

Optimization of Operational Processes in Coffee Production: A Systematic and Bibliometric

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ABSTRACT

This bibliometric study analyzes and synthesizes the scientific literature on optimizing operational processes in coffee production. Using a systematic methodology based on SCOPUS database records (n=179), selected through refined Boolean logic and Bradford's Law, the study integrates tools such as Biblioshiny and VOSviewer. Four core research questions guided the study: identification of key terms and authors, analysis of models and techniques, categorization of thematic areas, and assessment of optimization alternatives. Results reveal a multidisciplinary landscape encompassing technological, agronomic, and sustainability dimensions. The study offers a comprehensive state-of-the-art synthesis, highlighting knowledge gaps and proposing future research directions.

Key words: Optimization; operational processes; production; coffee.

1 INTRODUCTION

Bibliometric research on the optimization of operational processes in coffee production in the Colombian coffee region is highly relevant to both academic research and the coffee industry. Scientific output, i.e., the body of research published over time, is a key tool to understand trends, advances, and opportunities in production process optimization. Rodríguez-Rojas et al. (2018). Bibliometric studies help identify the main research lines, sources of knowledge, and actors (universities, authors, and countries) driving this field at global and local levels. Skute et al. (2019).

The Colombian coffee region represents a fundamental economic engine for the regions of Caldas, Risaralda, and Quindío. Therefore, understanding how research on improving operational processes has evolved globally is essential for fostering innovation and competitiveness in the coffee industry. This includes studies that characterize techniques used in specialty coffee operations. Morris et al. (2024).

Scientific databases such as SCOPUS enable detailed analysis of publications on the optimization of operational processes in coffee production Sott et al (2020) and Cortés et al. (2024). This work is based on a systematic review that defines research questions, retrieves articles from the SCOPUS database, applies inclusion and exclusion criteria, and answers the following questions:

1. What are the main terms and authors related to the optimization of operational processes in coffee production?

2. What are the models, techniques, and tools that impact the optimization of operational processes in coffee production?

3. What are the thematic areas related to the optimization of operational processes in coffee production?

4. What optimization alternatives have been developed for coffee production processes?

Analyzing thematic evolution and knowledge advances helps identify key contributions, research gaps, and opportunities for new areas of study. This bibliometric analysis enriches academic knowledge and provides valuable information for coffee producers, policymakers, and economic actors, supporting a more strategic approach to the optimization of operational processes in coffee production.

2 MATERIAL AND METHODS

Based on the guiding questions, the systematic review of the optimization of operational processes in coffee production was carried out in the SCOPUS database. Scopus (2025). In the identification phase, we performed a general search using Boolean operators and Scopus' abbreviations for the journal names. After several iterative tests to refine the terms and assess their results, we defined the final search equation: (coffee AND models OR study OR cluster) AND (operation OR optimization OR optimize OR solve OR management) AND (evolution OR memetic OR evolving OR evolutive OR genetic OR genetic OR program OR linear OR quadratic OR algorithm). The search was conducted in January 2025, limited to documents published between 2000 and 2025. Inclusion criteria included relevance to operational optimization in coffee production and presence in peer-reviewed journals. Exclusion criteria were non-scientific articles and duplicates.

We applied inclusion and exclusion criteria using bibliometric filters to the obtained results. Aria and Cuccurullo (2017). The selected results were exported in.csv and.bib formats and analyzed using two tools: Biblioshiny (bibliometric R package) and VOSviewer for making maps to visualize bibliometric network data. An electronic tabulator was also used to construct certain graphs, which included all types of documents, such as bibliographic reviews. The search retrieved 540 documents. After applying the language filter (English and Spanish) and the Bradford law filter to identify core sources. Locatelli (2021), we narrowed the selection to 179 documents (out of 540), 57 sources (out of 406), and 782 authors (out of 2319). In each phase, the available empirical evidence was used to address specific research questions. Higgins et al. (2011). This process helped identify gaps in existing literature, propose new research directions, and provide background information to guide future research. Kitchenham and Charters (2007).

This study followed previous methodological approaches for systematic reviews Kitchenham and Charters (2007), Medina-López et al. (2010). The process included several phases, summarized in the Figure 1:

The dataset used for the bibliometric analysis, including the 179 selected articles, is available in CSV format in an open public repository: <https://doi.org/10.5281/zenodo.16748486>

Our research questions and motivations are summarized in Table 1.

3 RESULTS

3.1 What are the main terms and authors related to the optimization of operational processes in coffee production?

An analysis of the most frequently occurring words in SCOPUSrevealed, in order of importance, those with representativeness greater than or equal to 4%: coffee (14%), arabica coffee (13%), genetic diversity (7%), coffee canephora (5%), agroforestry (5%), coffee berry borer (4%), Hypotenemus hampei (4%), and innovation (4%). Figure 2 shows the word cloud illustrating the most frequently occurring words.

