

Likewise, and using the same Momentum method, Terra et al. (2023) conducted a study to structure three future scenarios to help the managers of a junior company (JC) compose their project portfolio. The Momentum method was used to prospect scenarios in the organization in question, so that the results would help it in the challenge of effectively facing uncertainties about the coming years. From the data collected, three possible future scenarios were created, which can support the project portfolio selection problem and help the company's decision makers prepare for the worst-case scenario and maximize the use of the best of the structured scenarios.

The monitoring team was constituted of members or stakeholders of the firm or chain who were knowledgeable about the issues under discussion. In contrast, the methodological group was tasked with providing guidance on the scenario method and conducting the statistical analysis.

In contrast, Chermack et al. (2019) published an article presenting the results of a scenario planning study conducted with four organizations. The objective of the study was to ascertain the impact of scenario planning on the perceptions of organizational agility held by participants. The researchers collected pre-and post-test data on organizational agility perceptions from participants in four companies that had engaged in scenario work for approximately 4 months. The results demonstrate that there was no notable alteration in the participants' perceptions of organizational agility as a consequence of scenario planning. The implications, limitations, and conclusions are discussed in the following sections.

In a recent contribution to the literature, Zhu et al. (2024) conducted an exploratory review of how speculative thinking approaches have been leveraged within the field of Human-Computer Interaction (HCI) to envision and shape potential futures. Speculative thinking methods, including speculative design, critical design, design fiction, and design futures, integrate imagination, extrapolation, and fictional elements to broaden the spectrum of potential future scenarios. Despite their growing significance within HCI research, there is still a lack of clarity regarding their implementation and application. This review reveals that there are three principal methods by which HCI constructs futures in conjunction with speculative thinking. It is evident that there is a necessity for the implementation of more systematic and rigorous methodologies for the deployment and evaluation of multiple futures within the domain of HCI research. Furthermore, the significance of methodologies and instruments in HCI pedagogy for fostering the development of speculative thinking abilities among students and professionals is underscored. The Design Futures research process is proposed as a structured approach to exploring and shaping possible futures, with the aim of benefiting the HCI field. The objective of this work is to act as an intermediary between the Design Futures community and HCI, thereby facilitating cross-disciplinary collaboration and advancing speculative thinking within HCI.

The prospective scenario analysis was conducted in the following stages

The first, second, and third stages were based on a previous prospective study related to dairy products (Unidad de Planificación

Rural Agropecuaria – UPRA, 2020) and a new technology watch. In these stages, the variables were recognized and prioritized using a MICMAC structural analysis.

Stages 4, 5, and 6 entailed the grouping of key variables and the preliminary construction of simple hypotheses based on current and future projects, as well as potential threats to each variable or grouping. Additionally, these stages involved the establishment of four status categories—excellent, good, fair, and poor—using quantitative indicators.

Stages 7, 8, and 9: Simple probability analysis, positive and negative conditional, was applied to obtain the possible scenarios in order of probability from highest to lowest, using the software Cross-Impact Matrix System—Probability Expert (SMIC ProbExpert). This last phase was the input to collectively choose the betting scenario on which the alignment of the results of the two-round MD is designed.

Delphi method (MD)

In the context of the MD (Aengenheyster et al., 2017; Adini et al., 2017; Di Zio et al., 2017; Jiang et al., 2017; Li et al., 2017; Montes Hincapié et al., 2017; Münzberg et al., 2017; Melnikovas, 2018); Ollenburg, In the meantime, a stepwise analysis was conducted (Paniagua, 2019; Schwarz, 2019; Tranmaleo et al., 2019; Farrow, 2020; Marzban and Mohammadi, 2020; O'Brien and Forbes, 2021; Cedeño and Mena, 2022; Jae, 2023). The following section delineates the stages of the MD.

Stage 1: Technology Watch: A literature review was conducted to identify pertinent topics, innovations, technologies, and new companies. The TITLE-ABS-KEY search equation was utilized in the Scopus database, employing the following search terms: productive chain and/or dairy; dairy and/or prospective scenarios; dairy and/or MD. Subsequently, the articles were organized into thematic affinity groups. The results of this stage were used to construct a thematic/technological tree.

Stage 2: Profiling of the Experts: The experts who responded to the Delphi questionnaire were profiled in terms of their academic level, experience, topics, and subtopics. It is noteworthy that the experts or stakeholders represented a diverse range of national and international institutions across various sectors, including agro-industrial companies, academic institutions, government agencies, and public and private organizations associated with the dairy agro-industrial chain.

The stage 3 of the process is now complete. The initial Delphi round commenced with the preparation of a questionnaire encompassing the topics and subtopics derived from the technology watch and the thematic/technological tree. The initial survey was distributed to experts, who were tasked with prioritizing each topic to 2035. This was done using a Likert scale, ranging from 0 to 5, with the option of selecting "Do not know" (NS) or "No answer" (NA) if necessary.

Results of the first Delphi rounds

One month after the distribution of the questionnaire, the responses were subjected to statistical analysis, employing mean, mode, modal frequency (modal frequency 1—MF1), and percentage of consensus.

In consideration of the mean percentage of consensus per subtopic, it was established that a subtopic would be designated as a priority in the initial Delphi round if it exhibited a percentage of consensus exceeding the group average and a modal value of 4 or 5 or higher in the rating. The modal value represents the most frequently occurring rating within the responses. Subtopics with a modal value of 2 or below and a percentage above the group mean were classified as non-priority in the initial Delphi round. The remaining topics that did not satisfy the aforementioned criteria were classified as topics under discussion. The resulting classification was as follows: priority (P), under discussion (D), not a priority (NP), and "do not know/no answer" (DA).

The second Delphi round was designed to solicit feedback from participants regarding the results obtained in the initial round. At this juncture, experts are tasked with reviewing the list of priority (P) and non-priority (NP) topics and those under discussion (D) at the time of questionnaire completion. If necessary, they are expected to modify the assigned topics, technologies, or innovations. For example, any topic initially designated as P could be transferred to the D or NP group, and so on. The second round was accompanied by an executive report, which was provided to assist the expert in making decisions regarding potential alterations to the categorization of the subtopics.

Results of the second Delphi rounds

Four months after the questionnaire was distributed, the responses were analyzed using the techniques described in the results of the initial Delphi round. The modal frequency 2 (MF2), which enables the identification of priority topics, was calculated through consensus in the two Delphi rounds. In this context, MF2 can be expressed as the sum of MF1 and E2-S2 (Equation 1), where E2 represents the number of times a specific item progresses to the second round and S2 denotes the number of times the item is removed from the second round.

