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Evaluation of agroecological processes implemented in olive production systems: an analysis in Boyacá, Colombia

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The development of agriculture based on an agroecological approach has become a strategic commitment for various national and international organizations. This commitment seeks to establish new production alternatives capable of meeting food market demands while addressing the impacts of climate variability and climate change. Within this framework, olive cultivation has gained traction in Colombia, particularly in regions where other crops fail to adapt, sparking interest among farmers and rural development researchers. Nonetheless, this production model faces significant limitations, especially in the comprehensive development of the value chain, as Colombia's olive sector struggles to consolidate the production of table olives and olive oil. Combined with the rising costs of soil amendments and synthetic fertilizers, this situation limits the strengthening of productive chains and, consequently, the socioeconomic advancement of farmers. This document therefore aims to analyze available information and identify successful experiences involving the adoption of agroecological practices in olive farming, with a focus on enhancing producers' social and economic outcomes by addressing different components of the value chain. To achieve this, the PRISMA methodology was applied to define search thresholds and establish inclusion and exclusion criteria, guiding the research toward its objective. The results show that olive farming is among the most developed agricultural value chains in several European and Asian countries; however, some regions in Latin America have also gained relevance in olive and olive oil. Production and marketing. In addition, certain countries have introduced incentives to encourage sustainable agricultural systems, both to mitigate the environmental impacts of farming and to strengthen markets for healthy food products. In Colombia, current research on olive cultivation highlights its potential in the country's central region, but also points to a lack of studies supporting the development of the value chain as a climate adaptation strategy. In areas where other crops are not viable, olive farming could offer a sustainable land use alternative and contribute to territorial development through the reinforcement of resilient agri-food systems.

KEYWORDS

climate change adaptation, food systems resilience, sustainable agriculture, multidimensional, production

1 Introduction

The global environmental crisis, the depletion of natural resources, and the growing inequality in rural territories have challenged the prevailing agricultural production models, which remain focused on the intensification and standardization of outputs according to market demands and standards (Durham and Mizik, 2021). In response to this scenario, an agroecological transition has gained traction, urging a rethinking of the ways in which rural territories are produced, inhabited, and governed through the articulation of ecological principles, local knowledge, and climate change adaptation strategies (Peña-Torres and Reina-Rozo, 2022). As a result, agroecology has emerged as a comprehensive approach that, beyond being a mere technique or production model, represents a transdisciplinary paradigm aimed at transforming the relationship between society, nature, and the economy, in alignment with situated and sustainable territorial knowledge (García-Parra et al., 2023).

In this regard, trends in sustainable production emphasize that agricultural systems must go beyond productivity and profitability. It has become urgent to incorporate a complex understanding of the social, cultural, economic, environmental, technological, and territorial dimensions that form the foundation of agroecology as a science, a practice, and a resilience-oriented strategy so it may serve as a key tool for designing rural development models that are responsive to specific contexts, while strengthening local capacities, territorial rootedness, and ecological resilience (Wezel et al., 2014).

Likewise, the diversification of agri-food systems has become an essential step to ensure medium- and long-term sustainability. Some non-traditional crops have gained prominence due to their adaptability, low environmental impact, and potential to stimulate local economies through differentiated value chains (Kanarp et al., 2025). One such example is the olive tree (*Olea europaea* L.), a species historically associated with the Mediterranean basin but which, in recent decades, has begun to establish itself as a viable alternative in territories with similar agroclimatic conditions. Its social, environmental, and economic relevance has grown in several Latin American countries (Filoda et al., 2021).

In line with this, olive cultivation presents a combination of agronomic, ecological, and commercial attributes that position it as a strategic option for promoting productive reconversion in rural areas characterized by edaphoclimatic limitations and low agricultural profitability (Ruiz et al., 2019). Its rustic nature, water use efficiency, resilience under adverse conditions, and increasing demand in specialized markets particularly for organic products such as extra virgin olive oil and table olives make it a compelling candidate for integration into agroecological practices and sustainable business models (Souissi et al., 2024). Various studies have pointed out that, when incorporated into diversified production systems adapted to local conditions, olive farming can contribute to the ecological restoration of degraded soils, the strengthening of peasant economies, and the development of short supply chains with added value (Altieri et al., 2015; Pino-Vargas and Ascencios, 2022).

In recent years, olive cultivation has gained visibility in tropical and subtropical regions, being adopted as a viable agroecological alternative in areas where traditional crops face growing challenges due to climate variability. Countries such as Chile, Mexico, Peru, Brazil, and Colombia have demonstrated the olive tree's capacity to thrive in poor soils and under water stress, making it a crop of

increasing agronomic interest (Herrera-Cáceres et al., 2017; Ariza-Ortega et al., 2024; Beghé et al., 2015; Osco-Mamani et al., 2025). In Colombia in particular, the olive tree has not only been harmoniously integrated into the local agroecological landscape but has also contributed to virtuous dynamics of territorial valorization, inclusive production, and sustainable rural development (Lozano-Castellanos et al., 2023).

The purpose of this article is to present a comprehensive review aimed at analyzing the relationship between olive cultivation, agroecology, and rural development, based on emerging experiences in diverse contexts. Through a systematic analysis of specialized literature, the paper identifies conceptual frameworks, tensions, and opportunities for articulating these three axes, with the goal of contributing to the consolidation of agri-food systems that are resilient, culturally relevant, and ecologically sustainable. This review seeks to highlight the role that olive farming may play in central Colombia, especially when it is conceived under agroecological principles and framed as a strategy for reconfiguring rural territories toward long-term sustainability.