For the analysis of authors, we applied Lotka's Law. Lotka, Alfred (1926). This bibliometric law describes the distribution of scientific output among authors. Applying such laws helps identify the proportion of highly productive

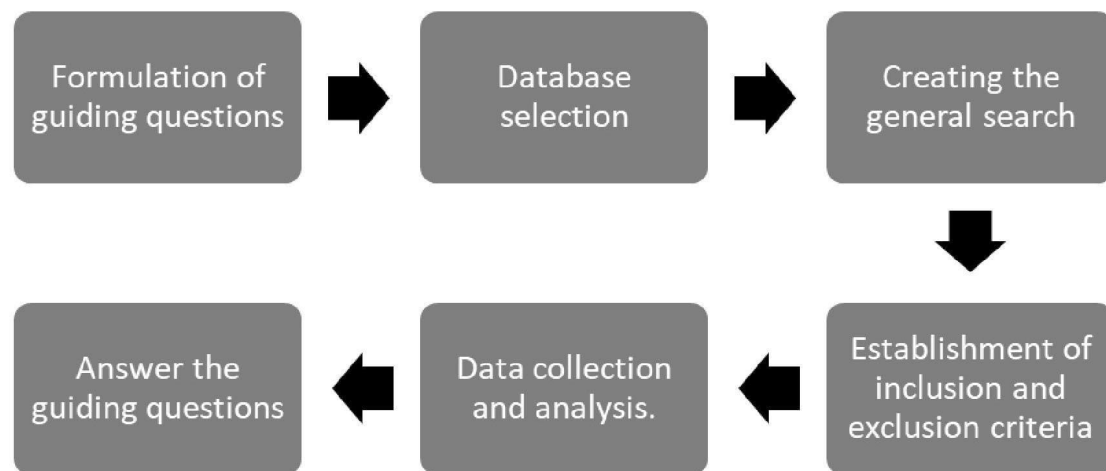


Figure 1: Flowchart of the methodology adopted in this systematic review.

Table 1: Research questions and motivations in this study.

Research Questions	Motivations
What are the main terms and authors related to the optimization of operational processes in coffee production?	Identify the key terms and authors related to optimization of operational processes in coffee production.
What are the models, techniques, and tools that impact the optimization of operational processes in coffee production?	Sort and describe the models, techniques, and tools that impact optimization of operational processes in coffee production.
What are the thematic areas related to the optimization of operational processes in coffee production?	Identify and explain the thematic areas related to optimization of operational processes in coffee production.
What optimization alternatives have been developed for coffee production processes?	Recognize and define the optimization alternatives that have been developed concerning coffee production processes.

of seven), 6.5% published two articles, and 91.6% published only one article.

Thirteen authors were identified as the most productive in research on the optimization of operational processes in coffee production, each with at least three articles (Figure 4). Among them, Partelli-Dos Santos stood out with seven articles, followed by Ferrão-Serna with five articles, Caixeta with four articles, and Davis, Benavides, Bertrand, Campa, Krishnan, Leroy, Méndez, Pérez, Ramalho, and Sanudin each with 3 articles.



Figure 2: Word cloud showing the most frequent words.

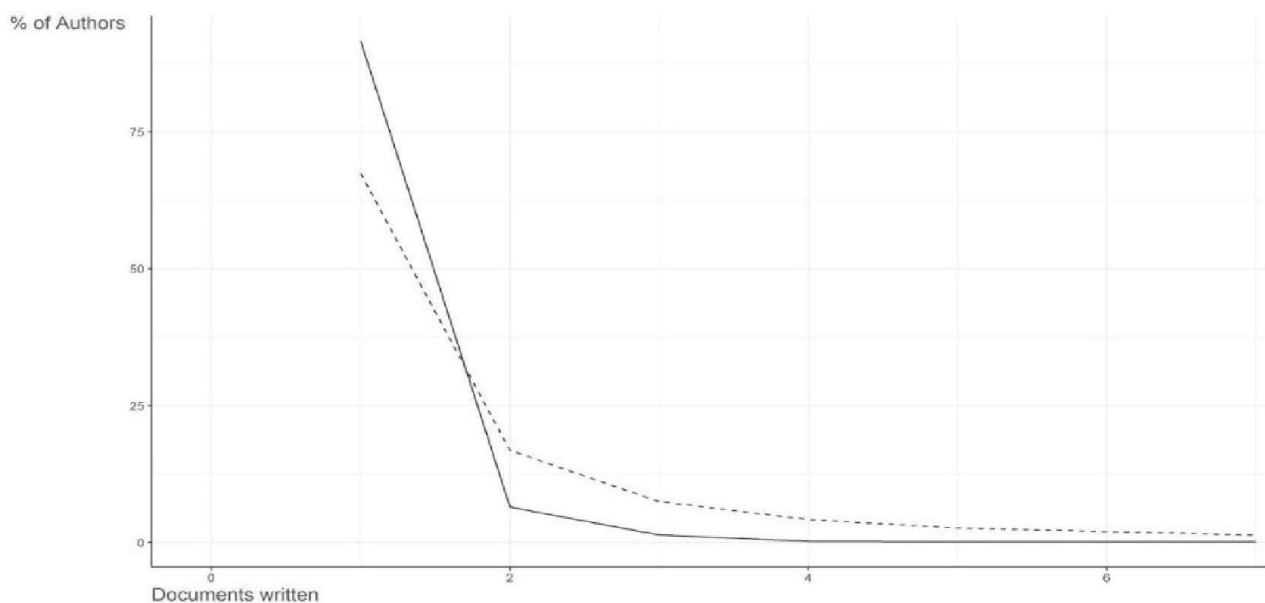


Figure 3: Percentage of authors and number of documents published (Lotka's Law). Agada (1987).

3.2 What are the models, techniques, and tools that impact the optimization of operational processes in coffee production?

Research on the optimization of operational processes in coffee production covers a wide range of advanced techniques and tools aimed at improving efficiency, sustainability, and product quality. Figure 5 summarizes the

models, techniques, and tools identified in the literature, grouping 27 references. These approaches include predictive modeling, bioinformatics, and genomics tools, reflecting multidisciplinary efforts that address both agricultural and industrial aspects of coffee production. A detailed analysis of these technologies and their contributions to the optimization of operational processes in coffee production is presented below.

