sciendo

PRODUCTION ENGINEERING ARCHIVES 2024, 30(4), 431-441

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exists since 4th quarter 2013
Available online at https://pea-journal.eu



Unveiling Critical Innovation Factors in Sustainable Coffee Production: A Colombian Perspective

Eyder James Ramirez-Zuñiga[1*], Hugo Fernando Castro-Silva[2], Torcoroma Velásquez-Pérez[3], Ehidy Karime Garcia-Cruz[4]

[1] Universidad EAN, doctorado en ingeniería de procesos. Calle 79 11 45, Bogotá, Colombia; eramire17896@universidadean.edu.co
[2] Universidad Pedagógica y Tecnológica de Colombia, Escuela de Ingeniería Industrial. Grupo de Investigación GITYD. Calle 4 A Sur No. 15-134, Sogamoso, Boyacá, Colombia; hugofernando.castro@uptc.edu.co
[3] Universidad Francisco de Paula Santander Ocaña, Grupo de Investigación GITYD. Vía Acolsure, Sede el Algodonal Ocaña. Colombia; tvelasquezp@ufpso.edu.co
[4] Universidad Pedagógica y Tecnológica de Colombia, Calle 4 A Sur No. 15-134, Sogamoso, Boyacá, Colombia; ehidy.garcia@uptc.edu.co
*Correspondence: hugofernando.castro@uptc.edu.co

Article history
Received 10.06.2024
Accepted 16.09.2024
Available online 18.11.2024

Keywords
Innovation,
Agribusiness innovation,
Innovation factors,
Coffee production,
Sustentable production.

Abstract
The coffee sector stands as a cornerstone of Colombia's economy, ranking third in the nation's export portfolio. Despite the Colombian coffee esteemed global reputation, it has yet to fully exploit its potential for diversification into differentiated products. Present agro-industrial paradigms emphasize trade and sustainable, efficient agricultural practices, underscoring the imperative for innovation across production, marketing, and distribution channels. This study aims to pinpoint the pivotal innovation factors within coffee farm production processes. To this end, a sample of 66 coffee farms was selected through simple random sampling. Drawing from the 2018 Oslo model, innovation types associated with sustainable specialty coffee certifications were delineated. Within this framework, seven fundamental factors emerged for investigation: economic, social, environmental, production, knowledge, technology, and change management. Through cluster analysis, it became evident that economic, environmental, knowledge, technological, and change management factors are indispensable for fortifying the coffee industry.

DOI: 10.30657/pea.2024.30.41

1. Introduction

In 2021, global coffee exports amounted to approximately USD 29.2 billion, with Colombia's marketing sales reaching USD 3.2 billion, positioning it as the third-largest exporter of the commodity (Workman, 2022). As depicted in Figure 1, Colombia holds a privileged position in this market, contributing 11% to the total sales, trailing behind only Brazil and Switzerland. It is important to note that Switzerland's business model involves product transformation before exportation.

Highlighting the significance of coffee in Colombia's export landscape, it holds the third position among traditional exports, trailing only petroleum and its derivatives, and coal. In February 2023 alone, coffee sales amounted to approximately USD 250 million (DANE, 2023). Figure 2 showcases the nation's key exports, underscoring the pivotal role played by coffee in the economy. This agricultural commodity not only generates substantial dividends through its marketing but also serves as a catalyst for development across various regions of Colombia.

Coffee is the primary economic product of the Huila region in Colombia. The agricultural activities associated with coffee cultivation support approximately 84,000 rural families. These families collectively cultivate 145,741 hectares of Arabica coffee, encompassing the varieties Castillo, Colombia, Caturra, Typica, Bourbon, and Tabí. The region's annual coffee production amounts to 2.0 million 60-kilogram bags (FNC, 2019).

© 2024 Author(s). This is an open access article licensed under the Creative Commons Attribution (CC BY) License (https://creativecommons.org/licenses/by/ 4.0/).

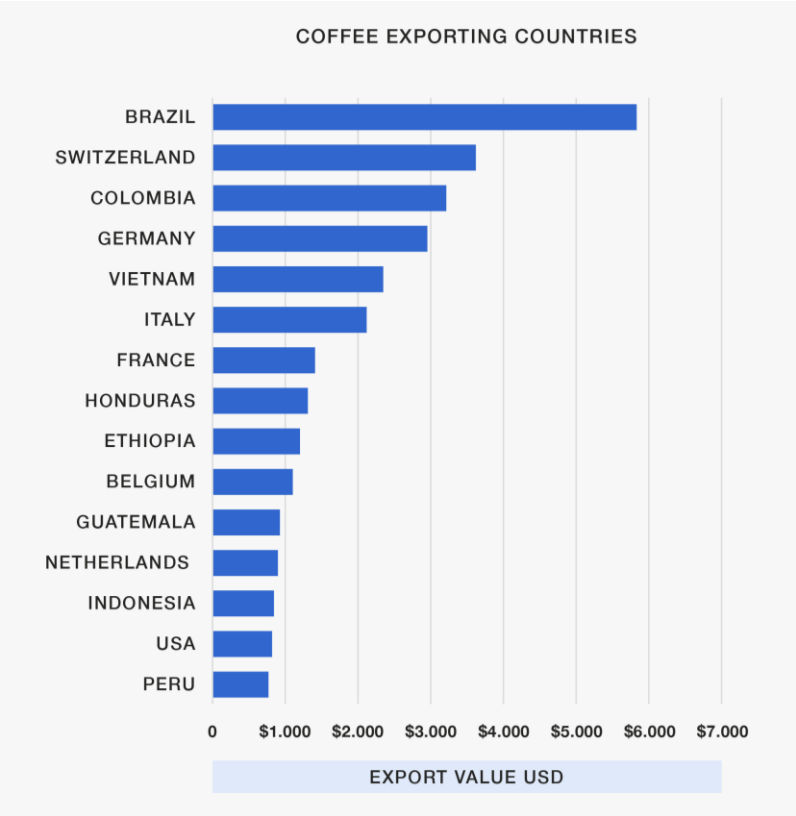


Fig. 1. Global coffee exports in 2021. Adapted from Workman (2022)

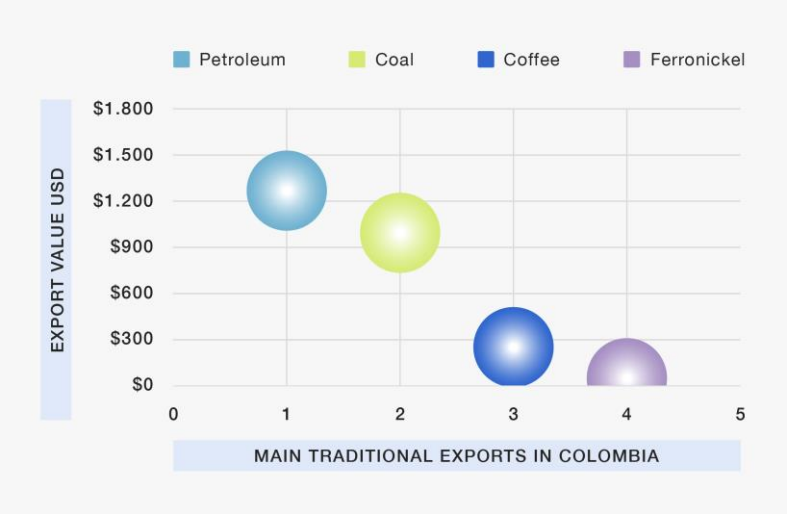


Fig. 2. Traditional Exports in Colombia in February 2023. Adapted from DANE (2023)

The research conducted by Ramírez and García (2020) indicates that there is a diverse range of coffee growers whose incomes are directly linked to the quality of the coffee they offer in the market. However, it has been observed that the quality attributes of coffee are not clearly defined in many instances. These specific conditions in the coffee production process in Colombia highlight the critical need to identify key innovation factors that can improve the coffee supply chain.