2 Materials and methods

This scientific review was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Urrútia and Bonfill, 2010) (Figure 1) guidelines, which provide a structured framework for identifying, selecting, and analyzing relevant literature. The objective was to explore the current state of agroecological practices and olive cultivation, emphasizing their application in rural development and sustainability in the Colombian Andes, with a focus on the department of Boyacá.

2.1 Search strategy and data collection

To ensure the relevance and sensitivity of the search process, the equations “olive” and “olive AND agroecological production” was used as the main search string. This combination of keywords was applied using the Boolean operator AND to capture documents that explicitly address both olive cultivation and agroecological production systems.

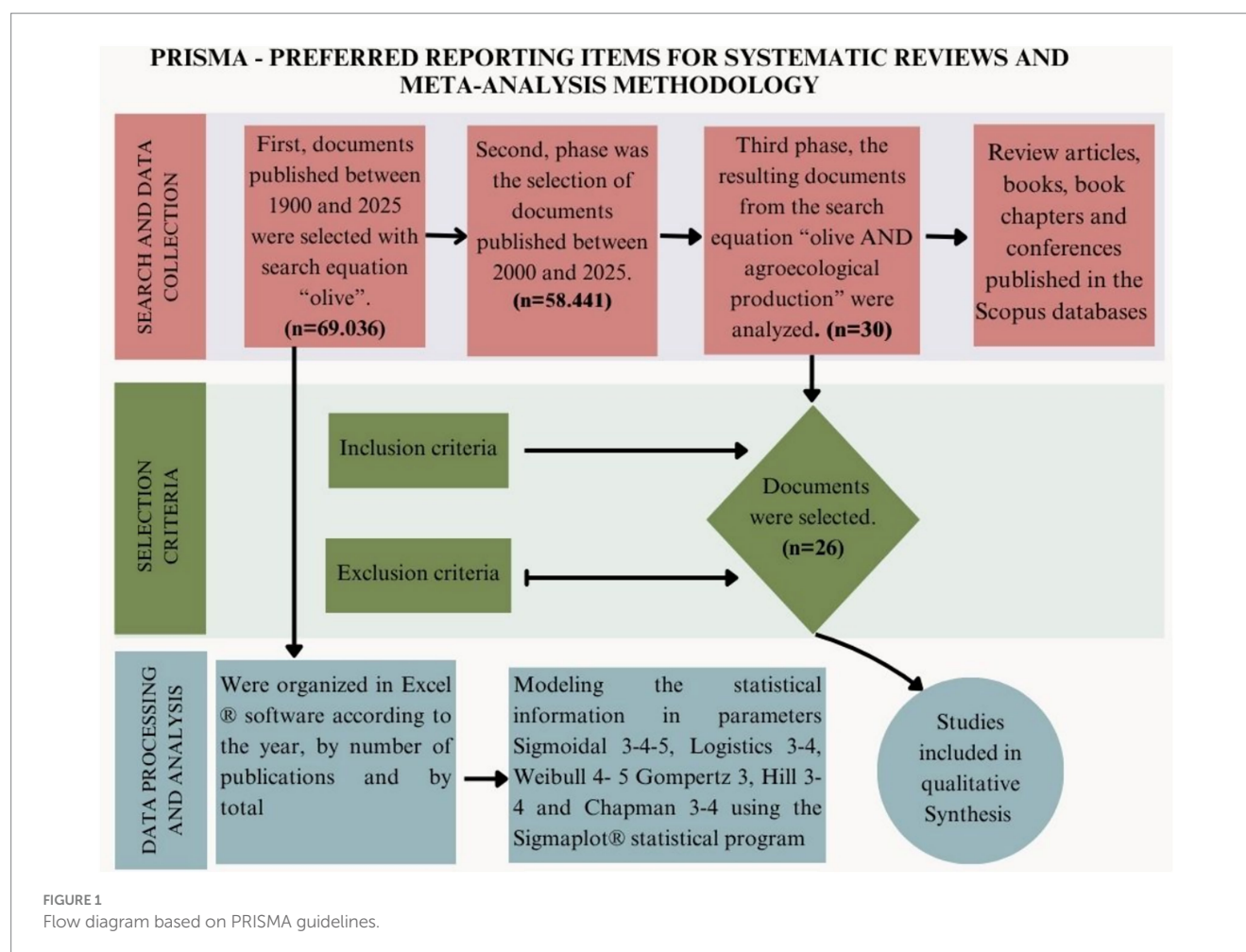
The search was performed in the Scopus database and included peer-reviewed scientific articles, review papers, books, book chapters, and conference proceedings.

2.2 Inclusion and exclusion criteria

The selection process involved three phases. First, documents published between 1900 and 2024 were selected with search equation “olive.” The second phase was the selection of documents published between 2000 and 2024. In the third phase, the resulting documents from the search equation “olive AND agroecological production” were analyzed (Figure 1).

Inclusion criteria were:

Publications indexed in Scopus; studies focused on agroecological systems, olive cultivation, sustainable agriculture, or rural innovation. Documents that analyzed territorial dynamics, biodiversity, or resilience in agriculture with agroecological approach.



Exclusion criteria included:

Scientific documents that are outside the established time interval.
Documents that focus on agriculture with conventional models without considering topics such as olive growing, agroecology, or territorial development.

2.3 Data processing and analysis

All retrieved documents were imported into Mendeley reference manager to eliminate duplicates. The remaining documents were organized in Excel and classified by publication year, thematic focus, and geographical context. A descriptive analysis was conducted to identify trends in scientific production over time, authorship concentration, and key countries and institutions contributing to the topic.

To examine the evolution and maturity of the field, the life cycle of publications was modeled using non-linear regression techniques, including Sigmoidal, Logistic, Weibull, Gompertz, Hill, and Chapman functions, as applied in previous bibliometric studies. Curve fitting was performed in SigmaPlot (Systat Software Inc., San José, CA, USA), selecting the best-fitting model based on the coefficient of determination (R^2) and significance level ($p < 0.05$).