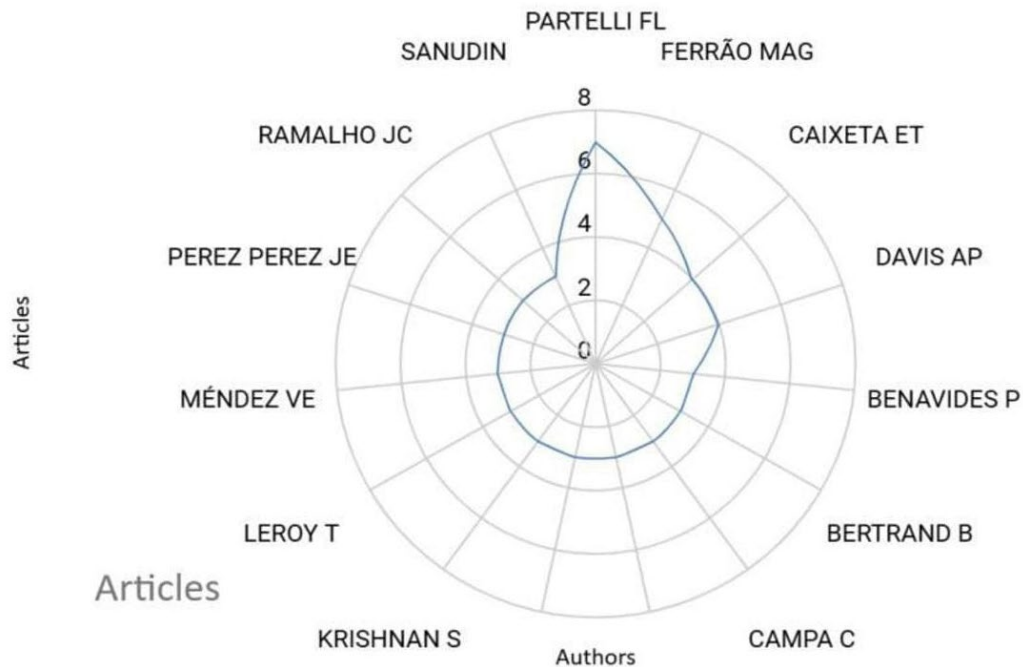


Figure 4: Most productive authors.

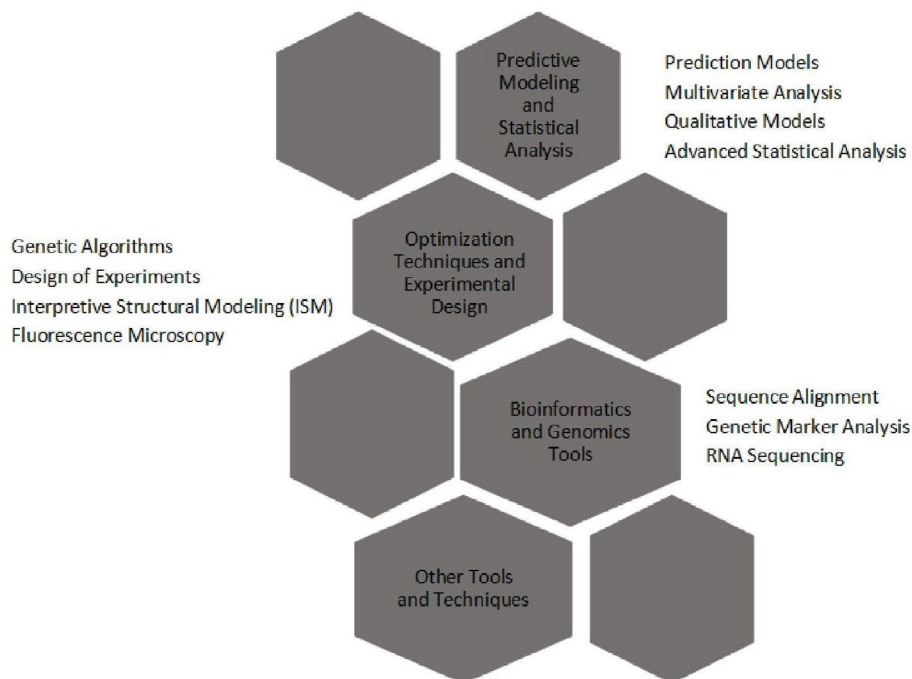


Figure 5: Models, techniques, and tools that impact the optimization of operational processes in coffee production.

3.3 Predictive Modeling and Statistical Analysis

Predictive models help to anticipate critical variables in coffee production, such as the moisture content of - biochar derived from coffee waste during roasting. By optimizing this process based on energy consumption predictions, it is possible to improve energy efficiency, lower operating costs, and reduce the environmental footprint. Lima et al. (2015). This approach can be applied to various phases of coffee production, enabling fine-tuning that increases both profitability and sustainability. In coffee breeding, genomic prediction models play a crucial role in assessing resistance to diseases such as coffee rust and leaf miner. By using genomic relationship matrices, these models help identify resistant genotypes, making breeding programs more efficient and reducing dependence on chemical treatments. This contributes to more sustainable coffee production. Wang and Lefkowitz (2005).

Multivariate analysis is also used to determine the geographical origin of coffee beans, supporting product traceability and authentication. Krishnan et al. (2013). This approach not only optimizes the quality and integrity of coffee in the market but also supports the marketing of specialty coffees, which increasingly rely on transparency and traceability as added value. Qualitative models also contribute to coffee production optimization. One example is ExpeRoya, a tool designed to predict the incidence of coffee rust, a major concern for producers. This model integrates variables such as climate, crop management, and coffee tree characteristics to predict infection risk Callo-Concha et al. (2017), Silva et al. (2019). This model helps inform preventive management decisions and improve the effectiveness of agricultural practices.