Within this context, Rivera et al. (2020) indicate that innovation tends to enhance production processes by making them more appealing and presentable, facilitating change, and introducing novelties to achieve established goals. Furthermore, Isa et al. (2019) note that process innovation aims to reduce production costs, generate environmental benefits, and improve business competitiveness.

Innovation in agricultural production processes has the potential to revolutionize the way we cultivate and harvest, aligning with increased productivity and cost reduction (AIA, 2020). In terms of sustainability, innovation is essential to boost productivity and lower costs by enhancing the efficiency of production factors.

Innovation in sustainable coffee production processes at the farm level represents a crucial yet underexplored area of research (Panhuysen and Pierrot, 2020). This study addresses this gap by developing an innovation model based on fair trade standards, focusing on the base of the coffee value chain. The methodology, which includes a validated questionnaire applied to a representative sample of coffee growers, offers a novel approach to improving sustainability and equity in production (Samper et al., 2017).

The research not only contributes new knowledge in a field with scarce literature but also proposes scalable and replicable solutions, potentially applicable to other producing regions and crops (Hernandez-Aguilera et al., 2022). This innovative approach at the production base has the potential to generate significant impacts throughout the entire coffee value chain, addressing critical sustainability and fair trade challenges from their origin (Vicol et al., 2023).

Other purpose of research is to identify key innovation factors in the production and marketing processes of coffee, enabling the categorization of production units as either innovative or non-innovative. This analysis will provide critical insights for differentiated product marketing processes, considering a market focused on sustainability and equitable pricing in the coffee sector. The findings of this research are also significant given the absence of similar studies specifically within the coffee production and marketing sector. As presented in the following section of this article, background studies on critical innovation factors in agro-industrial sectors other than coffee and in countries other than Colombia are provided.

The results of this research will be valuable to government entities in planning action lines to improve the coffee supply chain from production to marketing stages. Additionally, government entities could identify areas for improvement in the links of production and supply chain, aiming to ensure productivity and sustainability of production units, thus enhancing the competitiveness of coffee on a global scale.

2. Literature review

Specialty sustainable coffee continues to be a topic of great interest in the global coffee industry, encompassing aspects of quality, environmental sustainability, and social responsibility. This review synthesizes the most recent key findings in this field.

Recent research has reinforced the positive relationship between sustainable farming practices and coffee quality. According to Sepúlveda et al. (2016), agroecological practices, such as shade management and crop diversification, not only improve environmental sustainability but can also enhance the sensory quality of coffee. This finding underscores the importance of sustainable practices not only for the environment but also for the quality of the final product.

Coffee agroforestry systems continue to be crucial for biodiversity conservation and climate change mitigation. Jezeer et al. (2019) found that coffee agroforestry systems can sequester significant amounts of carbon, comparable to secondary forests in some regions. Additionally, these systems have demonstrated greater resilience to climate changes.

The socioeconomic impact of sustainable specialty coffee production remains a topic of debate. Meemken et al. (2019) observed that while fair trade and organic certifications can increase the prices received by farmers, the impact on net incomes is often limited due to associated costs. This underscores the need for a holistic approach in evaluating the benefits of sustainable practices.

The impact of certifications remains an important area of research. A meta-analysis by Oya et al. (2018) concluded that the effect of agricultural certifications on farmers' incomes and environmental outcomes is positive but small. However, DeFries et al. (2020) argue that certifications can have impacts beyond income, including improvements in organizational capacity and access to support networks.

Innovations in coffee processing are gaining attention in the specialty coffee sector. According to Shen et al. (2023), controlled fermentation techniques are emerging as a powerful tool to modulate the flavor profile of coffee, allowing producers to create unique and high-quality profiles. These innovations are changing the way specialty coffee is produced and perceived.

Open innovation in sustainable coffee production is at a turning point, where the intersection of sustainability and technology offers unprecedented opportunities. The triple bottom line framework highlights the importance of balancing environmental, social, and economic aspects in the manufacturing industry (Tiuncika and Bormane, 2024), while innovation champions play a crucial role in the successful implementation of sustainable development projects (Kamal and Hassan, 2024).

In this context, the article by Kuzior et al. (2023) emphasizes the transformative role of artificial intelligence (AI) in open innovation. The integration of AI into open innovation processes not only provides new perspectives for managing innovation but also presents opportunities to address sustainability challenges in coffee production more efficiently and effectively, potentially revolutionizing how environmental, social, and economic aspects are addressed in the coffee industry.

Table 1 presents a comprehensive review of literature related to innovations in sustainable specialty coffee. It showcases various findings and results from numerous studies, all aimed at enhancing the quality and sustainability of coffee production, with the goal of securing fair prices for coffee growers.

Table 1. Analysis to identify the innovation in the process of coffee

Author	Findings	Results
Nur et al. (2023)	Sustainable coffee cultivation practices for quality specialty coffee production Emphasis on agronomical measures for enriching high-value specialty coffee	Sustainable coffee cultivation practices for high-quality specialty coffee production Emphasis on agronomical measures for coffee farmers in Indonesia
Hadi et al. (2022)	Key dimensions: coffee consumption, sustainable supply chain, environmental sustainability Further research: green coffee beans, specialty or fine coffee.	Identified key dimensions for future research in coffee agro-industry sustainability. Highlighted areas for further research, including coffee consumption and environmental sustainability.
Laili, et al. (2022)	K-means clustering. Identified five treatment clusters based on BOD and Acidity levels.	Developed a coffee wastewater treatment system using K-means clustering.
Mancini et al. (2022)	Diversification in coffee systems positively impacts sustainability dimensions. Interdisciplinary approach needed for comprehensive assessment of diversification impacts.	Indicators used to quantify the impact of diversification on sustainability dimensions: ecosystem services, biodiversity, input use, socio-economic sustainability, and resilience capacity. Diversification in coffee agroforestry systems has a positive impact on sustainability dimensions.
Proenca et al. (2021)	Delta Cafés shows sustainable business methods in coffee supply chain. Case study confirms leadership in sustainability practices and innovation.	Delta Cafés is a business leader in innovation and sustainability practices. The company focuses on sustainable supply chain management and green purchasing policies.
Peluso (2023)	Coffee by-products create economic value through sustainable practices. Coffee industry shifts towards renewable energy sources for cost-saving.	Coffee by-products create economic opportunities through sustainability and innovation. Coffee industry shifts towards renewable energy sources and functional food ingredients.

The research on sustainable specialty coffee encompasses a wide range of aspects, from production to marketing, emphasizing innovation and sustainability throughout the value chain. Studies such as those by Nur et al. (2023) and Hadi et al. (2022) highlight the importance of sustainable cultivation practices for producing high-quality specialty coffee, while Laili et al. (2022) and Peluso (2023) focus on innovations in processing, such as wastewater treatment and by-product utilization. Diversification in coffee systems, according to Mancini et al. (2022), positively impacts multiple sustainability dimensions, including ecosystem services and socioeconomic resilience. Proenca et al. (2021) underscore the importance of sustainable business methods and green purchasing policies in the supply chain. These studies collectively point to a trend towards more holistic and interdisciplinary approaches in sustainable coffee research, addressing environmental, economic, and social aspects in an integrated manner. Innovation emerges as a key factor in improving sustainability and quality in the specialty coffee industry, from cultivation to the end consumer.