Moreover, a validation of the MICMAC analysis was conducted using an artificial intelligence code developed in Python software (Van Rossum and Drake, 2009). The code was employed to calculate the mean similarity of each element within the matrix. Subsequently, a data set was constructed in descending order based on the calculated average similarity. The final result presents the items ordered by their average similarity, with the most similar items positioned at the top of the generated dataset. In conclusion, a word cloud was constructed using the MD. In order to generate and visualize the word cloud derived from the set of Delphi opinions, the "Word cloud" library was utilized in conjunction with other tools, including NLTK and Matplotlib. The process commences with the importation of the requisite libraries and the downloading of the English language resources. Subsequently, a list of words to be excluded is generated. These are defined by the methodological group as not contributing to the analysis and are thus specified. Subsequently, the process of tokenization and elimination of stop words is carried out in order to enhance the precision of the terminology utilized in the comments.

Ultimately, the word cloud is generated with defined parameters, such as size and maximum font, and excludes specific words and those categorized as stop words (Figures 1, 2).

Results

Results of the pro-scenario foresight methodological approach

In this method, the actors to whom the instruments were applied responded to a total of 39 variables, which were registered in the MICMAC software. It was estimated that the cross-influence of the same 39 variables in columns configured the direct influence matrix (MID). Ratings of 0 (no influence), 1 (weak influence), 2 (medium influence), 3 (strong influence), and P (potential influence) were employed. The following table provides a summary of the variables entered into MICMAC for the dairy sector.

The stakeholders identified the 39 most pertinent variables (Table 1) through a process of data reduction using the MICMAC software. Subsequently, the aforementioned variables were employed to ascertain the cross-influence exerted by variables in rows against the same 39 variables in columns, thereby configuring the direct influence matrix (MID). The ratings were assigned according to the following criteria: The ratings were as follows: 0 (no influence), 1 (weak influence), 2 (medium influence), 3 (strong influence), and P (potential influence). Upon completion of the matrix solution, the software generated four graphs corresponding to the four influence/dependence maps: direct (Figure 3), indirect (Figure 4), direct potential (Figure 5), and indirect potential (Figure 6). The generation of the graphs was performed for each of the four influence/dependence maps, with the direct map being generated first, followed by the indirect map, direct potential map, and indirect potential map. The graphs were generated using six iterations, with 100% of the results reaching stability after six iterations.

In order to analyze the key variables within the dairy sector, we intended to include variables at the direct level. In total, 12 variables were identified, namely: The following variables were identified as key factors in the dairy sector: climate change, biotechnology, e-commerce infrastructure, rural entrepreneurship, substitute products, investments, research and development management, new markets, new consumers (prosumers), clean production, and innovation. At the indirect level, the sole variable subjected to analysis was that pertaining to skilled labor.

Concurrently, at the indirect level, the sole variable subjected to analysis was that pertaining to skilled labor. At the direct potential level, two variables were identified. Ancestral Flavors and Product Diversity At the indirect potential level, an additional variable was identified. The concept of intelligent packaging is worthy of further investigation.

According to Figure 3, the key variables were: climate change, biotechnology, e-commerce, infrastructure, rural entrepreneurship, substitute products, investments, R&D management; Innovation; New markets, new consumers, clean production.

In Figure 4, the key or winning variables, which complements the direct variables, was Skilled labor.

Figure 5 highlights two new key variables related to ancestral knowledge and product diversity; these two new variables complement the winning variables of the direct and indirect levels.

This last motor-dependency plane (Figure 6) shows the importance of the smart/active packaging variable, which complements the winning or key variables of the three previous planes.

To validate the quality of the data and information in MICMAC, it was ensured that the arrangement of the variables in the direct influence-dependence planes corresponded to unstable systems, as described by Godet (1995). This involved an arrangement of variables in all quadrants and around the diagonal. The diagonal criterion indicates that key variables are selected based on the largest sum of rows and columns, which represents the greatest influence and dependence of the variables. This is illustrated graphically by the diagonal in the upper left quadrant of each influence-dependency diagram.

The MACTOR method was implemented with the participation of defined stakeholders, including primary producers, dairy chain associations (such as Fedegan), MADR, universities, technological development centers, the National Learning Service (SENA), and the National Planning Department.

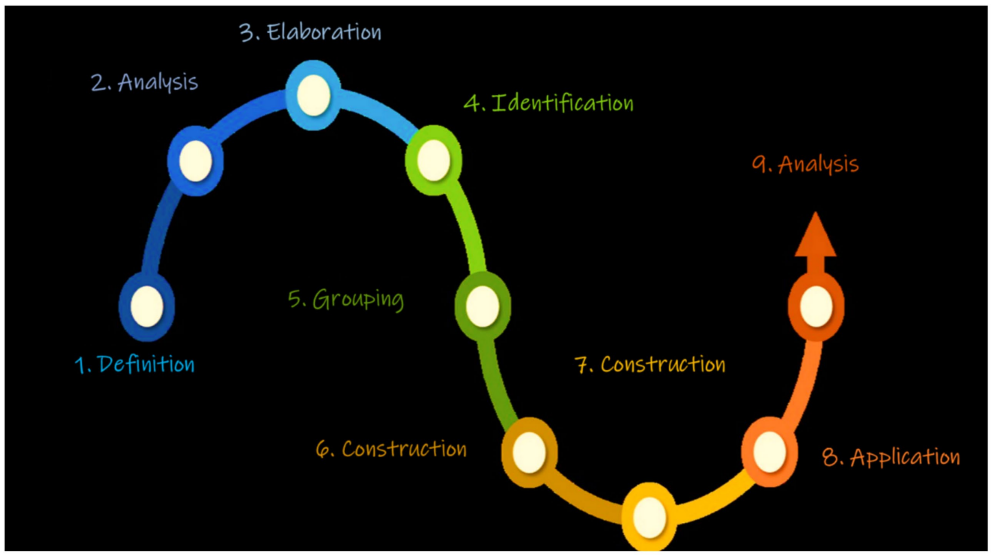

FIGURE 1
Stages of scenario-based foresight. Source: Own elaboration (2024).