In genetic studies, advanced statistical methods such as analysis of variance (ANOVA) are used to identify significant differences between genotypes and environments. Yue et al. (2009). This is crucial for selecting varieties with desirable agronomic traits. Furthermore, multivariate techniques such as principal component analysis (PCA) reduce the complexity of large datasets, allowing researchers to identify relevant patterns in coffee genetics more efficiently Yue et al. (2009), Senra et al. (2022), Carvalho, Humberto et al. (2023).

3.4 Optimization Techniques and Experimental Design

Genetic algorithms are powerful tools for optimizing industrial processes such as coffee waste roasting to maximize calorific value while minimizing energy consumption. Lima et al. (2015). Furthermore, genetic algorithms have also been used to optimize battery design using activated carbon derived from coffee waste, demonstrating the potential of this by-product for developing high-value, sustainable products. Abdelwahab

et al. (2024). Experimental designs, such as factorial designs and randomized complete blocks, are widely used to evaluate the interaction of multiple factors in coffee production. Some examples are the different methods for determining leaf area, an essential indicator of plant growth and health Sallin et al. (2025), Perez (2022), and the evaluation of genotype stability and adaptability under varying conditions. Wulandari and Fadry (2021). These approaches help to optimize agricultural practices and guide the selection of the best strategies for different environments. Additionally, interpretive structural modeling is used to analyze the interactions among institutions involved in the development of the coffee agroindustry and to identify factors affecting forest management in coffee-growing communities Motisi et al. (2022), Ortuño et al. (2013), Vargas et al. (2017). This systemic approach helps understand the social and economic dynamics influencing coffee production and provides a framework to support decision-making for industry development.

3.5 Bioinformatics and Genomics Tools

Sequence alignment is essential for identifying key genetic patterns in coffee breeding. Algorithms based on methods such as Monte Carlo and hidden Markov models (HMMs) help detect conserved DNA regions and assess genetic variability Yang et al. (2024), Yamada, Osamu and Hayato (2006). These tools support a better understanding of coffee genetic diversity and enable the design of more precise breeding strategies. In bioinformatics, iterative methods are used to improve the accuracy of multiple sequence alignments, as seen in tools like T-Coffee. Alam et al. (2020). These approaches help refine subalignments and reduce computational complexity, offering applications beyond genetics, including agricultural production. Furthermore, sequence alignments based on multi-objective algorithms, such as the model proposed by Ortuño et al. (2013), optimize structural features, allowing more precise evaluations of sequence relationships that can support improvements in coffee cultivation and management practices. Genetic control is also applied to manage pests such as the coffee berry borer. When combined with other control methods, this strategy helps to reduce costs and crop losses by incorporating resistant coffee varieties that allow more efficient pest management. Molina (2023). Genetic markers such as SNPs (single nucleotide polymorphisms) and microsatellites (SSRs) are widely used to assess genetic diversity and select coffee genotypes with desirable traits like pest and disease resistance Manikandan and Ramyachitra (2017), Jansen et al (2006), Nugroho et al. (2019), Quispe et al. (2021). These markers accelerate the selection of productive and sustainable coffee varieties in breeding programs. While these tools originate from general bioinformatics research, their applications in coffee-specific studies remain emergent and are discussed with caution in this review.

RNA sequencing is another powerful tool that reveal gene expression patterns, helping researchers to understand the molecular mechanisms behind coffee somatic embryogenesis. Santos et al. (2023). This technique uncovers key cellular processes that affect plant propagation and adaption to different environmental conditions.

3.6 Other Tools and Techniques

Fluorescence microscopy has been recently applied to study pollen tube development in self-incompatibility studies in *Coffea canephora*. Chalfoun et al. (2018). This method is useful to understand plant reproduction and genetics, supporting the development of improved cultivated varieties.

Geographic information systems (GIS) are also used to model the distribution of coffee species and evaluate how environmental conditions influence their occurrence. Perez (2023). GIS is key for guiding decisions on plantation sites, biodiversity conservation, and planning adaptation strategies for climate change.

3.7 What are the thematic areas related to the optimization of operational processes in coffee production?

Analyzing the relationships between documents based on their abstracts reveals key areas of coffee research. These include agronomic and technological topics, as well socioeconomic and environmental aspects. Figure 6 summarizes 40 references related to the optimization of operational processes in coffee production. It shows how topics like production efficiency, genetic improvement, sustainability, and coffee quality connect to market dynamics and community impacts.

3.8 Process Optimization and Resource Use

Several studies focus on the optimization of coffee-related processes, particularly roasting and hydrothermal

carbonization. One study used genetic algorithms to maximize the calorific value of coffee waste-derived biochar (CWB) while minimizing energy consumption (Rodriguez-Rojas et al. (2028). This research connects directly to using biochar for improving soil fertility and promoting sustainability in coffee farming.

Other studies address wastewater treatment using sustainable technologies, such as the EGSB bioreactor (Morris et al., 2023). This research relates to broader studies on reducing the environmental impact of coffee cultivation (Morris et al., 2024), Sott et al. (2020), Cortés et al. (2024). These efforts aim to reduce water use, improve agricultural inputs, and enhance sustainability in coffee production.

3.9 Genetic Improvement and Disease Resistance

Genetic improvement is a key topic in coffee research, with many studies addressing resistance to diseases such as rust, leaf miner, and nematodes Callo-Concha et al. (2017), Silva et al. (2019). This research aims to identify superior genotypes using genomic prediction and SNP markers to improve resistance to biotic and abiotic stresses. Genetic diversity studies on *Coffea arabica* and *Coffea canephora* Lima et al. (2015), Wang and Lefkowitz. (2005), Krishnan et al. (2013) are closely linked to these efforts. Advances in genetics contribute to better coffee quality and stronger pest resistance.