3. Experimental

The focus of this research is on identifying critical factors for sustainable coffee production in Colombia, with a focus on various types of innovation outlined in the Oslo Manual (OECD - Oslo Manual, 2018). Special attention is placed on improving business processes (IPN), aiming to identify the factors driving innovation in these processes. Once these factors are identified, the selection of specialty coffee types proceeds, which, according to the National Federation of Coffee Growers (FNC, 2019), is linked to aspects such as social category, origin, and sustainability. It is noteworthy to mention what Samper and Quiñonez (2017) emphasized regarding the importance of sustainable specialty coffee, which represents approximately 15% of the Colombian market. This figure justifies the specific focus of this research on this particular type of coffee.

The methodological design of the research addressed, in one of its early phases, the analysis of the fundamental criteria used to grant the most prominent sustainable coffee certifications in the literature. These certifications are linked to the 4C code of conduct (2018), Starbucks practices (2016), Rainforest Alliance (2023), Fairtrade (2019), and IFOAM organic certifications (2019). Through this analysis, common factors among these certifications were identified, as well as the most significant process innovation variables.

Once the types of innovation, specialty coffee varieties, and innovation variables in the production and marketing processes of specialty coffee are established, the design of the data collection instrument through surveys proceeds. These surveys are divided into two parts: the first focuses on the socio-economic environment, while the second addresses the identified innovation factors, such as economic, social, environmental, production, knowledge, technology, and change management aspects. The questions are related to variables in the context of international norms that govern fair pricing and sustainable products worldwide, they are formulated in a closed-ended ordinal level format, where respondents must indicate their level of agreement on a four-level scale: 1) Completely disagree; 2) Disagree; 3) Agree; and 4) Completely agree.

The validation of the instrument was conducted through expert judgment, leveraging the knowledge and experience of highly qualified individuals in the specific area of innovation in agro-industrial processes. These experts evaluated the validity and reliability of the information collection instrument, following the methodology established by Polit and Beck (2017). Furthermore, a pilot test was performed with 10 farm owners to run the instrument and gather feedback about the clarity of questions, grammar, and coherence. Once with the information collected, the Cronbach's reliability indicator was calculated, yielding a result of 0.97, which, according to the University of California UCLA (2016), allows us to conclude that there is consistency in the data generated with the application of the information collection instrument used in this research.

After confirming the reliability and consistency of the data collection instrument, the data collection process was carried out on coffee farms or production units located in two sectors of the Huila region, situated in Colombia's coffee-growing zone. These locations were selected for their abundance of human resources and short distances between farms, facilitating effective data collection. To establish the sampling framework, data from Colombia's national agricultural census (DANE, 2014) were utilized, identifying 169 farm owners and 44 owners of coffee-producing farms in each of the study areas, resulting in a population size of 213 owners of coffee production units.

In this study, a simple random sampling (SRS) design was employed due to the fundamental characteristic shared by the selected farms, which is coffee production. In simple random sampling, every element of the population has an equal probability of being selected to form part of the sample (Rahi, 2017). To determine the sample size, Equation 1 was applied:

$$n = \frac{N\left(Z_{\alpha/2}\right)^2 p(1-p)}{(N-1)e^2 + \left(Z_{\alpha/2}\right)^2 p(1-p)} \quad (1)$$

Where:
N= Total number of farm owners = 213
Z= = Confidence level, 95% = 1.96
ϭ (p,q)= Proportion value= 50%
e= Error =10%.

Applying Equation 1 for simple random sampling (SRS), it was determined that the representative sample size is 66 coffee-producing farms. The data collection instrument, designed based on literature review and international certification models of sustainable trade applicable to the coffee production and marketing sector, was implemented in these farms. It is worth mentioning that data collection was performed in October 2023.

The dataset collected through the information collection instrument was analyzed using a clustering method via the software R. The objective of this analysis is to identify critical innovation factors that can drive increased productivity in

coffee-producing farms through the marketing of sustainable coffee.

Figure 3 illustrates the methodological design of this research, aiming to identify critical innovation factors that distinguish innovative coffee-producing farms from those considered non-innovative. These innovation criteria should align with the types of innovation outlined in the Oslo Manual (OECD - Oslo Manual, 2018) and with certifications for sustainable coffee marketing, ensuring compliance with quality standards demanded by consumers and international certifications.

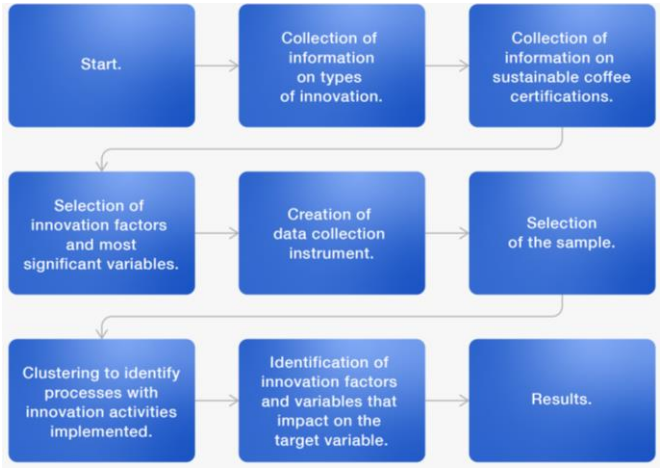


Fig. 3. Research methodological design

4. Results and discussion

When conducting the analysis to identify the type of innovation to be addressed in this research, the results presented in Table 1 are obtained, which depict the focus of various studies regarding types and variables of innovation. The Oslo Manual (OECD - Oslo Manual, 2018) has a significant influence on the referenced investigations in Table 2, as it serves as a leveraged point to identify innovation processes. Hence, the Oslo Manual is also utilized as the theoretical foundation for this research.

Table 2. Analysis to identify the type of innovation

Autor	Variables of innovation
Lambrecht et al., (2014)	Product, process and organizational marketing innovation.
Kalay and Lynn, (2015)	Innovation strategy, organizational structure, innovation culture, technological capacity and customer-supplier relationship.
Rajapathirana and Hui, (2017)	Innovation activity, innovation capacity, innovation performance.
Oliva, F., Et al., (2019)	Innovation and its typology, innovation and innovation determinant sectors and knowledge management.
Dorjsuren (2019)	Product, process, organizational and market innovation.

Table 3 identify the primary sustainable coffee certifications cited in various coffee-specific studies. The literature review conducted in this research reveals that the certifications with the greatest impact on the sustainable specialty coffee sector are: 1) 4C Code of Conduct, 2) Fair Trade, 3) Organic (IFOAM), 4) Rainforest Alliance, and 5) Starbucks Practices.