Additionally, the main thematic clusters were identified according to Scopus classification codes (e.g., Agricultural and Biological

Sciences, Environmental Science, Social Sciences), allowing for an integrative understanding of the multidimensional nature of agroecological research in the region.

3 Results

Through the analysis, it was determined that a total of 69,036 documents related to olive cultivation have been published since 1900 in the Scopus database. These publications are primarily focused on the following areas: (i) agricultural and biological sciences, (ii) medicine, (iii) biochemistry, genetics and molecular biology, (iv) chemistry, and (v) environmental sciences. The leading institutions in this field of research include the Spanish National Research Council (CSIC), the Institute of Fat (IG, Spain), the University of Córdoba (Spain), the National Research Council (CNR, Italy), and the University of Granada (Spain).

By conducting a technology foresight analysis using the nonlinear regression models proposed by [Botero-Montoya et al. \(2024\)](#), it was found that the research outputs resulting from the search term “Olive” exhibit an exponential growth trend over the years, driven by the growing relevance of this production system in the economies of various countries worldwide. The data analysis was fitted to a three-parameter sigmoidal model, showing an inflection point projected for the year 2037 ($R^2 = 99\%$, $p < 0.01$) ([Table 1](#)).

TABLE 1 Nonlinear regression models fitting the search pathway for “Olive” analyzed from 2000 to 2024.

Model	Inflection point	a	b	c	p-value	Durbin Watson	R ²
Sigmoidal 3	2037	287262.1	11.8	–	0.0001	0.005	99%
Weibull 4	2026	163145.5	489010.8	41,010	0.8	0.5	99%
Hill 3	2,130	5756530.3	91.19	–	0.0001	0.05	92%

The a, b, c, and inflection point values belong to the equation of the models used.

Between 2000 and 2024, research on this crop has grown exponentially (58,441 publication), as reflected in the increasing number of scientific articles (45,587), review papers (3,550), conference proceedings (3,361), book chapters (2,153), and scientific notes (444) mainly. These publications have primarily focused on topics such as sustainability, biochemical properties, culinary uses, and health benefits (Figure 2).

As part of the methodological process, and following the inclusion and exclusion criteria established by the PRISMA methodology, a total of 30 publications were identified in the Scopus database using the search equation “olive AND agroecological production.” These publications were screened according to the defined criteria, as shown in Table 2, resulting in a final set of 26 studies that are directly related to the objective of this systematic analysis. This process allowed for the identification and categorization of relevant research conducted in various countries, addressing key topics such as sustainability, soil management, climate change adaptation, product quality, biodiversity conservation, and circular economy approaches within olive production systems.

The analysis of the information highlights the relevance of this production system across various regions of the worldwide, demonstrating the multifaceted impact of olive cultivation in Mediterranean countries, the Americas, and North Africa. Notably, countries such as Italy and Spain lead in research output, reflecting their strategic role in global olive oil production as well as in the development of its many derivatives for industrial use (Table 2). Based on this analysis, global research trends emphasize topics such as organic production, agroecological soil management, and climate change adaptation strategies areas that currently dominate the scientific agenda. In parallel, regions like Tunisia, Greece, and Turkey stand out for studies focused on agroecological transition and the impacts of sustainable practices within olive production systems (Pleguezuelo et al., 2018).

A key insight from the comparative analysis is the growing importance of agroecological practices, which contribute not only to environmental indicators but also to rural wellbeing, productive resilience, and the quality of both primary and secondary olive-based products. Additionally, a rising interest is observed in the adoption of technological and innovative tools, such as biocontrol agents and origin tracking sensors, suggesting a progressive integration between traditional knowledge and scientific advancements (Gkisakis et al., 2020). This trend underscores the need for public policies that support the implementation of sustainable practices in the olive sector, while acknowledging the territorial particularities that shape production systems. Furthermore, it positions rural areas as key spaces for development, where education, research, and technical assistance can converge to foster sustainability.

The findings underscore the need to reconsider olive cultivation not only as an economically significant activity, but as a socioecological