Plant-microorganism interactions also play an important role Abdelwahab et al. (2024). Studies on soil microbiota and symbiotic interactions show how these factors influence plant health and coffee quality. Together, genetic improvement and microbiome management offer a holistic approach to enhance disease resistance and optimizing final product quality.

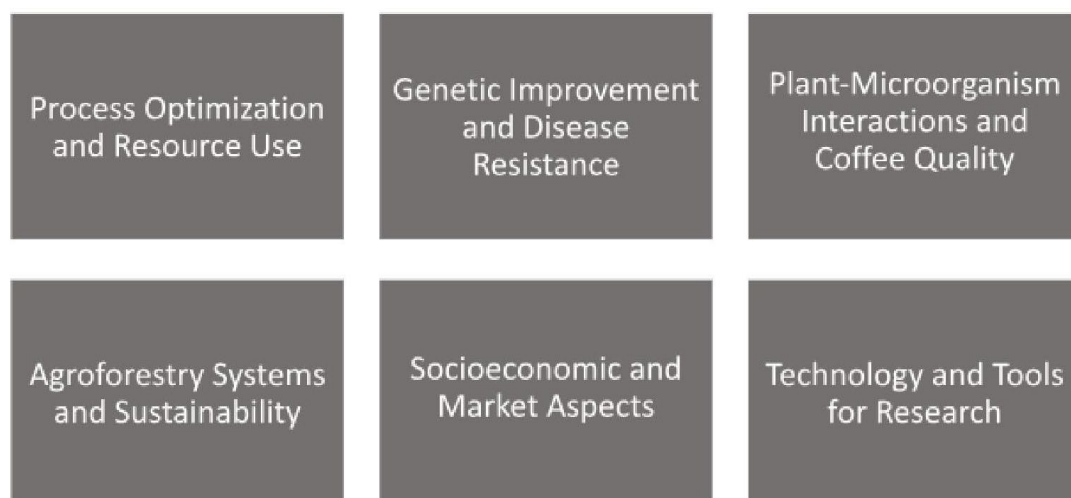


Figure 6: Thematic areas related to the optimization of operational processes in coffee production.

3.10 Plant-Microorganism Interactions and Coffee Quality

The interaction between plants and microorganisms is crucial for both plant health and coffee quality. Studies on how microbial communities influence coffee fermentation (Abdelwahab et al., 2024) and affect the beverage's sensory characteristics are central to improving coffee quality. Understanding these interactions helps optimize fermentation, a critical step in specialty coffee production. Furthermore, research on mycorrhizal fungi and their role in plant nutrition Abdelwahab et al. (2024) also connects with sustainability studies in agroforestry systems Sallin et al. (2025), Perez (2022), Wulandari and Fadjry (2021), highlighting the importance of proper ecosystem management for producing high-quality, environmentally friendly coffee.

3.11 Agroforestry Systems and Sustainability

Agroforestry systems play a fundamental role in the sustainability of coffee cultivation. Research on tree diversity and shade management Sallin et al. (2025) and Perez (2022) is closely linked to studies on the environmental impact of coffee production, including Life Cycle Assessment (LCA) Morris et al. (2024), Sott et al. (2020). Both approaches emphasize the need to adopt agricultural practices that boost productivity, protect biodiversity, and use natural resources more efficiently.

Other sustainable practices, such as removing moss and epiphytes from coffee plantations (Motisi et al., 2022) and applying biochar from coffee waste (Sánchez et al., 2023) support ecosystem conservation while optimizing production. These examples highlight the importance of integrating ecological management into coffee cultivation to achieve both economic and environmental goals.

3.12 Socioeconomic and Market Aspects

Studies on the coffee market and socioeconomic factors provide a complementary view of the coffee industry. While many research focuses on product quality and production sustainability, these studies examine challenges such as recruiting skilled staff for coffee shops (Ortuño et al., 2013), developing innovation strategies in coffee companies (Vargas et al., 2017), Yang et al. (2024), Molina (2022), and understanding consumption trends, particularly in the specialty coffee sector. Manikandan and Ramyachitra (2017). These economic aspects are closely linked to technological and agricultural innovations, highlighting how improvements in coffee quality and sustainability can boost market competitiveness.

The competitiveness of the roasting industry (Rodriguez-Rojas et al., 2018) also depends on process optimization, including roasting techniques and moisture content prediction, Jansen et al. (2006). These improvements enhance production efficiency and final product quality.

3.13 Technology and Tools for Research

Technological innovation plays a crucial role in coffee research. Predictive models for roasting and genetic improvement (Wang et al., 2005), Krishnan et al. (2013), Jansen et al. (2006) are linked to advanced tools used to improve coffee productivity and quality. Tools like multivariate analysis to determine the geographic origin of coffee beans. Nugroho (2019), and qualitative models to predict the risk of coffee leaf rust illustrate the growing importance of technology in managing coffee from farm to market.

Mathematical and computational tools are also used to analyze and improve the coffee value chain. For example, interpretive structural modeling (ISM) has been applied to study the robusta coffee agro-industry Perez (2023), while multiple sequence optimizations help understand complex interactions in the coffee production and distribution Perez (2022), Dang et al. (2023), Gebreselassie, Tesfaye, and Gedebo (2024).

3.14 What optimization alternatives have been developed for coffee production processes?

Process optimization in coffee production is essential to improve efficiency, product quality, reduce operating costs, and enhance sustainability. This review presents various techniques applied to key stages of coffee production and processing, using advanced algorithms and innovative strategies. These approaches cover areas such as roasting and pest management, aiming to increase crop yield and product quality. A total of 15 references address these topics.