Table 3. Identification of sustainable coffee certifications

Autor/ Research names	Most important certifications for sustainable coffee
Farfán, et al. (2007) - Coffee production systems in Colombia	Bird Friendly Coffee Organic - IFOAM Fairtrade - Fairtrade Starbucks C.A.F.E. Practices Rainforest Alliance
Biswas-Tortajada and Biswas (2015) - Sustainability in coffee production: Creating shared value chain in Colombia.	Rainforest Alliance Fairtrade - Fairtrade 4C Code of Conduct (Collaboration, Control, Communication and Commitment) Nestle Practices Rainforest Alliance
Echavarría, et al. (2016) - Water Resource Management Manual	Fairtrade - Fairtrade Bird-friendly - SMBC Nespresso ecollaboration Organic product - IFOAM Rainforest alliance Starbucks C.A.F.E. Practices
Levy, et al. (2016) - The dynamic politics of sustainable coffee: contested value regimes and the transformation of sustainability.	4C Code of Conduct Fairtrade - Fairtrade Nespresso AAA Starbucks C.A.F.E. Practices Organic - IFOAM Rainforest alliance
Frohmann, (2017) - Sustainability standards and producer participation.	4C Code of Conduct (Collaboration, Control, Communication and Commitment) Fair Trade - Fair Trade Nespresso AAA Organic - IFOAM Rain Forest alliance
Wahyudi, et al. (2020) - Sustainability certifications as a pillar to promote Indonesian coffee competitiveness.	4C Code of Conduct Fair Trade - Fairtrade Organic - IFOAM Rainforest alliance
Bager, et al. (2022) - Blockchain is not a silver bullet for sustainability in the agri-food supply chain: Insights from a coffee case study	4C Code of Conduct Fairtrade - Fairtrade Organic - IFOAM Rainforest alliance
Barreto, et al. (2022) - Sustainability issues in the coffee chain: From field to cup.	4C Code of Conduct Fair Trade - Fair Trade Organic - IFOAM Rainforest alliance

Having identified the type of innovation and the pertinent innovation factors in the coffee production and commercialization sector, we have determined 54 innovation variables for classifying innovative farms in Colombia. However, the variables X5, X11, X20, X28, X44, X49 and X55 has not been considered because they are confirmatory variables in each factor, and the information is not relevant. As shown in Table 4. Additionally, Table 3 lists the seven (7) innovation factors

associated with sustainable coffee production and commercialization processes, each with its respective innovation variables.

Table 4. Identification of innovation factors and their respective variables

Factors	Variables	Certifications
Economic - F1	X1- Long-term profitability and productivity X2- Record keeping. Market and trade information X3- Market and trade information X4- Traceability of product quality	Conduct 4C Starbucks C.A.F.E. Practices Rainforest alliance Fair trade
Social – F2	X6- Free from discrimination X7- Free of forced and compulsory labor X8- Child labor and child protection X9- Freedom of association and collective bargaining X10- Conditions of employment	Starbucks C.A.F.E. Practices Rainforest alliance Fair trade IFOAM
Environmental - F3	X12- Biodiversity conservation X13- Plant health management X14- Soil conservation X15- Soil fertility and nutrient management - Organic Matter X16- Water - Water sources X17- Water - Wastewater X18- Waste identification and management X19- Climate change management	Conduct 4C Starbucks C.A.F.E. Practices Rainforest alliance Fair trade IFOAM
Production - F4	X21- Planting and Rotation X22- Pruning and Tree Crop Renovation X23- Genetically Modified Organisms X24- Management of Agrochemicals X25- Management of production practices X26- Evaluation of conservation areas X27- Organic production	Conduct 4C. Starbucks C.A.F.E. Practices Rainforest alliance Fair trade IFOAM
Knowledge - F5	X29- Hazardous substances X30- Implementation of improvements to reduce risks from hazardous substances. X31- Soil erosion X32- Implementation of improvements to reduce soil erosion. X33- Fertilizer management X34- Implement improvements for proper disposal of fertilizers X35- Sustainable water use X35- Sustainable water use X36- Implementation of measures to improve water quality X37- Wastewater and risks to water quality. X37- Wastewater and health risks X38- Implement improvements for proper disposal of fertilizers. X38- Implementation of improvements to reduce wastewater risks. X39- Use of PPE X40- Implementation of improvements in the use of PPE X41- Use of Tools and machinery X41- Use of tools and machinery X42- Implementation of improvements in the use of tools and machinery X43- Emergency management X43- Emergency management	Conduct 4C Starbucks C.A.F.E. Practices Rainforest alliance Fair trade IFOAM
Technology - F6	X45- Management and monitoring X46- Energy X47- Digital Adoption X48- Digital platform	4C Behaviour Starbucks C.A.F.E. Practices Rainforest alliance Fair trade IFOAM
Change Management - F7	X50- Human resource management X51- Flexibility to change. X52- Resource leverage plans X53- Integrated process management X54- Internal inspection and self-assessment	Conduct 4C Starbucks C.A.F.E. Practices Rainforest alliance Fair trade IFOAM

After collecting data from the measurement instrument, a cluster analysis was performed to determine whether distinct groups of coffee-producing farms could be identified based on certain innovation variables presented in Table 3. The dendrogram in Figure 4 provides a graphical representation of hierarchical clustering algorithms, depicted as a tree-like structure defined by the database obtained through the research collection instrument (Labbé, et al., 2022). The hierarchical clustering represented by the dendrogram in Figure 4 clearly identifies two groups of coffee-producing farms: the first group consists of farms producing regular or conventional coffee, while the second group comprises farms producing specialty coffee.

Additionally, in Figure 4, it is evident that there are more branches around the farms that integrate differentiating factors into their production processes to generate specialty coffee. Moreover, it is noted that some farms producing regular or conventional coffee perform the entire production process necessary to generate differentiated coffee. Therefore, it is essential to identify the variables that influence innovation factors for a farm to produce specialty coffee with a focus on sustainability.

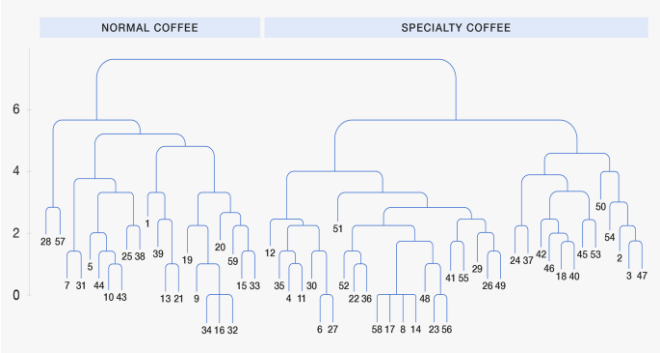


Fig. 4. Result of applying the hierarchical clustering algorithm

Using the database of innovation variables in coffee farms, generated from the information collected in this research, a cluster analysis was performed. The result of this cluster analysis is illustrated in Figure 5, where two clusters can be identified: the first is marked in red, and the second is highlighted in blue. The red cluster in Figure 5 consists of 35 out of the 66 coffee-producing farms that comprised the representative sample used in this research. The farms in the red cluster are characterized by a lack of innovation factors in their production processes, resulting in the production of conventional coffee.

In contrast, the blue cluster in Figure 5 consists of 31 out of the 66 coffee-producing farms in the representative sample of this study. The farms in the blue cluster are characterized by incorporating innovation factors into their production processes, thus enabling the production of specialty sustainable coffee.

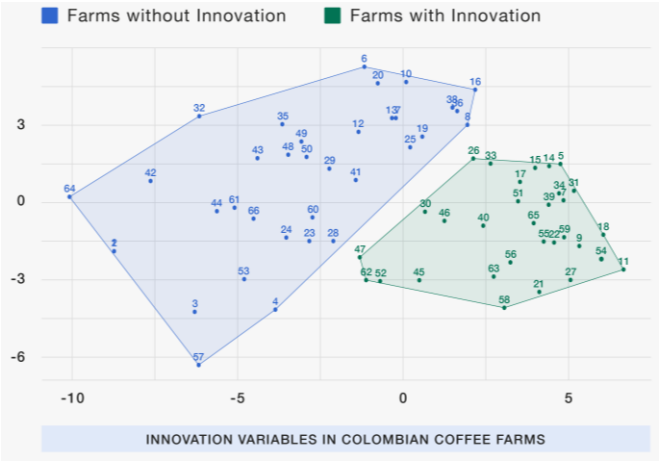


Fig. 5. Cluster analysis of coffee farms

Detailing the clustering analysis, Figure 6 is presented, where the innovation factors are compared between farms that incorporate innovation into their production processes and those that do not. Specifically, in Figure 6, the innovation factors associated with economic, social, environmental, production, knowledge, technology, and change management aspects are compared. The results represented in Figure 6 allow us to conclude that the critical innovation factors, which show the greatest distances, are as follows: 1) Knowledge (F1), 2) Environmental (F3), 3) Knowledge (F5), 4) Technology (F6), and 5) Change Management (F7).