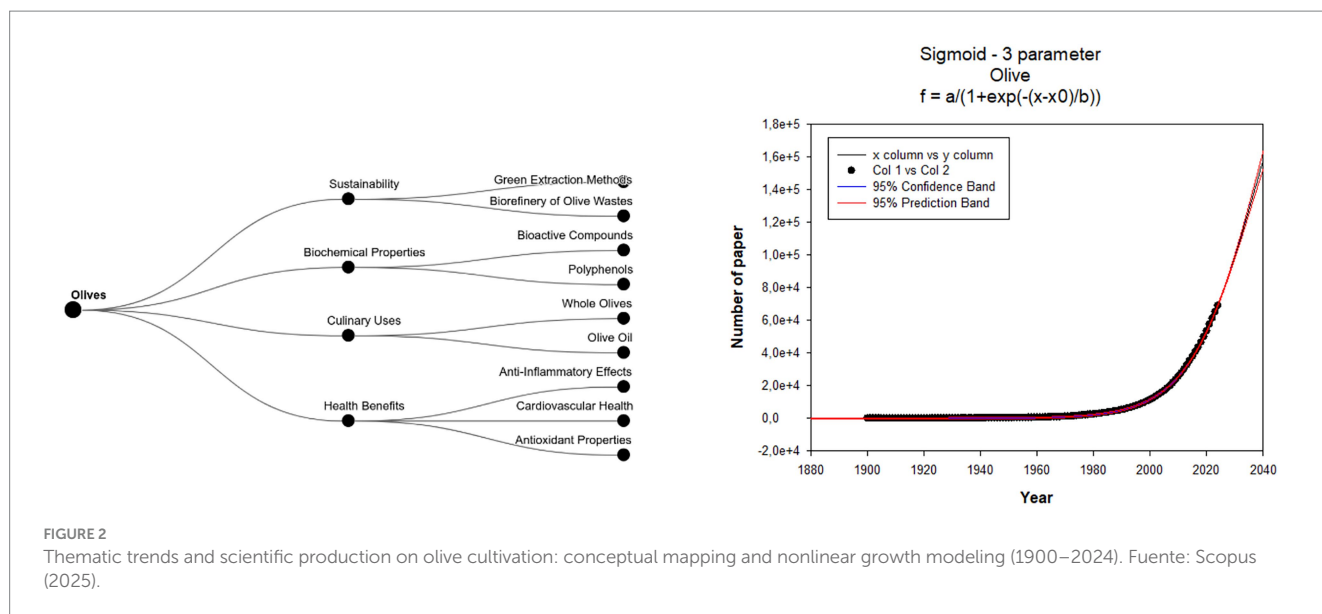
system deeply connected to territorial dynamics and the challenges posed by sustainability. This is evident in the prevalence of topics such as organic production, agroecological management, and climate change adaptation key elements in the consolidation of an emerging paradigm that goes beyond conventional agricultural models and incorporates the realities and actors embedded in the complexity of the productive system (Irhza et al., 2024). Within this context, agroecology offers a theoretical and practical framework capable of addressing the intricacies of olive production systems, particularly in regions characterized by environmental limitations, rural vulnerability, and strong agricultural traditions. It therefore becomes essential to examine the principles of agroecology and their relevance in rethinking olive cultivation through the lenses of resilience, equity, and harmony with natural resources.

3.1 Agroecological theory

Agroecology, conceived as a science, movement, and practice, represents an emerging paradigm that has established itself as a viable alternative to dominant agroindustrial models. According to Altieri and Nicholls (2017), agroecology proposes a holistic approach based on ecological principles for the design and management of sustainable agricultural systems, although its scope goes beyond that. Therefore, its transdisciplinary nature allows it to integrate traditional knowledge, peasant experiences, and scientific knowledge in the search for resilient and culturally appropriate systems. Therefore, far from being a simple green technification, agroecology seeks to transform the relations of production, the ways of inhabiting the land, and the social structures that have sustained dependence on agrochemicals and extractive agriculture.

From a comparative perspective, scholars such as Miguel Altieri and Clara Nicholls have emphasized that agroecology cannot be understood solely through productive parameters; rather, it must be interpreted as a process of social reconfiguration that centers the role of rural communities, their autonomy, and their relationship with nature. Gliessman (2007), for his part, proposed five levels of agroecological transition, ranging from energy efficiency to the transformation of the entire food system. This leads to the understanding that this process involves not only the revision of productive practices but also the questioning of power structures and marketing networks, recognizing the deeply political nature of agroecology as a struggle for models of life that transcend market logic.

Under this understanding, crops of food and industrial importance have sought to rethink their production methods in order to achieve greater efficiency in the use of resources and minimize the impacts they have on the environment (Ostrom, 2009). To this end, FAO continuously monitors the dynamics of crop production around the world, recognizing that crops such as olives represent one of the



main agricultural and economic strengths of countries such as Spain, Italy, Turkey, Portugal, and Tunisia, with more than 11 million tons of olives by 2023. In the case of America, countries such as Argentina, Peru, Chile, and the United States stand out, accounting for nearly 800,000 tons of olive production (FAO, 2023).

Under the productive dynamics of this crop, strategies have been developed that seek to strengthen more sustainable agricultural systems, where food production is not at the expense of natural resources and where social development becomes a fundamental axis within agriculture (Grandi et al., 2023). Thus, it is important to recognize that olive production is influenced by climatic and socioeconomic vulnerability, for which reason, different countries have sought to strengthen the development of orchards that achieve a lower demand for agricultural inputs, as is the case in some regions of the Mediterranean, where olive cultivation management has been transformed to maintain a balance between food production, economic investment, and the protection of biodiversity (Dias et al., 2022).

Thus, it is interesting to address the development of agroecological practices in olive production systems, as highlighted by Mejri et al. (2025), where special attention is paid to six principles associated with the co-creation of knowledge, social value, nutritional value, equity, connectivity, land governance, use and care of natural resources and community participation, with the aim of achieving comprehensive roadmaps and articulating sustainability within the framework of economic growth and commitment to the community from a holistic approach. Furthermore, Migliorini et al. (2018) detail the actions developed in sustainable agri-food systems in the Mediterranean, as the main olive-growing macroregion, highlighting fundamental actions around water, production, soil, research, waste and people and institutions (Figure 3). This analysis understands that agroecology is unfortunately still an emerging concept in agriculture. However, it shows great potential due to the sociocultural, biophysical, and political-economic characteristics of the producing regions. It also presents challenges focused on greater networking, with greater participation from different actors and institutions that support productive transition processes.

For this reason, to better understand the dynamics that arise in agroecological experiences, it is useful to resort to the theory of socioecological systems, developed by Ostrom (2009) and expanded by Berkes et al. (2000), where it is possible to analyze from a holistic vision, farms that address agroecological principles as complex and interdependent systems that integrate ecological, economic, organizational and cultural components, since unlike reductionist models, the socioecological approach starts from the interaction between human beings and their environment as a functional unit, where local decisions directly affect the health of the ecosystem.