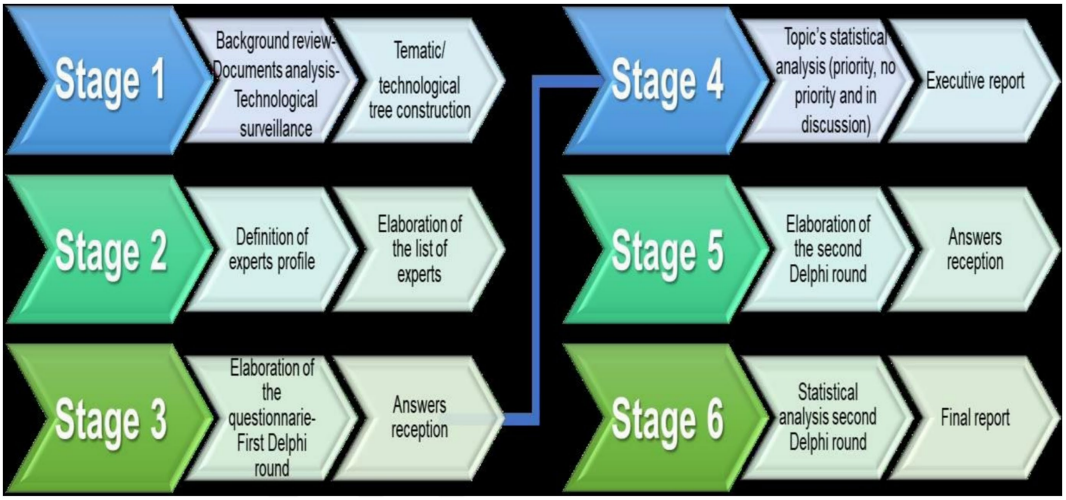

FIGURE 2
Stages of the MD. Source: Own elaboration (2024).

Once the list of stakeholders and objectives had been established, the AAM and AOM matrices were completed in accordance with the established criteria. The AAM matrix was developed with consideration of the interrelationships between the actors, which are reflected in a rating between 0 and 4, indicating the relative importance of each actor. The following scale was employed to assess the influence of each actor: 0 = no influence, 1 = processes, 2 = projects, 3 = mission, and 4 = existence. Figure 7 presents a histogram that illustrates the correlation of forces between the actors.

According to Figure 7, the actors with the greatest power relationship are dairy chain unions; primary producers; the Colombian Institute of Agriculture-ICA-, the Ministry of Agriculture and Rural Development; Universities; Agrosavia; the National Learning Service -SENA-; the Rural Agricultural Planning Unit; dairy processors; the National Institute for Food and Drug Surveillance -Invima; the Technological Development Center and the National Planning Department; the two future objectives prioritized by these actors were: sustainable specialization of fodder production and mass production and standardization in the collection centers.

Subsequently, the SMIC ProbExpert method was employed, which is a cross-impact method designed to eliminate the subjective element according to the coded responses. This was achieved through the formulation of essential hypotheses based on the probabilities of realization determined by the stakeholders, as indicated in the questionnaire. The data obtained from the grouping of key variables, current and future projects, and threats, as well as the assignment of excellent, good, fair, or poor for each axis, was used to construct simple, positive conditional, and negative conditional hypotheses, which served as a fundamental input for the scenario analysis.

The hypotheses presented in Table 2 were developed through a process of balancing current and future projects and threats within each group of key variables. A four-point scale was employed, with grades of excellent (E), good (G), fair (R), or poor (B) being assigned. Subsequently, a potential state for 2035 was postulated among the four categories of E, G, R, and B, and straightforward hypotheses were formulated based on this projected state for each of the six groups.

The construction of hypotheses for the scenarios can be achieved through various paths; after applying the MIGMAC methodology and obtaining the key variables or drivers, these 17 key variables were grouped into four axes: BPG, R&D&I, Sustainable Livestock and Agroindust. For each axis, current and future projects and threats were identified through meetings and workshops with stakeholders in the Chamber of Commerce of Armenia and Quindío-Colombia. This information allowed the generation of the states of excellent, good, regular and bad that were the inputs for the construction of the four hypotheses in Table 2.

In accordance with the available software data, the most probable scenario and the betting scenario were identified as the most likely outcomes. The second option was selected with the input of the supervisory team. This selection was made with the scenarios collectively accounting for 81.7% (for details, please refer to Table 3).

The values shown in Table 3 were obtained through the generation of hypotheses on which the stakeholders answered the probability of occurrence of each event/hypothesis, that is, simple probabilities P(i), they also answered the positive and negative conditional probability for each of the four hypotheses and their combinations, for this the Bayes theorem was used in order to calculate a new calculated probability or P(i)c, the SmicProbexpert software makes the sum of the errors or differences between these two squared probabilities [that is, the sum in absolute value of the differences between P(i)c and P(i) and performs a quadratic minimization model with restrictions (Godet, 1995)] the results of this model are those that give the probability of each scenario in Table 3, where the highest probability is generated for scenario 1111, which means that each of the four hypotheses presented as a whole have the highest probability of occurrence, the scenarios that add up to 80% were presented to the stakeholders for the selection of the bet scenario, which corresponded to 1111.

MD in two rounds

A total of 27 responses were obtained through the two rounds of the MD. The rounds were conducted in a phased manner, with each

TABLE 1 Dairy sector variables for MICMAC.

N°	Long label
1	Regulatory entities
2	Distribution logistics
3	Positioning in the national marketing
4	Quality standards for your products
5	Competition
6	Investments
7	Innovations
8	Domestic agribusiness marketing
9	International agribusiness marketing
10	Customer satisfaction
11	Infrastructure
12	Human talent
13	Clean production
14	Associative administrative model
15	New products
16	Regulations
17	Climate change
18	Territorial marketing
19	E-commerce
20	New consumer: Prosumer
21	Rural entrepreneurship
22	New markets
23	Food safety
24	Substitute products
25	Conurbation
26	Smart automation
27	Biotechnology
28	Intelligent/active packaging
29	Research and Development Management
30	Production linkages
31	Business Model
32	Price stability
33	Migration of population from rural to urban areas
34	Skilled labor
35	Market reports
36	Decision-making applications
37	Tertiary roads
38	Diversity of products
39	Ancestral flavors

Source: Own elaboration (2024).

phase building upon the previous one. The following section delineates the phases in question.

The Technology Watch phase was based on the identification of scientific and technological trends, as well as converging technologies, among other factors. The aforementioned process yielded 174 topics, which constituted the foundation for the initial Delphi round. During this round, experts provided their opinion (see Figure 8).

These 174 topics were distributed into the following groupings/categories.

For Phase 2, the expert profile was defined by extending an invitation to participate in the inaugural round of the Delphi questionnaire to over 100 national and international experts hailing from institutions within the agroindustrial sector, academic institutions, government, the public and private sectors, and other organizations with a vested interest in the dairy production chain. The initial questionnaire was completed by 29 national and international experts, with 27 responses deemed valid. With regard to the academic qualifications of the experts, 34% had obtained a degree, 22% had completed a specialization, 22% had obtained a master's degree, 11% had completed a doctorate, and 11% had pursued other studies.