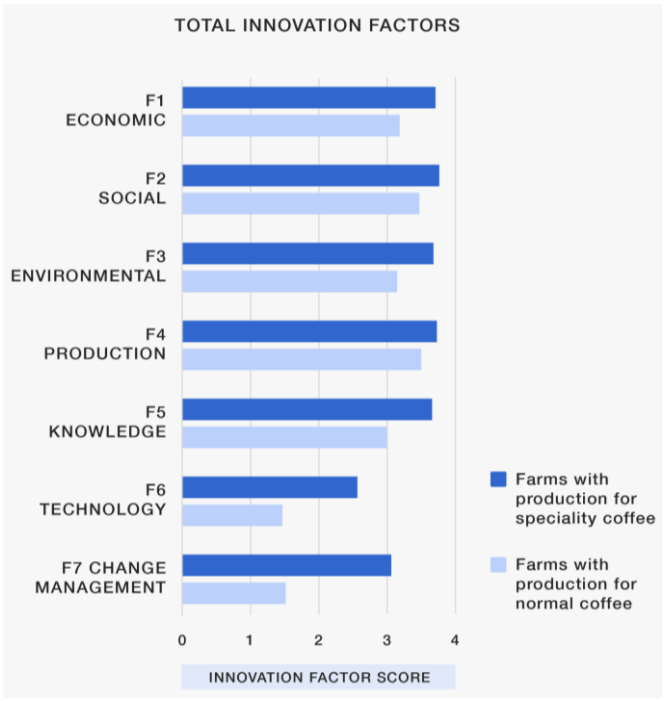


Fig. 6. Innovation factors in the production processes of coffee farms

Once the critical innovation factors were identified, as they allow differentiating between two clusters of coffee-producing farms, an analysis of the innovation variables within the economic and social factors was conducted. Figure 7 illustrates the distances of each innovation variable when comparing the two identified clusters of coffee-producing farms. As shown in Figure 7, within the economic factor, the variable X4 - Product Quality Traceability has the greatest impact, as there is a significant difference between the cluster of farms that have implemented innovation processes and those that have not. Additionally, the results presented in Figure 7 demonstrate that within the social factor, there are no variables with significant differences between the two clusters of coffee-producing farms.

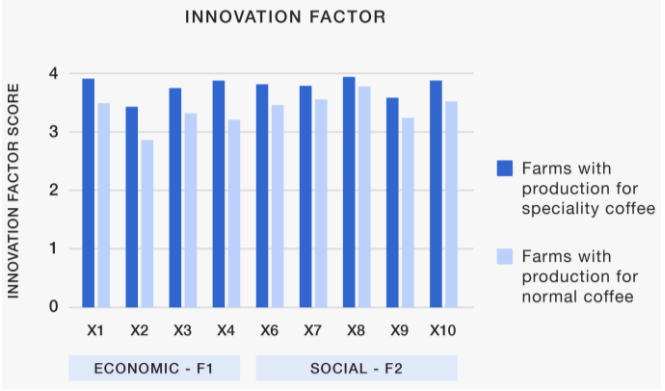


Fig. 7. Analysis of innovation variables in economic and social innovation factors

In Figure 8, the two clusters of coffee-producing units are compared according to the variables that compose the environmental and production innovation factors. As shown in Figure 8, the environmental innovation variables X13 (Plant Health Management), X18 (Waste Identification and Management), and X19 (Climate Change Management) have a significantly greater impact in the cluster composed of farms that implement innovation activities and produce specialty coffee, compared to the cluster of farms that do not implement innovation activities in their normal coffee production processes. It is important to highlight that the variables within the environmental innovation factor influence the processes of farms for the sustainable production of specialty coffee. In the analysis of the innovation variables within the production factor, no significant differences were found between the two clusters of coffee farms.

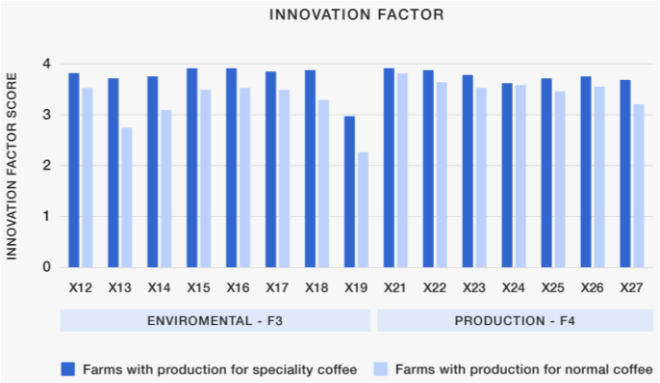


Fig. 8. Analysis of innovation variables in environmental innovation and production factors

When comparatively analyzing the behavior of the innovation variables within the knowledge factor, a significantly greater distance was identified in the variable X43 (Emergency Management) in the cluster composed of farms that implement innovation activities in their processes compared to the cluster of coffee farms that do not implement innovation activities, as shown in Figure 9. Therefore, emergency management constitutes a critical key element for farms to produce differentiated coffee that can be marketed at a fair price.

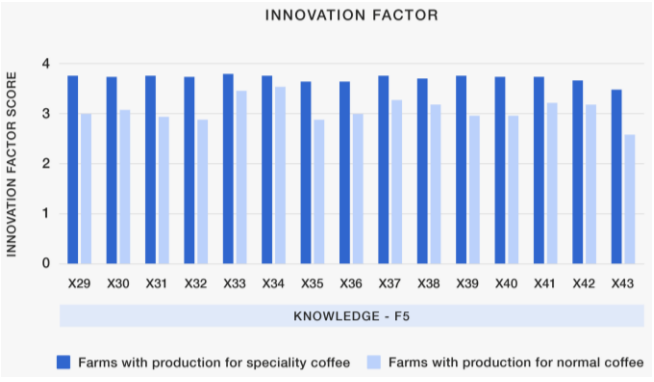


Fig. 9. Analysis of innovation variables in the knowledge innovation factor

When comparatively analyzing the behavior of the innovation variables within the technology and change management factors for the two clusters of coffee farms, Figure 10 demonstrates the findings. The analysis of the distances between each of these variables allowed the identification of significant differences in the variable X47 (Digital Adoption) of the technology innovation factor, and in the variables X50 (Human Resource Management), X51 (Change Flexibility), X52 (Resource Leverage Plans), X53 (Integrated Process Management), and X54 (Internal Inspection and Self-Assessment) of the change management innovation factor. The behavior of these variables is significantly higher in coffee-producing farms grouped in the cluster that implements innovation activities compared to the other cluster. Therefore, it is important to highlight the notable impact of these variables on the production processes of coffee farms to generate specialized coffee.