In the particular case of Alto Ricaurte (Colombia), biophysical characteristics limit the full development of crops and hinder economic competitiveness compared to other regions, mainly because this area has poor soils with low availability of minerals and organic matter, along with a limited water supply, which results in low olive production (García-Parra et al., 2023). However, in this region, olive trees manage to remain green (abundant foliage) and bloom throughout the year, mainly because climatic factors such as temperature and radiation do not allow these trees to undergo physiological differentiation and therefore permanent fluctuations in harvest yield. Under this scenario, strategies should be established that seek to diversify the use of this crop, generating bets with a focus on organic production (Paffarini et al., 2021), production of other crops associated with the olive tree (Irhza et al., 2024), honey production in olive orchards (Moreno-Delafuente et al., 2022) and olive leaf tea (Ferdousi et al., 2019).

Thus, these bets align with Edgar Morin's concept of complex thinking, where the adoption of agroecology is based on a non-fragmented perspective. For Morin, vital phenomena, including production processes, cannot be understood from isolated disciplines, but rather require a systemic and contextual perspective (Gómez et al., 2015). This implies recognizing the multidimensionality of agroecological processes, understanding that agriculture is not limited to food production, but also builds culture, regenerates soils, strengthens identities, and mobilizes diverse knowledge systems. Considering that complex thinking rejects linearity and simplicity, it

TABLE 2 Summary of recent scientific research on agroecological practices in olive cultivation: trends, countries, findings, and sources.

Trends	Country	Findings	Source
Organic production	Italy	The study analyzes how origin, organic, and carbon footprint certifications influence olive oil purchasing behavior, with greater preference for well-known labels. It was found that combining several labels can either increase or decrease willingness to pay, depending on the country.	Paffarini et al. (2021)
Agroecological practices	Tunisia	In 50 olive farms in central Tunisia, limited adoption of agroecological practices was observed (average 41%), mainly due to low technical capacity and weak institutional support. Larger farms showed the highest level of transition, which could be accelerated through training in agroecological performance and rural resilience.	Gharbi et al. (2025)
Ecological soil management	Greece	Desertification in the Mediterranean basin is worsened by intensive land use, particularly in olive groves. A study in southern Greece compared three soil treatments and found that cover crops improved fertility, increased biomass, and conserved arthropod biodiversity, contributing to soil regeneration and climate change mitigation.	Michail et al. (2025)
Production conditions	Croatia	Biostimulants improve soil quality, fruit quality, and stress tolerance in olive trees. Their effectiveness varies by cultivar and growing conditions, indicating the need for more targeted research.	Batelja Lodeta et al. (2025)
Sustainable production	Turkey	Local plant residues were evaluated as sustainable alternatives to peat in olive propagation. After 24 months, seedlings grown in compost made from olive prunings showed similar development to those grown in peat, with notable root quantity and structure, confirming compost as an effective agroecological option in Mediterranean climates.	Kir (2025)
Agroclimatic conditions	Jordan	The study analyzed data from 1995 to 2022 across four regions and found that optimal temperatures support olive production, while extreme cold and heat reduce yields. Yield increases are projected due to climate trends, prompting recommendations for adaptation measures to protect agricultural production.	Al-Kofahi et al. (2025)
Agroecological strategies	Italy	Climate change severely affects agriculture in regions like California and Italy, where rising temperatures and water scarcity threaten crops. This comparative analysis highlights agroecology as an effective strategy to enhance resilience, conserve water, and safeguard agricultural production.	Negri et al. (2025)
Agriculture and climate change	United States	Agrobiodiversity in the Mediterranean is threatened by olive monocultures, especially in Spain, Morocco, and France. Peasant and food sovereignty movements promote practices that preserve traditional crops such as cereals and legumes. There is a call for policies that link production and consumption to foster sustainability, biodiversity conservation, and climate adaptation.	Zimmerer et al. (2024)
Sustainable production	Spain	The feasibility of agroecological practices in olive groves was evaluated, revealing social, economic, and environmental benefits. Using the Delphi method with 26 experts, key practices identified included cover crops, minimal soil disturbance, and multifunctional borders highlighted for their high potential in sustainable olive oil production.	Vergara-Romero et al. (2024)
Agroecological practices	Tunisia	The agroecological transition in arid areas of northwest Tunisia was analyzed, emphasizing the role of peasant organizations in the olive oil value chain. Despite challenges like water scarcity, low income, and lack of incentives, locally compatible practices were identified as beneficial for the environment and health. The study stresses the importance of participatory, gender-sensitive approaches in building sustainable and resilient food systems.	Souissi et al. (2024)
Sustainable production	Portugal	The intensification of olive cultivation in Portugal and the Mediterranean raises concerns about its impacts. Agronomic strategies in high-density irrigated groves were analyzed, highlighting deficit irrigation, cover crops, and no-till practices that reduce erosion, improve soil carbon, and support biodiversity.	Sobreiro et al. (2024)
Agricultural sustainability	Morocco	Agricultural systems in central Morocco frequently use agroforestry with olives and associated crops. Although practices close to agroecology are present, regional, crop, and management differences persist. Strengthening local knowledge and introducing agroecological practices is necessary.	Irhza et al. (2024)
Agricultural sustainability	Italy	Mediterranean olive growing is threatened by intensive practices and synthetic inputs. The Sustainolive project promotes sustainability in the olive oil sector through agroecological solutions that integrate scientific and traditional knowledge, contributing to environmental, economic, and social development.	De Luca et al. (2023)
Product quality	Argentina	In Argentina, 18 olive varieties were evaluated for oil quality. Five lesser known varieties outperformed common ones in industrial yield, oxidative stability, and phenolic content, highlighting their potential for the local olive oil industry.	Banco et al. (2023)
Agritourism	Spain	In Madrid, the “Olivares de Miel” project introduced aromatic plants and beehives to diversify production, improve soil quality, and prevent erosion. Preliminary results show positive impacts on sustainability and ecosystem services, benefiting the olive, beekeeping, and agritourism sectors.	Moreno-Delafuente et al. (2022)