The third and fourth stages. The initial Delphi round and subsequent subtopic analysis yielded the following results. Following a comprehensive statistical analysis, the classification of subtopics resulted in 72 priority topics and 103 additional topics requiring further discussion.

The fifth stage of the process is now complete. The second Delphi round commenced with the distribution of the second round Delphi questionnaire to the same 27 experts. The results of the 27 questionnaires were then employed in the calculation of the modal frequency 2 (MF2) and a new consensus percentage.

The sixth stage of the process is now complete. The second Delphi round was subjected to the same statistical analysis as the first round. In this case, the modal frequency 2 (MF2) was calculated in order to ascertain the priority subtopics (Equation 1). In the statistical analysis, 92 subtopics were identified as requiring priority attention, while 82 were designated as requiring further discussion.

Table 4 shows the priority topics in the two rounds, as well as those that were under discussion in the first round but became priority topics in the second round. The top 5 with the highest percentage of consensus were: milk quality; environmental impact; enzymes; food safety; and proteins.

The products and by-products table highlights topics such as functional foods, yogurt with concentrated whey protein probiotics, alternative milks and different types of cheeses. The top five with the highest percentage of consensus were: fermented dairy products, fermented milk, functional foods, whey derivatives and organic milk (Tables 5, 6).

In the table related to the ICT group, topics related to AI and block chain, cloud computing, and neural networks are highlighted. The top five with the highest percentage of consensus were: geographic information systems, image analysis, computer vision, artificial insemination, and e-commerce.

In the Table 7 related to dairy species and breeds, genetics and others, 14 topics in total were identified as priorities. The topics that were priorities in both rounds in dairy species and breeds were two, namely: hygiene and quality assurance. In the others grouping, they were pro-environmental agriculture, smart packaging and food for children with growth delays, while for genetics, only three topics were priorities in both rounds: generic breed improvement, genetic selection of high-production breeds and synchronization and insemination techniques.

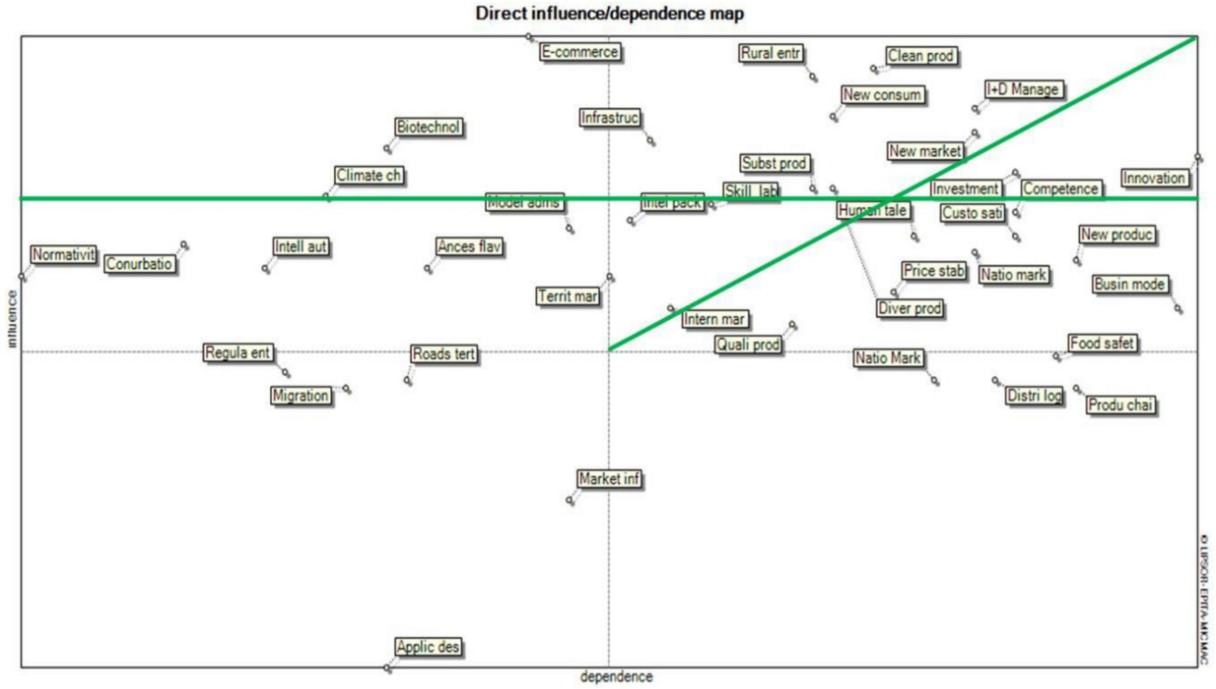

FIGURE 3
Direct influence/dependence maps—Dairy. Source: Own elaboration (2024).