3.15 Roasting Optimization

Roasting is a critical process in coffee production, strongly influencing the final flavor and quality. An innovative method to optimize this process is the use of an NSGA-II genetic algorithm. Manikandan and Ramyachitra (2017). This algorithm maximizes the calorific value of biochar produced from coffee waste while minimizing energy consumption. Results show that roasting at 244°C for 27 minutes yields a calorific value of 23.98 MJ kg⁻¹, using 20.042 MJ kg⁻¹ of energy for biochar production. Rodriguez-Rojas et al. (2018). This optimization improves the energy efficiency of the roasting process, reducing operating costs and promoting more sustainable practices in the coffee industry.

3.16 Hydrothermal Carbonization (HTC) Optimization

HTC transforms coffee waste into energy-rich products. By optimizing HTC and post-treatment steps, such as washing and agglomeration, the energetic properties of biochar can be improved, while simultaneously reducing unwanted substances and improving workability. Dang et al. (2023).

Genetic programming (GP) models help predict process performance and optimize parameters such as solids yield and calorific value. These models provide accurate predictions with errors below 15%, supporting improvements in process efficiency. This optimization enhances the production of valuable byproducts, increasing both the profitability and sustainability of coffee production. (Wang; Lefkowitz, 2005), Gebreselassie Tesfaye, and Gedebo (2024).

3.17 Genomic Selection Optimization

Genetic improvement is critical to address challenges such as pests and diseases in coffee cultivation. Genomic prediction models help select varieties resistant to leaf rust, leaf miner, and other diseases, reducing pesticide use and improving long-term productivity. Genomic relationship matrices are effective tools for identifying individuals with desirable traits like disease resistance. Furthermore, threshold models enhance the accuracy of genomic prediction, reducing selection costs and improving process efficiency. Wang, and Lefkowitz (2005).

3.18 Pollination Optimization

Pollination is essential for efficient coffee production, especially in *Coffea canephora* (robusta coffee). Optimizing pollination requires evaluating pollination efficiency and selecting suitable clones to improve plant stability and yield. Using a diverse set of clones from different compatibility groups ensures efficient pollination, leading to higher productivity. Ferrão et al. (2021). This strategy also helps improve coffee quality and enhance resistance to adverse weather conditions.

3.19 Optimizing Fertilizer Use

Proper fertilizer use is essential to maximize coffee yield. Foliar fertilization has proven effective in improving both cherry yield and cup quality. Studies have shown that fertilizers like K₂SO₄ and KNO₃ benefit certain coffee varieties, while KCl offers a more economical option for improving productivity. Cost-benefit analyses indicate that using affordable fertilizers such as KCl can significantly improve the profitability of coffee production Sott et al. (2020), Cortés et al. (2024), Yue and Tang (2008), Santos et al. (2023).

3.20 Optimizing Coffee Drying

The drying process is essential for preserving coffee quality, preventing mold growth, and reducing the loss of essential compounds during dehydration. An innovative solution is the solar drying dome, which reduces electricity consumption and improves drying efficiency. This method also protects coffee beans from moisture, ensuring optimal quality and preventing mold. De León-Solis et al (2023). Optimizing

drying enhances coffee quality while supporting sustainability and reducing operating costs.

3.21 Mini-Program Interface Design Optimization

Although not directly related to coffee cultivation or processing, optimizing interface design in coffee purchasing and distribution applications is important for enhancing the consumer experience. The semantic differential method from Kansei Engineering helps design mini-program interfaces that align with user's perceptual needs, improving customer interaction and satisfaction on coffee retail platforms. Yang et al. (2024). This improvement can boost sales and strengthen customer loyalty.

3.22 Pest Management Optimization

Pest management remains a constant challenge for coffee producers. Plant extracts from *Azadirachta indica* and *Trichilia pallida* help control pests like *Leucoptera coffeella*, while *Beauveria bassiana* is effective against the coffee berry borer. Mass trapping with trimedlure dispensers also controls the Mediterranean fruit fly. These biological control methods and integrated pest management strategies are crucial for reducing dependence on chemical pesticides and promoting sustainable and environmentally friendly agricultural practices. Ratnadass et al. (2021).

3.23 Linear Programming in Sequence Alignment Optimization

Linear programming is widely used in bioinformatics, especially for optimizing protein and DNA sequence alignments. While not directly applicable to coffee breeding, this technique supports breeding of coffee plants by optimizing multiple structural alignments (MSTA) of genomic sequences. Optimization algorithms used in sequence alignment can enhance the accuracy of genomic prediction models, improving the selection of more resistant and productive coffee varieties (Rodriguez-Rojas et al., 2018; Morris et al., 2023; Sott et al., 2020).

4 DISCUSSION

Research on coffee production reveals strong connections between diverse fields, including process optimization, genetic breeding, environmental sustainability, and socioeconomic aspects. These interrelated topics reflect not only technological and scientific advances, but also the challenge of integrating these innovations into sustainable models that benefit producers, consumers, and the environment. The convergence of research across these areas promises a more efficient and sustainable future for the coffee industry, guided by a comprehensive approach that balances technological and social needs.

The tools, models, and technologies discussed, such as genetic algorithms, predictive modeling, and bioinformatics, are essential for optimizing operational processes in coffee production. From improving energy efficiency in roasting to developing disease-resistant varieties, these innovations reduce costs while supporting sustainable and profitable production. The implementation of these advanced methods in both research and practice is transforming the coffee industry, fostering more competitive and environmentally responsible production in the global market.

The optimization of coffee production processes like roasting, pest management, and genetic breeding directly impacts the quality, profitability, and sustainability of coffee production. Techniques such as genetic programming, linear programming, and biological control strategies improve operational efficiency, reduce costs, and encourage sustainable agricultural practices. Linear programming, in particular, has been applied through models using decision variables, objective functions, and constraints to parameterize coffee production.