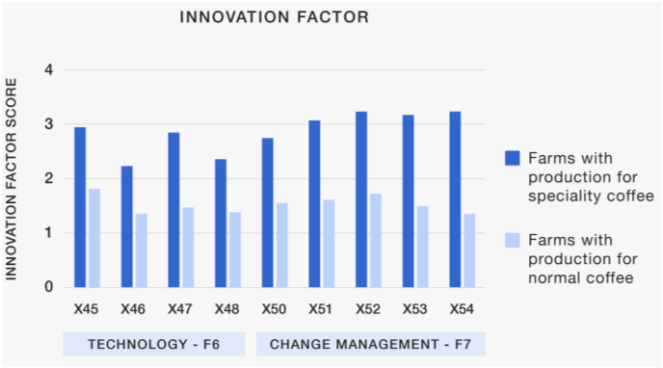


Fig. 10. Analysis of innovation variables of technology and change management factors

Table 5 presents a condensed summary, grouping variables that wield substantial influence within the innovation factors. Furthermore, these identified variables are categorized based on their type of innovation, whether common or uncommon, as per the classification outlined in the Oslo Manual (OECD - Oslo Manual, 2018). This study emphasizes variables that deviate from customary or routine production processes. Critical innovation factors have been pinpointed within economic, environmental, knowledge-based, technological, and change management realms. These factors are pivotal for propelling high-quality coffee production, in alignment with sustainability and fair trade principles.

The variables exerting the most substantial impact in terms of uncommon innovation are as follows:1) Product Traceability (X4); 2) Plant Health Management (X13); 3) Waste Identification and Management (X18); 4) Climate Change Adaptation (X19); 5) Emergency Management (X43); 6) Digital Technology Adoption (X47); 7) Human Resource Management (X50); 8) Change Flexibility (X51); 9) Resource Optimization (X52); 10)Integrated Process Management (X53); 11) Internal Self-Assessment (X54). This enumeration encapsulates the key variables driving uncommon innovation within the realm of coffee production.

Table 5. Common and uncommon innovation variables in coffee farms

Innovation factor	Common innovation variables	Non-common innovation variables
Economic – F1	X1,X2, X3	X4
Social – F2	X6, X8, X9, X10	-
Environmental – F3	X12, X14, X15, X16, X17	X13, X18, X19
Production – F4	X21, X22, X23, X24, X25, X26, X27	-
Knowledge – F5	X29, X30, X31, X32, X33, X34, X35, X36, X37, X38, X39, X40, X41, X42	X43
Technology – F6	X45, X46, X48	X47
Change management – F7	-	X50, X51, X52, X53, X54

The findings of this study reveal that critical innovation factors are tied to economic (F1), environmental (F3), knowledge (F5), technological (F6), and change management (F7) aspects. These components are considered foundational and should be effectively integrated into various coffee farm production processes to ensure the sustainable production of specialty coffee. Essentially, the appropriate adoption and implementation of practices addressing these key aspects foster product quality and differentiation, while also contributing to marketing strategies centered on fair pricing.

In the data clustering analysis, it is evident that out of the 66 farms examined, 31 demonstrate an innovative approach in their production processes, granting them the capability to produce high-quality specialty coffee. In contrast, the remaining 35 do not implement such innovations and produce standard quality coffee. This in-depth analysis reveals that farms opting for innovation in their processes exhibit a narrower gap concerning relevant factors. Consequently, this grants them a significant advantage in producing specialty coffee aligned with rigorous international fairtrade standards.

Upon meticulous examination of the dendrogram representing coffee farms, a conspicuous denser branching is evident within the sector associated with specialty coffee. This observation implies that farms opting to specialize in high-quality coffee production demonstrate remarkable coherence and proximity in their agricultural practices and processes. Such cohesion among specialized farms not only reinforces consistency in the final product's quality but also bolsters the sector's capacity to offer a differentiated and highly valued commodity in the international coffee market.

This analysis of clustering and dendrogram underscores the paramount significance of innovation and specialization in coffee production, particularly within a context where the global demand for quality and sustainable coffee is incessantly burgeoning. The discernment of these trends and patterns within the coffee industry furnishes invaluable insights for producers and market stakeholders, motivating them to embrace strategies that foster quality and sustainability.

Uncommon innovation variables play a pivotal role in driving enhancements in coffee farm production processes. These variables encompass facets such as product traceability (X4), plant health management (X13), waste identification and management (X18), climate change adaptation (X19), emergency management (X43), digital technology adoption (X47), human resource management (X50), change flexibility (X51), resource optimization plan implementation (X52), integrated process management (X53), and internal self-assessment (X54). The findings of this research suggest that these aspects are instrumental in the innovation factors for fostering specialty coffee production within a sustainable milieu in Colombia and other countries.

The focus of this study is grounded in the types of innovation delineated in the Oslo Manual (OECD - Oslo Manual, 2018), which have been correlated with the principal certifications of sustainable specialty coffee. Building upon this alignment, innovation factors sharing common characteristics, alongside the most significant variables, have been identified. The objective of this study was to ascertain the most pertinent innovation criteria for implementation in production processes, with the aim of augmenting differentiation within the coffee industry.

The functional processes intertwined with business innovation in the Oslo Manual (OECD - Oslo Manual, 2018) align with management and governance for economic (F1), environmental (F3), knowledge (F5), and change management (F7) factors, tethered to pivotal subcategories such as strategic direction and corporate governance. Furthermore, the functional category of information and communication systems is accentuated for the technology factor (F6), correlated with hardware and software subcategories—fundamental elements for enhancing production processes on coffee farms and engendering specialty coffee for equitable marketability.

It is important to emphasize that this research was focused on a single coffee-producing country. While this country is a major global coffee producer, it represents only a portion of the broader international landscape. The dynamics of innovation and sustainability may differ across coffee-producing nations, creating a significant opportunity for future studies to compare innovation practices across various countries.

Moreover, the research has the potential to inspire similar studies on innovation, as the methodologies and research approaches employed here can be adapted and applied in different contexts. This would contribute to the global understanding of sustainable and innovative practices in coffee production.

5. Summary and conclusion

This empirical study aims to identify critical innovation factors enabling coffee farms to specialize in sustainable coffee production. To accomplish this, it draws upon the innovation types outlined in the Oslo model, as well as common innovation factors and key variables from sustainability certifications such as the 4C code of conduct, Starbucks practices, Rainforest Alliance, Fairtrade, and IFOAM organic certifications.

Having identified the innovation types, factors, and variables associated with sustainable specialty coffee, data was collected through a measurement instrument. It was determined

that critical factors for implementing on a farm to produce specialty coffee are linked to economic (F1), environmental (F3), knowledge (F5), technological (F6), and change management (F7) aspects. These elements facilitate product marketing in a fair price environment and contribute to an increased production of specialty coffee.

A prospective avenue of research involves developing an innovation model that employs logistic regression to ascertain the impact of innovation factor variables on the likelihood of innovation in coffee farms when integrating these variables into their production processes. This could significantly elevate product quality in a unique and distinctive manner. The model development process may entail analyzing data using correlation methods such as "pairs" matching or a "heat map" to pinpoint the most influential innovation variables. Subsequently, a logistic regression model could be employed, with results parametrically analyzed to ensure compliance with necessary assumptions, thereby ensuring the reliability and robustness of the findings.

The authors advocate caution in generalizing the results, as the study utilized a representative sample of farms in Colombia's coffee region. For future research, it is recommended to apply this methodology to other regions and countries to enable comparisons and obtain a broader, more comprehensive perspective. This would enhance understanding of the specific dynamics within each context and identify potential variations in results, thereby enriching overall comprehension of innovation factors in the coffee industry.