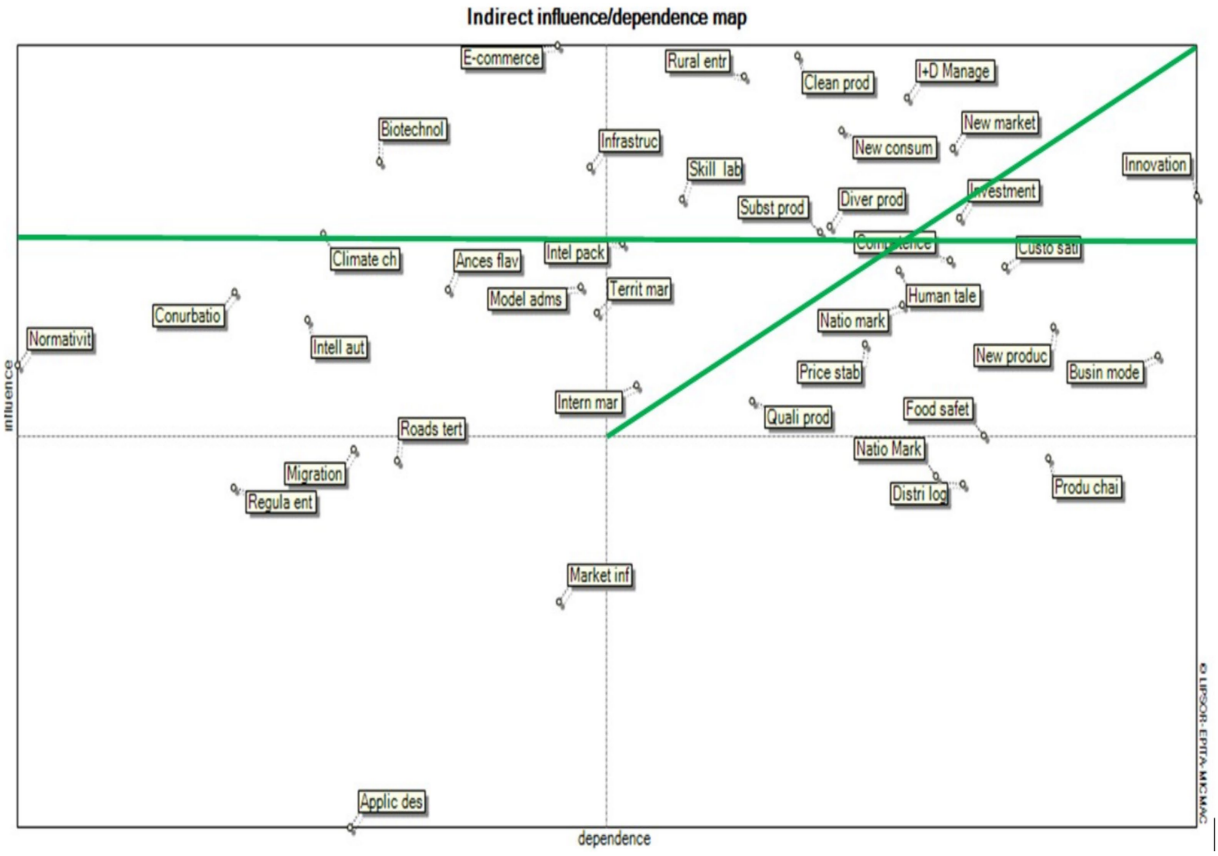

FIGURE 4
Map of influence/indirect dependence—Dairy. Source: Own elaboration (2024).

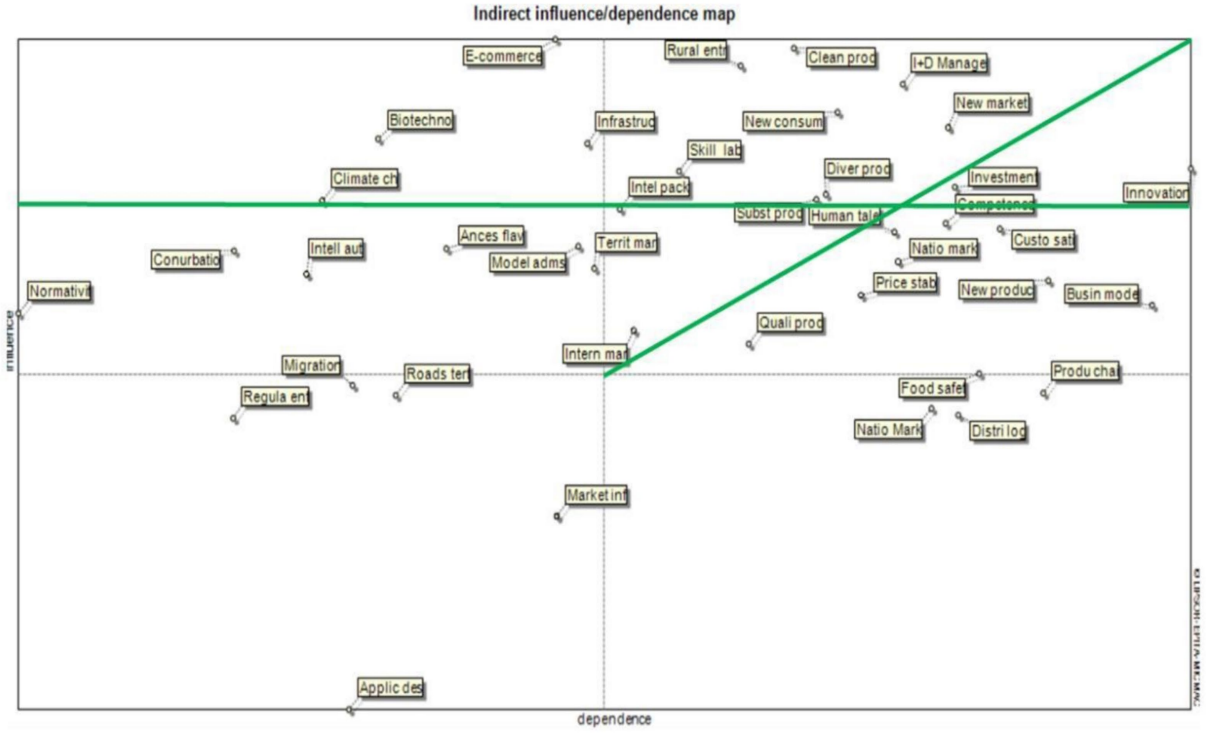

FIGURE 5
Map of potential direct influence/dependence—Dairy. Source: Own elaboration (2024).