The benefits of optimizing operational processes include increased efficiency, reduced environmental impact, and improved energy use. Predictive modeling, experimental design, and advanced bioinformatics tools enable the precise optimization of coffee production, ensuring cost-effective and eco-friendly practices.

Genetic breeding, including genetic marker analysis and sequence alignment, contributes to developing coffee varieties that are more resistant to pests, diseases, and environmental stresses. These superior varieties require fewer inputs and offer greater resilience to climate fluctuations, supporting long-term sustainability in coffee cultivation.

Advances in genomics and sequencing technologies have also deepened our understanding of coffee's molecular biology. This knowledge is essential for creating informed, sustainable agricultural practices and allows for the early detection of potential production issues, such as disease outbreaks or environmental stress.

Finally, the optimization of operational processes plays a key role in supporting decision-making. Integrating, predictive models and big data analysis provides valuable insights for managing both coffee cultivation and marketing strategies. These technologies empower producers to make informed, timely decisions, enhancing efficiency, product quality, and market competitiveness.

5 CONCLUSIONS

The convergence of research in genetic breeding, energy efficiency, socioeconomic factors, and environmental sustainability demonstrates the coffee industry's evolution toward an integrated model. Optimization tools such as

predictive modeling, linear programming, and genetic algorithms enhance operational efficiency, reduce costs, and strengthen sustainability. Moreover, bioinformatics and data analytics support informed decision-making, improving product quality and adaptability to climate and market dynamics, thus positioning the coffee sector for greater competitiveness and sustainable growth globally.

6 AUTHORS' CONTRIBUTIONS

Conceptual idea: Morris Molina, L.H.; Salazar de Morris, O.J.; Methodology design: Morris Molina, L.H.; Sánchez Castro, J.J.; Data collection: Morris Molina, L.H.; Data analysis and interpretation: Sánchez Castro, J.J.; Writing and editing: Morris Molina, L.H.; Salazar de Morris, O.J.; Sánchez Castro, J.J.

7 DATA AVAILABILITY STATEMENT

Data available upon request to authors.

8 REFERENCES

- ABDELWAHAB, S. et al. Coffee arabica research (1932–2023): Performance, thematic evolution and mapping, global landscape, and emerging trends. **Heliyon**, 10:e36137, 2024.
- AGADA, J. **Bibliometrics, History of the development of ideas in**. Encyclopedia of Library and Information Science: Volume 42-Supplement 7: The Albert I Royal Library to The United Nations Bibliographic Information System, UNBIS, 1987.
- ALAM, S. et al. Analysis of community sector affected for village forest management in Bantaeng Regency, South Sulawesi, Indonesia. **IOP Conference Series: Earth and Environmental Science**, 575:012063, 2020.
- ARIA, M.; CUCCURULLO, C. *Bibliometrix*: An R-tool for comprehensive science mapping analysis. **Journal of Informetrics**, 11(4):959-975, 2017.
- CALLO-CONCHA, D. et al. Bridging science and development: lessons learnt from two decades of development research. **Agroforestry Systems**, 91:799-810, 2017.
- CARVALHO, H. et al. On the accuracy of threshold genomic prediction models for leaf miner and leaf rust resistance in arabica coffee. **Tree Genetics and Genomes**, 19:11, 2023.