(Continued)

TABLE 2 (Continued)

Trends	Country	Findings	Source
Soil management	Turkey	Nine agroecological alternatives to copper for controlling olive leaf spot were evaluated under organic management in a Mediterranean climate. Vermicompost tea, potassium silicate, and certain biocontrols reduced disease and increased phenolic compounds. Vermicompost tea showed promise, though further research is needed to fully replace copper.	Kir et al. (2022)
Plant ecophysiology	Cyprus	Low fruit set in olives, despite abundant flowering, is due to ecophysiological factors like genetic variability, nutrient competition, floral architecture, and climate change. Yield alternation and self-pollination also negatively impact production.	Maniriho (2022)
Production systems	France	In Tunisia, farmers adopt agroforestry systems combining olives and summer vegetables to diversify income and reduce costs amid limited access to land and water. While not fully agroecological, these systems offer a basis for transitioning to more sustainable production models.	Leauthaud et al. (2022)
Circular economy	Italy	The application of circular economy principles in the olive oil value chain is analyzed, identifying strategies, technological advances, and knowledge gaps. The study provides a theoretical and practical foundation for promoting circularity and overcoming barriers in the sector.	Stempfle et al. (2021)
Organic production	Greece	The study evaluated energy use and greenhouse gas emissions in organic, integrated, and conventional olive groves. Fossil fuels and synthetic fertilizers were major sources. Although differences among systems were minimal, organic groves tended to use less energy. The CO2MPUTOLIV 1.0 tool was developed to assess these impacts and support sustainable production.	Gkiskakis et al. (2020)
Production in humid climate	Uruguay	Olive cultivation in Uruguay has proven viable under humid climate conditions, achieving yields over 8 t/ha and 40% oil content (dry weight). Arbequina and Picual varieties stood out for their productive efficiency, though biennial bearing was identified as a major limiting factor.	Conde-Innamorato et al. (2019)
Organic production	Spain	Organic olive farming in Andalusia has grown as a response to sustainability challenges, prioritizing quality, health, and environmental protection. The study highlights improvements in biodiversity and soil, but emphasizes the need for economic viability, institutional support, and greater understanding of consumer behavior regarding organic olive oil.	Pleguezuelo et al. (2018)
Product quality	Portugal	A potentiometric electronic tongue combined with linear discriminant analysis was shown to accurately identify the geographical origin, variety, and quality of Tunisian olive oil. This technique offers an innovative tool for protecting designations of origin and addressing consumer preferences.	Souayah et al. (2017)
Biodiversity	Greece	In Crete olive groves, soil arthropod biodiversity was more influenced by climate, agricultural practices, and landscape complexity than by management type. Temperature, tillage, and relative humidity were key factors, highlighting the need to consider both environment and farming practices in biodiversity assessments.	Gkiskakis et al. (2020)
Agroecological production	Spain	The potential of organic farming as an agroecological strategy in Andalusia was analyzed through a case study of an olive growers' cooperative. Although ecological management involves higher costs, it generates greater income and employment compared to conventional systems, positioning it as a key alternative for rural development.	Mielgo et al. (2001)

Source: Scopus (2025).

allows for the identification of synergies, tensions, and contradictions inherent in agroecological practices.

Thus, the development of agriculture is closely linked to rural development, as highlighted by [Manzanal et al. \(2011\)](#), who, from a theoretical and conceptual perspective, analyze how agroecological processes are integrated into the social, economic, and environmental dynamics of rural territories, considering the territory not only as a geographical area, but as a socially constructed and contested space. In this sense, olive plantations in Alto Ricaurte have become an attraction, not only because of their great capacity to adapt to this region with degraded and arid soils, but because it is currently the only region that has trees with olive production and from which products such as preserved olives, olive oil and olive leaf tea are obtained, thus strengthening the tourist interest in this region and what has become a territorial project that redefines the relationships between actors, resources and spaces, especially in coherence with the adaptive capacity to climate change and the development of agricultural practices, which result in the adequate use of natural resources, which

has allowed different actors linked to this agricultural chain to combine the appropriation of the territory, not only from an exclusively production perspective, but also from identity, governance and symbolic recognition as conceived from the agroecological production approach ([León-Sicard et al., 2017](#); [Acevedo-Osorio et al., 2024](#)).

3.2 Agroecological practices in cropping systems

The implementation of organic agricultural practices contributes to reducing nutrient leaching, enhancing carbon sequestration, and mitigating both soil erosion and the presence of pesticide residues in water sources ([Gamage et al., 2023](#)). From this perspective, the farm is conceived as a self-sufficient ecosystem in which reliance on external inputs is kept to a minimum ([Bohórquez Sandoval et al., 2024](#)). One of the core principles of this model is the optimization of nutrient