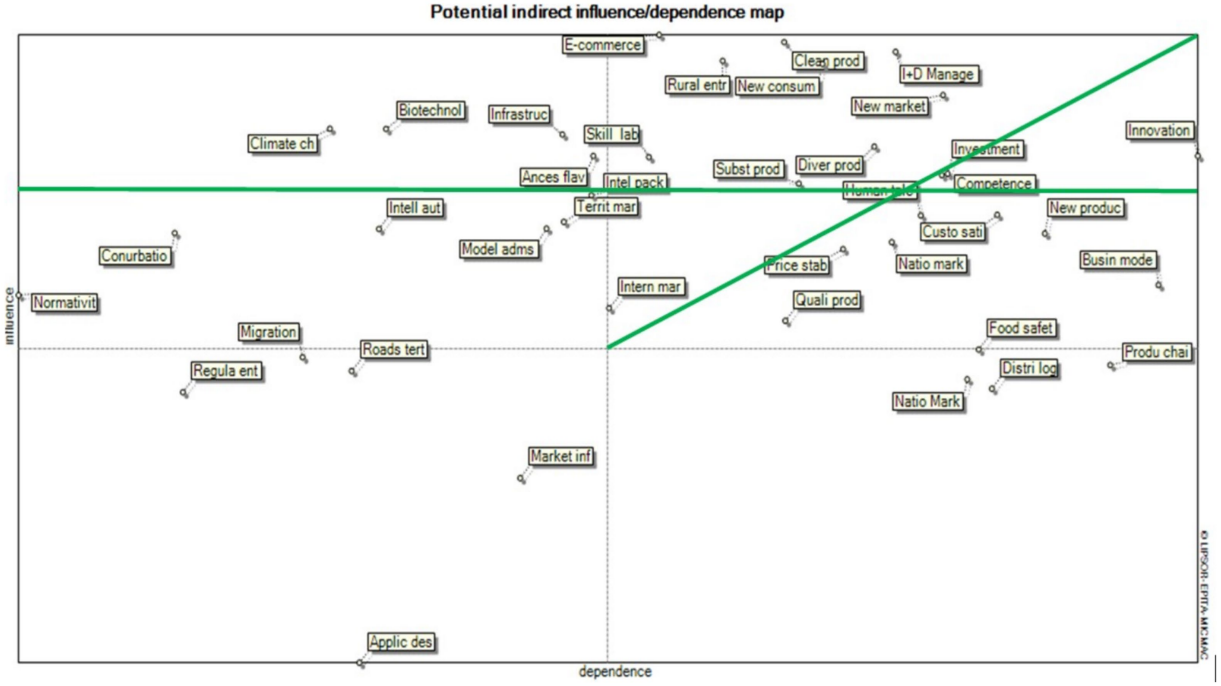

FIGURE 6
Map of potential indirect influence/dependency—Dairy. Source: Own elaboration (2024).

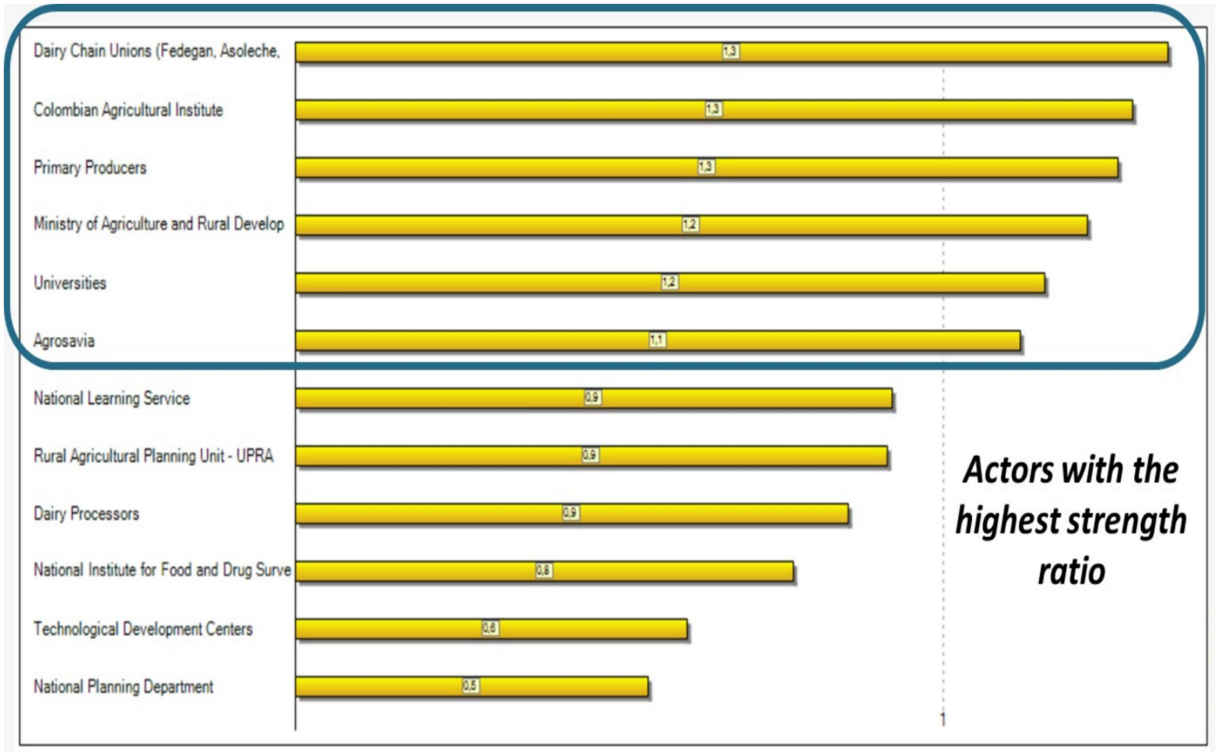

FIGURE 7
Histogram of MIDI strength ratios. Source: Own elaboration (2024).

TABLE 2 Description of hypotheses.

Hypothesis	Description
(BPG)	By 2035, between 40 and 45% of producers will be implementing technologies with good farming practices and sustainable livestock production
(R&D&I)	By 2035, the production chain will manage between 30 and 49% of its budget in R&D&I projects.
(Sustainable Livestock)	By 2035, between 40 and 59% of producers in the sustainable livestock chain will be integrated into solidarity economy organizations.
(Agroindust)	By the year 2035, between 40 and 59% of producers will implement agro-industrial processes, mechanization (automation), improvement of production processes, nutrition, genetics, and management, in cooperation with sources of bank loans, SENA, MADR, governor's office, mayor's office.

Source: Own elaboration (2024).

TABLE 3 Scenarios and probabilities.

Scenarios	Probability
01-1111	39.6%
16-0000	20.4%
05-1011	9.8%
03-1101	8.1%
02-1110	3.8%
Total	81.7%

Source: Own elaboration (2024).

FIGURE 8
Delphi first-round groupers. Source: Own elaboration (2024).

Discussion

A review of the literature and the results obtained from the research indicated that while there have been publications on the subject of dairy production, they have not addressed the topic in sufficient depth.

A search in the Scopus database using the search term TITLE-ABS-KEY ("dairy") W/1 foresight OR prospective criteria revealed that the published articles did not align with the criteria for dairy studies, specifically in terms of the prospective method by scenarios and the MD. Of the five articles identified, four are relevant to the topic of dairy, while the remaining article addresses a specific issue regarding the long-term efficacy of percutaneous tibial nerve stimulation (PTNS) in the treatment of fecal incontinence.

TABLE 4 Priority topics/technologies general in the two Delphi rounds.

General
Milk quality
Selection of cattle breeds with higher milk production
Energy efficiency in feeding
Energy efficiency in livestock irrigation
Sustainability
More sustainable practices in cattle feeding
Fatty acids
Lactose intolerance
Ultrasound
Heavy metals
Lipolysis
Protein
Adulteration
Fortification
Antioxidant activity
Cheese ripening
High performance liquid chromatography
Microbiota
Milk fat globule membrane
Reduced fat
Fatty acid composition
Food matrix
Environmental impact
Enzymes
Rheological properties
Food safety
Dietary intake
Casein extraction
Electromembrane filtration (EMF) technology for separation and concentration of proteins and protein peptides from whey
Ekonek PCD (Pulse Combustion Drying) technology more sustainable for the transformation of whey into powder
Medicinal products from dairy products
Impact of dairy products on public health

Source: Own elaboration (2024).