- CHALFOUN, S. M. et al. Conductivity to rust in coffee under different wooden and fruit tree intercropping systems. **Coffee Science**, 13(2):245-51, 2018.
- CORTÉS, V. H. et al. Challenges in coffee fermentation technologies: Bibliometric analysis and critical review. **Journal of Food Science and Technology**, 61:2223-2234, 2024.
- DANG, C. et al. Enhancing the fuel properties of spent coffee grounds through hydrothermal carbonization: output prediction and post-treatment approaches. **Sustainability**, 16:338, 2023.
- DE LEÓN-SOLIS, C. et al. Metabolomics as a tool for geographic origin assessment of roasted and green coffee beans. **Heliyon**, 9(11):e21402, 2023.
- FERRÃO, M. et al. Characterization and genetic diversity of *Coffea canephora* accessions in a germplasm bank in Espírito Santo, Brazil. **Crop Breeding and Applied Biotechnology**, 21(2):e36132123, 2021.
- GEBRESELASSIE, H.; TESFAYE, B.; GEDEBO, A. Genetic diversity of Arabica coffee genotypes in south Ethiopia using quantitative agro-morphological traits. **Genetic Resources and Crop Evolution**, 71:3485-3506, 2024.
- HIGGINS, J. P. et al. **Cochrane handbook for systematic reviews of interventions**. Version 5.1.; The Cochrane Collaboration: Chichester, UK, 2011.
- JANSEN, H. et al. Policies for sustainable development in the hillside areas of Honduras: A quantitative livelihoods approach. **Agricultural Economics**, 34(2):141-153, 2006.
- KITCHENHAM, B.; CHARTERS, S. **Guidelines for Performing Systematic Literature Reviews in Software Engineering**. EBSE: Durham, UK, 2007.
- KRISHNAN, S. et al. The study of genetic diversity patterns of *Coffea commersoniana*, an endangered coffee species from Madagascar: A model for conservation of other littoral forest species. **Tree Genetics and Genomes**, 9:179-187, 2013.
- LIMA, E. et al. The multi-resistant reaction of drought-tolerant coffee 'Conilon Clone 14' to *Meloidogyne* spp. and Late Hypersensitive-Like Response in *Coffea canephora*. **Phytopathology**, 105(6):805-814, 2015.
- LOCATELLI, M. et al. (2021). Exploring Natural language processing in construction and integration with building information modeling: a scientometric analysis. **Buildings**, 11(12):583, 2021.
- LOTKA, A. J. (1926). The frequency distribution of scientific productivity. **Journal of the Washington Academy of Sciences**, 16(12), 317-323.
- MANIKANDAN, P.; RAMYACHITRA, D. Bacterial foraging optimization-genetic algorithm for multiple sequence alignment with multi-objectives. **Scientific Reports**, 7: 8833, 2017.
- MEDINA-LÓPEZ, C. et al. Una propuesta metodológica para la realización de búsquedas sistemáticas de bibliografía. **Working Papers on Operations Management**, 1(2):13-30, 2010.
- MOLINA, D. Revisión sobre la broca del café, *Hypothenemus hampei* (Coleoptera: Curculionidae: Scolytinae) con énfasis en la resistencia mediante antibiosis y antixenosis." **Revista Colombiana de Entomología**, 48(2):e11172, 2022.
- MORRIS, L. et al. **Análisis comparativo de la demanda de café verde colombiano para proyecciones en niveles de fabricación**. Universitaria Autónoma de Nariño, Colombia, 2024. 509p.
- MOTISI, N. et al. Improved forecasting of coffee leaf rust by qualitative modeling: Design and expert validation of the ExpeRoya model. **Agricultural Systems**. 197:103352, 2022.
- NUGROHO, A. P. et al. Design of integrated database of smart coffee enterprise support system for coffee small medium enterprise. **IOP Conference Series: Earth and Environmental Science**, 365:012022, 2019.
- ORTUÑO, F. M. et al. Optimizing multiple sequence alignments using a genetic algorithm based on three objectives: Structural information, non-gaps percentage and totally conserved columns. **Bioinformatics**, 29(17): 2112-2121, 2013.
- SANTOS, M. P. dos. et al. Natural parasitism of the coffee leaf miner: Climate factors, insecticide, and landscape affecting parasitoid diversity and their ecosystem services in coffee agroecosystems. **Bulletin of Entomological Research**, 113(6):814-828, 2023.
- PEREZ, J. E. P. Café Galavis: the challenge of internationalization of a family business. *Emerald Emerging Markets Case Studies*, 1-18, 2023.
- PEREZ, J. E. P. **Tradition or innovation?** Café Galavis, a brand with an international vision. *Emerald Emerging Markets Case Studies* Vol. ahead-of-print No. ahead-of-print 12.1 1-27. 2022.
- QUISPE, C. et al. Spatial and temporal genetic diversity and population structure of hemileia vastatrix from peruvian coffee plantations. **The Plant Pathology Journal**, 37(3):280-290, 2021.

- RATNADASS, A. et al. Synergies and tradeoffs in natural regulation of crop pests and diseases under plant species diversification. **Crop Protection**, 146:105658, 2021.
- RODRIGUEZ-ROJAS, Y. et al. 5 acciones para la toma de decisión en investigación, desarrollo e innovación I+D+i. **Revista EAN**, (85):85-104, 2018.
- SÁNCHEZ-REINOSO, A. D. et al. (2023). The application of coffee pulp biochar improves the physical, chemical, and biological characteristics of soil for coffee cultivation. **Journal of Soil Science and Plant Nutrition**, 23(2), 2512-2524.
- SALLIN, V. et al. Trends and findings in the rooting of conilon coffee: a bibliometric review. **Ciência Rural**, 55(2):e20240105, 2025.
- SCOPUS. **Scopus Data Base**. Available in: <<https://www.scopus.com/search>>. access in: 25 January, 2025.
- SENRA, J. et al. Genetic variability of conilon coffee population from cultivar 'ES8152' based on morphoagronomic variables. **Coffee Science**, 17: e171986, 2022.
- SILVA, B. S. R. et al. Population structure and genetic relationships between Ethiopian and Brazilian Coffea arabica genotypes revealed by SSR markers. **Genetica**, 147:205-216, 2019.
- SKUTE, I. et al. (2019). Mapping the field: A bibliometric analysis of the literature on university–industry collaborations. **The Journal of Technology Transfer**, 44:916-947, 2019.
- SOTT, M. et al. Precision techniques and agriculture 4.0 technologies to promote sustainability in the coffee sector: state of the art, challenges and future trends. **IEEE Access**, 8:149854-149867, 2020.
- VARGAS, R. et al. Suppression of mediterranean fruit fly (Diptera: Tephritidae) with trimedlure and biolure dispensers in Coffea arabica (Gentianales: Rubiaceae) in Hawaii. **Journal of Economic Entomology**, 111(1):293-297, 2017.
- WANG, C.; LEFKOWITZ, E. J. Lefkowitz. Genomic multiple sequence alignments: refinement using a genetic algorithm. **BMC bioinformatics**, 6:200, 2005.
- WULANDARI, S.; FADJRY, D. Technology transfer strategy for women in coffee livestock integration as climate-smart agriculture practice. **E3S Web of Conferences**, 316:04010, 2021.
- YAMADA, S.; OSAMU, G.; HAYATO, Y. Improvement in accuracy of multiple sequence alignment using novel group-to-group sequence alignment algorithm with piecewise linear gap cost. **BMC Bioinformatics**, 7:524, 2006.
- YANG, C. et al. Applying TRIZ and Kansei engineering to the eco-innovative product design towards waste recycling with latent Dirichlet allocation topic model analysis. **Engineering Applications of Artificial Intelligence**, 133:107962, 2024.
- YUE, F.; TANG, J. A new approach for tree alignment based on local re-optimization. **International Conference on BioMedical Engineering and Informatics. IEEE**, 1:34-38, 2008.
- YUE, F. et al. Simultaneous phylogeny reconstruction and multiple sequence alignment. **BMC Bioinformatics**, 10:1-9, 2009.