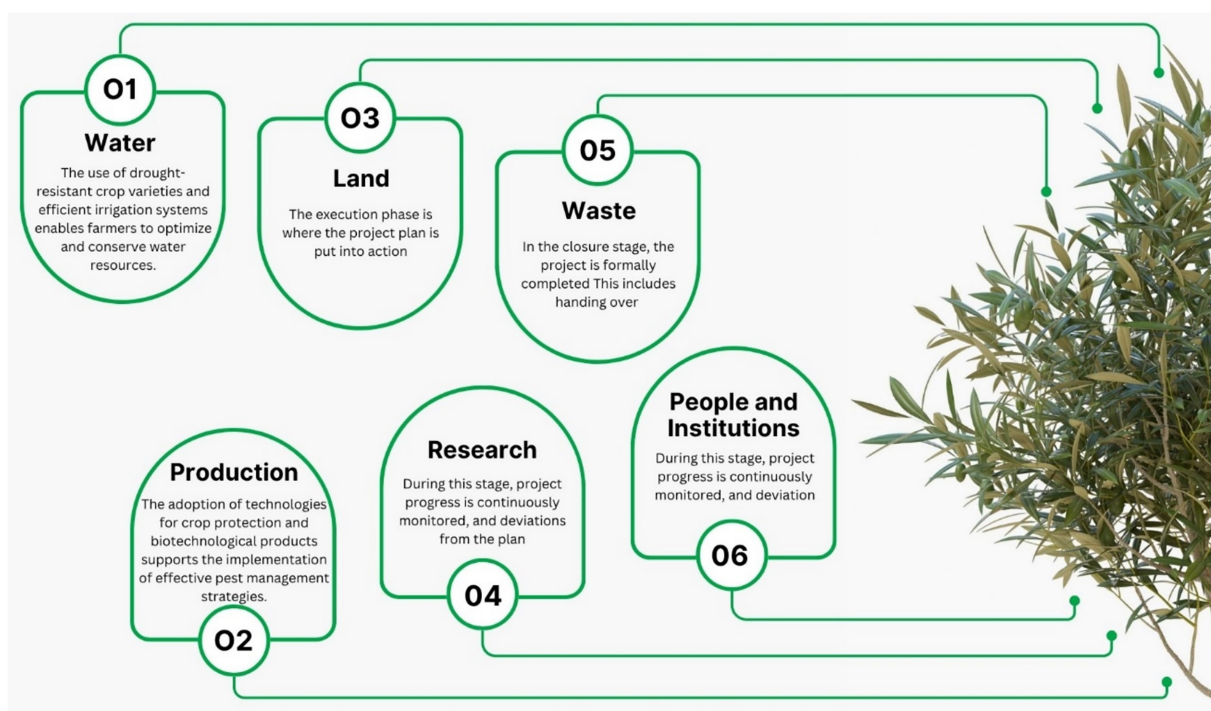


FIGURE 3
Agroecological factors associated with olive cultivation. Source: Authors (2025).

recycling within the production system itself, achieved through strategies such as biological nitrogen fixation and crop rotation. These techniques not only enhance soil fertility but also help preserve its organic matter content (García et al., 2024).

From an agroecological approach, this production system promotes biodiversity conservation, regulates biological cycles, and enhances microbial activity in the soil. By minimizing the need for external inputs, organic agriculture contributes to maintaining ecological balance and strengthening the resilience of agricultural ecosystems (Plazas-Leguizamón and García-Molano, 2014).

In this context, the development of intensive agriculture has led to the progressive depletion of forests and grasslands in recent decades. It is projected that, in the coming years, the expansion of such production systems will exert significant pressure on global biodiversity (Teixeira et al., 2021). A clear example of this impact is the decline in populations of agricultural organisms and microorganisms in Latin America, directly attributed to the intensification of agro-industrial practices (Gupta et al., 2022; Dhuldhaj et al., 2023). In this regard, the adverse effects of intensive agriculture become even more evident when compared to agroecological and organic approaches, considering that the wide diversity of species including birds, mammals, invertebrates, and cultivated flora experiences a decrease in both abundance and specific richness in highly managed agricultural environments (Outhwaite et al., 2022).

Despite the environmental and ecological benefits of organic agriculture, its viability is questioned by sectors that argue it leads to reduced yields. According to the FAO (2025), the productivity of these systems largely depends on the previous agricultural management model, as well as the socioeconomic and environmental context. In

industrialized countries, where conventional production predominates and the use of external inputs is high, the transition to organic practices often results in yield reductions, the extent of which varies depending on the intensity of prior input use. Nevertheless, globally, nearly 99 million hectares are devoted to organic agriculture, demonstrating production levels comparable to those of conventional agriculture (Durham and Mizik, 2021; Willer et al., 2025).

Conversely, in traditional rainfed agricultural systems characterized by limited use of synthetic inputs the adoption of organic practices has shown increases in productivity. This suggests that implementing such practices can be a viable strategy to strengthen food security in low-technology settings (Gamiero, 2021). In the case of Latin America, the development of ecological agriculture has followed a different path than in the European Union. While the EU has implemented subsidy policies and financial support since the 1990s to encourage conversion to ecological production, in Latin America, the expansion of organic agriculture has been driven mainly by market demand and the action of non-governmental organizations, cooperatives, and peasant movements (Ceja et al., 2024).

Some Latin American countries such as Argentina, Brazil, Mexico, and Chile have developed regulations and certification systems to regulate organic production, facilitating access to international markets (Tittone et al., 2021). However, government support in terms of direct subsidies has been limited compared to the European model. In some Latin American countries, incentives have focused more on technical assistance, participatory certification, and market access than on direct economic compensation for transitioning producers. Despite these differences in promotion policies, ecological agriculture has grown steadily in Latin America, due to its export potential and the recognition of its environmental and socioeconomic

benefits (Sabourin et al., 2018). In this sense, the adoption of this productive paradigm has gained importance, particularly as a response to the crisis of conventional neoliberal models, where rural communities seek greater productive autonomy and resilience in the face of climate change (Plazas-Leguizamón and García-Parra, 2017; Colmenares-Cruz et al., 2024).