TABLE 5 Priority topics/technologies products and by products.

Products and by-products
Organic milk
Alternative milks—soy milk
Alternative milks—almond milk
Acid milks
Infant formulas
Cheese
Yogurt
Butter
Fermented dairy products
Fermented milk
Ice creams
Cheese yield
Whey derivatives—Whey protein isolate
Goat cheese
Buffalo milk
Dairy protein
Functional foods
Yogurt with probiotics
Blue cheese
Halloumi cheese
Obtaining bioethanol from whey
Whey protein concentrates
Emulsifiers

Source: Own elaboration (2024).

One of these investigations, that of Kowalski et al. (2017), sought to perform a retrospective and prospective comparative analysis of pharmacokinetics in cattle. Concurrently, Kurnia et al. (2015) conducted a survey of 25 goat farms with the objective of obtaining data and information, determining farming practices, and assessing goat performance and market prospects. Melvin and Baglee (2008) conducted a study on the applicability of value stream mapping (VSM) to the food and beverage industry, with a particular focus on a company that manufactures yogurt-based products. The objective was to identify areas of waste and to determine the most effective means of reducing and/or eliminating them from the value stream. In a final study, Kirk et al. (2002) investigated the prevalence of Salmonella spp. in wild birds commonly found in California dairies. To achieve this objective, the researchers captured seven selected bird species at nine dairies in Kings and Tulare counties, California.

In the Journal of Futures Studies (JFS), two articles were identified that addressed the concept of dairy and prospective analysis. One of the articles corresponds to the one carried out by Boonmavichit and Boossabong (2022), who investigated in Thailand and inquired as to the optimal approach for practicing foresight and the most appropriate framing for this approach. Previous studies have proposed empiricism, constructivism, post-structuralism, and pragmatism as the core approaches. Notably, critical realism appears to be overlooked, particularly regarding its pivotal concept of intransitive reality, which can be elucidated in both concrete and abstract terms. The absence of this approach is particularly significant in the Global South, where injustices and authoritarian control have a profound impact on the trajectory of societal development. This article illustrates the potential of critical realism by drawing lessons from foresight practice in Thailand.

A second article corresponds to the work carried out by Dolan (2020), who notes that prior to the establishment of the nation-state system, China had developed a highly systematic philosophy of social relations known as Confucianism. However, this research is not directly relevant to the object of research on the dairy agroindustrial chain and the prospective analysis.

TABLE 6 Priority topics/technologies ICTs in the two Delphi rounds.

ICTs
Geographic information system (GIS)
Image analysis
Computer vision
Image processing
Modeling
Data analysis
Life cycle assessment
Precision livestock farming
Artificial intelligence (AI)
Epidemiology
Information systems
Risk factors
Probiotics
Blockchain
Cloud computing
Decision trees
Digital agriculture
Use of sensors and drones to monitor plant growth and health
E-commerce
Electrical conductivity
Neural networks
Artificial insemination
Humidity sensors
Dairy species and breeds

Source: Own elaboration (2024).

TABLE 7 Priority topics/technologies to dairy species and breeds, genetics and others in the two Delphi rounds.

Dairy species and breeds
Feeding supply
Thermal stress
Nutritional composition of pasture
Technological innovations in the milking process
Hygienization
Quality assurance
Genetics
Genetic improvement of Colombian breeds
Genetic selection of high-production breeds
Selection assisted by molecular markers (SAM)
Synchronization and insemination techniques
Others
Pro-environmental agriculture
Breeding of pastures for dairy production
Implementation of smart packaging for dairy products
Development of food for children with growth delays

Source: Own elaboration (2024).

A second search, utilizing the TITLE-ABS-KEY ("open innovation") W/1 foresight OR prospective search criteria yielded a limited number of articles (six in total). One of the articles is a research paper by Liu and Hansen (2022) that provides a comprehensive description of the current practices of equipment and technology suppliers to the forestry sector in the United States in light of open innovation and the integration of corporate foresight (CF). The results demonstrated that the majority of the surveyed companies had not only implemented innovative practices but also engaged in ongoing innovation activities. Consequently, Liu and Hansen (2022) posit that a novel perspective is frequently essential for innovative value propositions, redefined market segments, reconfigured value chain structures, and repositioning of the firm's value network with stakeholders.

In a subsequent study, Calof et al. (2020) put forth an alternative approach to open innovation. The researchers demonstrated that the integration of concepts derived from foresight and foresight networks can facilitate the process. Foresight can facilitate open innovation by providing analysis that addresses key open innovation questions, such as those pertaining to technology selection, identifying future customer needs, and anticipating disruptions.

Conversely, Carayannis et al. (2017) conducted research on cutting-edge science, technology, and innovation (STI) policy concepts, open innovation, and foresight, which are of significant interest to researchers, scientists, and managers. The authors examined the dynamics and interactions of clusters with smart specialization and innovation strategies, as well as targeted open innovation and foresight networks within the context of entrepreneurship and innovation ecosystems.

In light of the aforementioned, the findings of this research demonstrate that the scenario and MDs, in conjunction with the comparative analysis of the 39 variables utilized and the consultation of experts from diverse sectors, align with a subject of study devoid of existing references within the context.

Boonmavichit and Boossabong (2022) inquire as to the optimal approach for practicing foresight and the most effective manner of framing this approach. Previous studies have proposed empiricism, constructivism, post-structuralism, and pragmatism as the core approaches. Notably absent from this discussion is critical realism, particularly its central tenet of intransitive reality, which can be elucidated in both concrete and abstract terms. The absence of this approach is particularly significant in the Global South, where injustices and authoritarian control have a profound impact on the trajectory of societal development. In order to demonstrate the potential of critical realism, this article presents insights derived from the application of foresight practices in Thailand.

In the dairy chain sector, prospective studies with MD are not usually abundant; on the contrary, they are scarce and, except for some specific elements, they are complementary. In Colombia, for example, there is only evidence of an investigation by Trujillo Cabezas et al. (2007), who carried out a study on prospective and technological surveillance and competitive intelligence, especially designed to outline the research agendas of different agro-industrial production chains within the framework of the National Prospective Program, launched since 2003 thanks to the cooperation and financing of Colciencias, the National Learning Service (SENA), the Ministry of Commerce, Industry and Tourism and the Andean Development Corporation, with the purpose of developing national capacities for prospective and technological surveillance.