Innovation factor variables impacting coffee farm production processes include product traceability (X4), plant health management (X13), waste identification and management (X18), climate change adaptation (X19), emergency management (X43), digital technology adoption (X47), human resource management (X50), change flexibility (X51), resource optimization plan implementation (X52), integrated process management (X53), and internal self-assessment (X54). Implementing these variables will facilitate the transition of coffee farms from regular to specialized coffee production, enhancing product quality, and facilitating its marketing to sustainability-focused customers.

The findings and outcomes of this study hold significant implications for governmental bodies within the coffee sector, as they can prioritize identified critical and differentiating innovation variables when formulating plans to enhance the efficiency, competitiveness, and productivity of coffee farms. This underscores the importance of innovation and specialization in coffee production, particularly in a global context where the demand for quality and sustainable coffee is steadily rising.

The research was developed with questionnaires based on international fair trade standards, offering globally applicable insights that contribute to knowledge about sustainable practices in the coffee industry and providing potential solutions for challenges in any milieu, with the adaptability to be adjusted for any region. Both the questionnaire and the methodology have been validated using Cronbach's reliability, achieving a result of 0.97, that shows its reliability, and the results will be adjusted to the reality of each environment. Additionally, the questionnaire can also be used for other agricultural products.

Reference

Agriculture Innovation Agenda AIA, 2020. https://www.usda.gov/sites/default/files/documents/agriculture-innovation-agenda-vision-statement.pdf

Bager, S., Singh, C. Persson, M., 2022. Blockchain is not a silver bullet for agro-food supply chain sustainability: Insights from a coffee case study. Current Research in Environmental Sustainability, 1, 1-12. DOI: 10.1016/j.crsust.2022.100163

Barreto, J., Silva, J., Oliveira, B., Alves, R., 2022. Sustainability issues along the coffee chain: From the field. Journal metrics, 1, 287-323. DOI: 10.1111/1541-4337.13069

Biswas-Tortajada, A., Biswas, A., 2015. Sustainability in Coffee Production Creating Shared Value Chains in Colombia. Routledge, 5, 2 -273. ISBN: 978-1-315-69750-5

Código de Conducta 4C, 2018. https://www.4c-services.org/wp-content/uploads/2019/04/4C-Code-of-Conduct_v2.3_ES.pdf

DeFries, R., Chhatre, A., Davis, K. F., Dutta, A., Fanzo, J., Ghosh-Jerath, S., Smith, M. R., 2018. Impact of historical changes in coarse cereals consumption in India on micronutrient intake and anemia prevalence. Food and Nutrition Bulletin, 39, 185-195. DOI: 10.1177/0379572118783492

Departamento Nacional Administrativo de Estadísticas DANE, 2014. Censo Nacional Agropecuario. https://www.dane.gov.co/files/Censo Agropecuario/informacion-veredas.xls

Departamento Administrativo Nacional de Estadística DANE, 2023. Archivo Exportaciones tradicionales y no tradicionales. https://www.dane.gov.co/index.php/estadisticas-por-tema/comercio-internacional/exportaciones.

Dewi D., Handi, R., Nana H., 2023. Sustainable specialty coffee production: An agronomy perspective. Earth and Environmental Science, 1230, 2-13. DOI: 10.1088/1755-1315/1230/1/012067

Dorjsuren, B., 2019. Changing practices of modes of innovation and interactions in Estonian case. https://www.iris-france.org/wp-content/uploads/2021/09/71-Policy-Paper-Def-Innov-Estonian-Case-Sept-2021.pdf.

Echavarría, N., Atehortúa, N., Tobón, O., 2016. Manual de Producción y Consumo Sostenible. Gestión del Recurso Hídrico. https://www.corantioquia.gov.co/wp-content/uploads/2022/01/Cafetero.pdf.

Fairtrade, 2019. Criterio de Comercio Justo Fairtrade para Organizaciones de pequeños productores. https://files.fairtrade.net/standards/SPO_SP.pdf

Farfán, F, Arcila. J., Moreno, A., Hincapié, E., Salazar, L., 2007. Sistemas de producción de café en Colombia. 1, 234-254. https://www.cenicafe.org/es/documents/LibroSistemasProduccionCapitulo10.pdf.

Federación Nacional de Cafeteros FNC, 2019. Café de Huila. https://huila.federaciondecafeteros.org/cafe-de-huila/.

Federación Nacional de Cafeteros FNC, 2019. Cafés especiales. https://federaciondecafeteros.org/wp/programas/cafes-especiales/

Frohmann, A., Mulder, N., Olmos, X., 2017. Estándares de sostenibilidad y participación de los productores. https://repositorio.cepal.org/bitstream/handle/11362/46604/1/S2000778_es.pdf

IFOAM, 2019. The Common Objectives and Requirements of Organic Standards. https://ch.ifoam.bio/sites/default/files/2020-04/coros_2011_spreadsheet_final_5.xls

Hadi, A., Suprihatin, Pramuhadi, G., 2022. Exploring the sustainability dimensions of coffee agroindustry: a critical review and future research agenda. IOP Publishing, 1063, 2-13. DOI: 10.1088/1755-1315/1063/1/012049

Hernandez-Aguilera, J. N., Conrad, J. M., Gómez, M. I., Rodewald, A. D. , 2022. The economics and ecology of shade-grown coffee: A model to incentivize shade and bird conservation. World Development, 150, 110-121. DOI: 10.1016/j.ecolecon.2019.01.015

Isa SSM, Abidin NZ, Yahaya, I., 2019. Conceptualizing eco-innovation practices in contractor firms–the dynamic capability approaches. IOP Publishing, 601, 2-6. DOI:10.1088/1757-899X/601/1/012030

Jamal, I., Anggraeni E., Sailah I., 2024. Organic vegetable business model innovation village based. AIP Conference Proceedings, vol. 2957, pp. 2-8. DOI: 10.1063/5.0184498

Jezeer, R. E., Santos, M. J., Boot, R. G., Junginger, M., Verweij, P. A., 2018. Effects of shade and input management on economic performance of

small-scale Peruvian coffee systems. Agricultural Systems, vol 162., 179-190. DOI: 10.1016/j.agsy.2018.01.014

Kamal, A., Hassan, M., 2024. Innovation champions and sustainable development projects: systematic literature review and integrative model, 28, 2 -18. DOI: 10.1142/S1363919623300027

Kautsar, M., Arsyad, M., Tenriawaru, N., 2024. Existing Performance of Cocoa Agroindustry: Learn From Pt. Indonesia Hijau, Polewali Mandar, Indonesia. BIO Web Conf., 96, 2-13. DOI: 10.1051/bioconf/ 20249607012

Kalay, F., Lynn, G., 2015. The impact of strategic innovation management practices on firm innovation performance. Research Journal of Business and Management, 2, 2-18. DOI: 10.17261/Pressacademia.2015312989

Kozhakhmet, S., Boranbayeva, A., Gassanova, A., 2024. The interplay of access to organizational resources, firm innovativeness, and cooperative norms in technology transfer: testing a moderated mediation model. Technology Analysis & Strategic Management, 36, 486–500. https://doi-org.biblio.uptc.edu.co/10.1080/09537325.2022.2037543

Kuzior, A, Sira, M., Brozek, P., 2023. Use of Artificial Intelligence in Terms of Open Innovation Process and Management. MDPI Journal, 15(9), 2-16. DOI: 10.3390/su15097205

Lambrecht, E., Kuhne, B., Gellynck X., 2014. How do innovation partners differ with respect to innovation type and stage in the innovation journey of farmers? International Journal of Entrepreneurship and Innovation, 15, 191-201. DOI: 10.5367/ijei.2014.0155

Labbé, M., Landete, M., Leal, M, 2022. Dendrograms, minimum spanning trees and feature selection. European Journal of Operational Research, 308, 555-567. DOI: 10.1016/j.ejor.2022.11.031

Laili, N., Indrasti, N., Wahyudi, D., 2022. Design of sustainable coffee processing wastewater treatment system using K-means clustering algorithm. IOP Publishing, 1063, 28. DOI 10.1088/1755-1315/1063/1/012032.