Within the framework of this work, the authors developed a conceptual and methodological frame of reference for the technological prospecting of the Colombian dairy chain, reflected in the definition of a research agenda that facilitates the competitive performance of this chain.

The main aspects that influence the dairy chain from a logistical point of view, according to these authors, have to do with the handling, transportation and industrialization of products.

Although one of the strengths of the dairy chain is the consolidation of dairy cooperatives, which are estimated to represent more than half of the milk collected in the country, asymmetries remain in the processing industries, where the gap between informal and artisanal companies and large companies is evident. Despite the efforts in terms of Technical Assistance and Technology Transfer, it is necessary to consolidate joint strategies that promote a solid institutionality that leads to the development and transfer of technology.

After this analysis, and the comparison with other research, including those cited in this section, the findings found are relevant for prospective studies.

Conclusion

According to the application of the MD to two rounds, in the general grouping, the topics of greatest relevance and highest percentage of consensus for the dairy agro-industrial chain were 34, among which milk quality; environmental impact; enzymes; food safety; and proteins stand out. While in the products and by-products grouping there were 23, among which fermented dairy products, fermented milk, functional foods, whey derivatives and organic milk stand out.

On the other hand, for the ICTs grouping there were 24, among which geographic information systems, image analysis, computer vision, artificial insemination, and e-commerce stand out.

In the dairy species and breeds, genetics and others groupings there were 14 in total and the topics that were priorities in both rounds in dairy species and breeds were two, namely: hygiene and quality assurance. In the others grouping, they were pro-environmental agriculture, smart packaging and food for children with growth delays, while for genetics, only three topics were priorities in both rounds: generic breed improvement, genetic selection of high-production breeds and synchronization and insemination techniques.

As for the scenario methodology, 17 key variables were obtained that were grouped into four axes: good livestock practices, R&D&I, sustainability and agroindustrial, obtaining a bet scenario with 39.6% probability. This scenario includes two long-term objectives related to sustainable specialization of fodder production and mass production and standardization in collection centers. It also includes a description of the actors with the greatest power ratio by 2035.

This possible, probable and desirable scenario must be aligned with the priority Technologies and Innovations topics in the two Delphin rounds as well as the invariants, trends and other factors of change that may occur in the 2024–2035 timeline.

This prospective study was conducted in alignment with the perspectives and objectives of key actors in the dairy agribusiness chain in the Quindío region of Colombia. The scenario forecast analysis, conducted using the MICMAC and MACTOR methodologies, enabled the establishment of the most probable and desirable scenario in relation to the co-occurrence of the four hypotheses proposed as a betting scenario regarding Good Farming Practices (GFP), R&D&I projects, sustainable livestock, and agribusiness processes.

The scenarios and probabilities indicate that by 2035, between 40 and 45% of livestock producers in the Department of Quindío will implement technologies with good livestock farming practices and achieve sustainable livestock farming.

The production chain will allocate between 30 and 49% of its budget to research and development and innovation (R&D&I) projects. Additionally, it is estimated that between 40 and 59% of producers in the sustainable dairy farming chain will be integrated into solidarity economy organizations. Moreover, between 40 and 59% of dairy producers will implement a range of industrial processes, including mechanization (automation), improvements to the production process, nutrition, genetics, and management. This will be done in collaboration with sources of bank loans and support from SENA, the MADR, the Quindío Government, and the municipalities.

The results of the scenario methodology and the MD (with two rounds of application in the study) indicate that the strategies and projects to be carried out in the department of Quindío-Colombia over the next few years should be developed collectively in order to achieve the desired outcome. In light of these considerations, it is recommended that specific projects be implemented, with the support of studies on technologies and innovations that have been identified as priorities in the Delphi process. Furthermore, these studies should also consider supplementary aspects pertaining to market, competitive, and supplier surveillance.

The scenarios generated should be reviewed at regular intervals of one or two years, given the potential for new realities to emerge in the form of volatility, uncertainty, complexity, and short innovation cycles. Such Changes may result in alterations to the variables or the introduction of new factors that should be considered through their influence on the original MICMAC, the MACTOR method or the development of new hypotheses. Such revisions can be implemented through collective construction workshops, as exemplified by those conducted during the course of this project.

It is of the utmost importance to cultivate alliances with the most influential stakeholders and those who will be stakeholders in 2035. This will facilitate the implementation of initiatives and projects by stakeholders in the dairy agro-production chain, to achieve the indicators proposed in the proposed scenario. It is of the utmost importance to develop public policy spaces and mechanisms (public–private partnerships) as well as budget allocations that ensure compliance with the indicators of the proposed scenario.

Limitations

The proposed methodology is based on the alignment of methods, techniques and tools of prospective schools or approaches through scenarios and consultation with stakeholders—Delphi method. It is not in itself a methodology or forecasting model. It is based on several premises of prospective studies, among which it is highlighted that the future is a collective construction. The aim is to give an image of the future that is possible, probable and with a certain degree of desirability, in order to invite appropriation, anticipate decisions and generate actions to collectively build the future. It is not about predicting events, trends or technologies, it is an invitation to reflect on a future and a

betting scenario in which it is expected that the decision makers of the studied agro-industrial chain will collectively build their future through the inputs presented in scenarios and the MD.

In accordance with the above, for future studies it is recommended to increase the number of international experts with extensive knowledge and experience in the dairy chain, as well as to generate new spaces for updating the MICMAC variables and the ranges of indicators of the hypotheses, the same happens with the emergence of new emerging technologies that could be adopted by the actors in the sector.

Recommendations

It is recommended that municipalities in the Quindío region establish spaces for ideation and coworking (through boot camps and entrepreneurship marathons) around the priority themes, technologies, and innovations identified through the PESTAL format. Such spaces should facilitate the generation of solutions or new ventures, including startups, that can become new actors in the regional innovation system.

Likewise, it is necessary to develop research and development, innovation and training programs based on the winning technologies and innovations identified in the two Delphi rounds and the new priority topics identified in the second Delphi round of the dairy production chain. In addition, workshops and brainstorming sessions should be held to apply the concepts of nano, bio, info, cogno and green convergence, thus generating incremental innovations within the dairy chain. This could serve as the genesis of technological innovations that present convergent characteristics, which could be the subject of future analysis in the context of the development of the Department of Quindío-Colombia.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

JSo: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. AM: Formal analysis, Writing – review & editing. NP: Formal analysis, Writing – review & editing. LM: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. JP: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. GM: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. JSa: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. LG: Formal analysis, Writing – review & editing. CL: Writing – review & editing.

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Conflict of interest

AM and NP were employed by Alexander Von Humboldt University Corporation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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