Levy, D., Reinecke, J., Manning, S., 2016. The Political Dynamics of Sustainable Coffee: Contested Value Regimes and the Transformation of Sustainability. Journal of Management Studies, 5, 2-39. DOI: 10.1111/joms.12144.

Mancini, H., Schulte R., Anten, N., Bosco, L., Baartman, J., Moinet, J., Reidsma, P., 2022. How to quantify the impacts of diversification on sustainability? A review of indicators in coffee systems. Agronomy for Sustainable Development, 42(62), 1-26. DOI: 10.1007/s13593-022-00785-5

Meemken, E. M., Sellare, J., Kouame, C. N., Qaim, M., 2019. Effects of Fairtrade on the livelihoods of poor rural workers. Nature Sustainability, vol. 2, pp. 635-642. DOI: 10.1038/s41893-019-0311-5

Núñez, N., Gutiérrez, L., 2023. Historia Agraria. Open access, 23, 255 – 286. ISSN 11391472. DOI: 10.26882/histagrar.091e06n

Oliva, F., Semensato, B., Buzzulini, D., Jacques, E., Bution, F., Gomes, M., Bottacin, M., Ferranty, M., Lennan, M., Freire, P., 2019. Innovation in the main Brazilian business sectors: characteristics, types and comparison of innovation. Journal of knowledge management, 23, 135-167. DOI: 10.1108/JKM-03-2018-0159

Organización para la cooperación económica y oficina de desarrollo estadístico de las comunidades europeas – OCED, Manual de Oslo, 2018. Guidelines for collecting, reporting and using data on innovation. https://www.oecd-ilibrary.org/oslo-manual-2018_5j8p8jmbxgwb.pdf

Oya, C., Schaefer, F., Skalidou, D., McCosker, C., Langer, L., 2017. Effects of certification schemes for agricultural production on socio-economic outcomes in low-and middle-income countries: A systematic review. Campbell Systematic Reviews, vol. 13(1), 1-51. DOI: 10.4073/csr.2017.3

Panhuysen, S., Pierrot, J., 2020. Coffee Barometer 2020. Conservation International. https://hivos.org/assets/2021/01/Coffee-Barometer-2020.pdf

Polit, D.F., Beck, C.T., 2017. Nursing Research: Generating and Assessing Evidence for Nursing Practice. Wolters Kluwer Health, 10, 770-784. ISBN: 978-0-7817-7052-1

Prácticas C.A.F.E de Starbucks, 2016. Tarjeta de puntuación genérica. https://cdn.scsglobalservices.com/files/program_documents/cafe_scr_genericv3.4_esp_030916_1.pdf

Proenca, J., Torres, A., Santos, D., Fuly, G., Lopez, H., 2022. Sustainability in the Coffee Supply Chain and Purchasing Policies: A Case Study Research. Sustainability Journal, 14, 1-17. DOI: 10.3390/su14010459

Peluso, M., 2023. Coffee By-Products: Economic Opportunities for Sustainability and Innovation in the Coffee Industry. Sustainability Journal, 89, 1-6. DOI: 10.3390/ICC2023-14834

Rahi, S., 2017. Research Design and Methods: A Systematic Review of Research Paradigms, Sampling Issues, and Instruments Development. International Journal of Economics & Management Sciences, 6, 4-6. DOI: 10.4172/2162-6359.1000403

Ramírez, E., García L., 2020. Competitividad en la producción de cafés especiales del departamento del Huila. https://repository.universidadean.edu.co/handle/10882/10101?locale-attribute=en

Rivera, Y., Landero, J., Dávila, S., Sevilla, A., 2020. Influencia de la innovación en el proceso productivo. Revista Científica de FAREM-Estelí, https://camjol.info/index.php/FAREM/article/download/9609/10997?inline=1

Samper, L., Quiñones, X., 2017. Towards a Balanced Sustainability Vision for the Coffee Industry. Resources, 6(2), 1-28. DOI: 10.3390/resources6020017

Samper, L. F., Giovannucci, D., Vieira, L. M., 2017. The powerful role of intangibles in the coffee value chain, Economic Research, 39, 1-79. DOI: 10.34667/tind.29021

Sepúlveda, W. S., Chekmam, L., Maza, M. T., Mancilla, N. O., 2016. Consumers' preference for the origin and quality attributes associated with production of specialty coffees: Results from a cross-cultural study. Food Research International, 89(2), 997-1003 DOI: 10.1016/j.foodres.2016.03.039

Sgroi, F., 2022. The role of blockchain for food safety and market efficiency. Journal of Agriculture and Food Research, 10, 2-4. DOI: 10.1016/j.jafr.2022.100326

Tiuncika, L., Bormane, S. (2024). Sustainable Management of Manufacturing Processes: A Literature Review. MDPI Journal, vol. 12, pp. 1-16. DOI: 10.3390/pr12061222

Rainforest alliance, 2023. Requisitos para fincas. https://www.rainforest-alliance.org/wp-content/uploads/2023/02/SA-S-SD-1-V1.3ES-Rainforest-Alliance-2020-Estandar-Agricultura-Sostenible-Requisitos-para-Fincas.pdf

Rajapathirana, R. and Hui, Y., 2017. Relationship between innovation capability, innovation type, and firm performance. Journal of Innovation & Knowledge, 3, 1-4. DOI: 10.1016/j.jik.2017.06.002

Universidad de California, 2016. What does cronbach's alpha mean? https://stats.oarc.ucla.edu/spss/faq/what-does-cronbachs-alpha-mean/

Ureña-Espaillat, H. J., Briones-Peñalver, A. J., Bernal-Conesa, J. A., Córdoba-Pachón, J. R., 2023. Knowledge and innovation management in agribusiness: A study in the Dominican Republic. Business Strategy and the Environment, 32(4), 2008–2021. DOI: 10.1002/bse.3233

Vicol, M., Neilson, J., Hartatri, D. F. S., Cooper, P., 2023. Upgrading for whom? Relationship coffee, value chain interventions and rural development in Indonesia. World Development, 110, 26-37 DOI: 10.1016/j.worlddev.2018.05.020

Workman, D., 2022. Coffee Exports by Country. https://www.worldstopexports.com/coffee-exports-country/.

Wahyudi, A., Wulandari, S., Aunillah, A., Alouw, J., 2020. Sustainability certification as a pillar to promote Indonesian coffee competitiveness. IOP Publishing, 418, 1-9. DOI:10.1088/1755-1315/418/1/012009.

Xiaojing S., Chengting Z., Yuanjun Y., Qi W., Zhenlai Z., Junwen S., Pincai Z., Kunyi L., Xingyu L., Jiangping F., 2023. Effects of Different Primary Processing Methods on the Flavor of Coffea arabica Beans by Metabolomics. Fermentatio, 9(8), 1-18. DOI: 10.3390/fermentation 9080717

Zhai, T., Liu, J., Wang, D., 2023. Optimization path of agricultural products marketing channel based on innovative industrial chain. Econ Change Restruct, 56, 3949–3977. DOI: 10.1007/s10644-023-09495-8