In the specific case of Colombia, the implementation of crops adapted to new climate conditions is crucial for the adaptation of the agricultural sector, especially under the current scenario of permanent climatic variability, characterized by prolonged droughts and intense floods that affect the productivity of traditional crops (Korres et al., 2016; García-Parra et al., 2020). Therefore, it is urgent to adopt species with greater resistance to these changes, such as the olive tree (*Olea europaea* L.), which has shown a high capacity to adapt to low water availability and high tolerance to extreme conditions, as reported for the central region of Colombia (Bello et al., 2016). Moreover, the promotion of agroecological systems and crop diversification not only helps mitigate the effects of climate change but also enhances soil conservation, biodiversity, and food security. In this way, the adoption of such practices across different agricultural production systems in Colombia supported by development and research policies can strengthen the resilience of the agricultural sector and improve its long-term sustainability (León-Sicard et al., 2017).

3.2.1 General characteristics of the olive tree

The olive tree (*Olea europaea* L.) belongs to the Oleaceae family, which comprises 29 genera and approximately 600 species with cosmopolitan distribution. Among them, the olive is the most economically important species and the only one that produces edible fruit (Barazani et al., 2023). The tree typically reaches an average height of 4–8 meters, depending on the variety, and can remain alive and productive for several centuries. It has a thick trunk with bark that varies in color from shades of gray to green. The crown is rounded, and the branches tend to form a dense canopy. The leaves are small, thick-textured, green on the upper surface and silvery on the underside. The yellowish flowers are small, actinomorphic with regular symmetry, and arranged in clusters; they are hermaphroditic or bisexual. The fruit is a drupe, initially green, turning black upon ripening (Figure 4). It is oblong in wild varieties and oval or rounded in cultivated ones (Ruiz et al., 2019).

3.2.2 Fruit composition

The olive fruit has a fresh weight that may range from 1 to 10 g upon full maturation. Of this total weight, 70–90% corresponds to the pulp, 9–27% to the pit, and 2–3% to the seed (Khadiji et al., 2022). These proportions can vary significantly depending on the variety, the ripeness stage, and the fruit load on the tree (Mafrika et al., 2021). Additionally, it has been determined that the pulp is composed of 50–60% water, while oil concentration ranges between 20 and 30%, with an inverse relationship between the two (Salas et al., 2000).

The sugars that stand out in olives are primarily reducing sugars, which serve as the raw material essential for the fermentation process. As the fruit matures, the levels of reducing and total soluble sugars decline, reaching a minimum level that remains stable until the end of ripening. The main sugars present are glucose, fructose, mannitol, and sucrose, with smaller amounts of xylose and rhamnose (Alhajj-Ali et al., 2024).

What makes this crop particularly noteworthy is its capacity to accumulate fatty acids. This is achieved through the development of metabolic pathways that cause enlargement of the parenchymal cells in the pulp as the pit hardens. Several studies have shown that the carbon source for lipid biosynthesis can be either the leaf or the fruit itself; however, both sources of reduced carbon are required to achieve full oil accumulation (Sánchez and Harwood, 2002).

During ripening, the pigmentation of the olive changes as chlorophyll and, to a lesser extent, carotenoid levels decrease, while anthocyanin concentrations increase significantly (Motilva and Romero, 2010). This phenomenon produces a shift in color from green to yellowish-green, referred to as “green ripening,” followed by the biosynthesis of anthocyanins that give the fruit a reddish-violet hue. This colour change begins at the apical area of the epidermis and progresses toward the peduncle, eventually coloring the mesocarp, from the outermost layer to the endocarp (Moyano et al., 2010).

Among the most important compounds present in olives are phenolic compounds, which constitute one of the most prominent classes of secondary plant metabolites. Their physiological role is mainly associated with defense mechanisms in plants especially in response to herbivores and microbial attacks. However, they are also synthesized as protection against oxidative damage and are regulated by both genetic and environmental factors (Alagna et al., 2012).



FIGURE 4
General attributes of the olive tree and its fruits in Alto Ricaurte – Boyacá – Colombia. Source: Author (2022).

3.2.3 Uses of the olive fruit

According to the standard applicable to table olives, issued by the International Olive Council in December 2004, “table olive” refers to the product prepared from healthy fruits of cultivated olive varieties, harvested at the appropriate stage of maturity and subjected to processes aimed at eliminating natural bitterness. These fruits are preserved through natural fermentation or thermal treatment, with or without preservatives (Masquillan and Iturrieta, 2008). Among the cultivable varieties, those producing fruits with favorable characteristics such as volume, shape, pulp-to-pit ratio, pulp tenderness, flavor, firmness, and ease of detachment from the pit are particularly preferred for preservation (Al-Wilyan et al., 2002).

Table olives are classified according to their degree of ripeness into three types: Green olives: harvested during the ripening cycle before veraison, when they have reached their normal size; Turning-color olives: harvested before full ripeness, during the veraison stage; Black olives: harvested when fully ripe or shortly before full maturity. They are also classified by preparation method as seasoned, natural, dehydrated, or oxidized black olives (Garrido-Fernández and Romero-Barranco, 1999).

According to the International Olive Council (2020), olive oil is obtained exclusively from the fruit of the olive tree, excluding oils extracted by solvents, re-esterification, or mixtures with oils of other natures. The following designations and definitions apply:

Virgin olive oil: obtained solely by mechanical or other physical means from the olive fruit under conditions particularly thermal that do not alter the oil. The olives may only undergo washing, decantation, centrifugation, and filtration (IOC, 2020).

Extra virgin olive oil: virgin olive oil with a free acidity, expressed as oleic acid, not exceeding 0.8 g per 100 g, and meeting all other specifications for this category (IOC, 2011).

Virgin olive oil: with free acidity not exceeding 2 g per 100 g, and meeting the other specifications for this category (IOC, 2011).

Lampante olive oil: virgin olive oil with free acidity above 3.3 g per 100 g and/or other characteristics not meeting the requirements of the previous categories (IOC, 2011).

Refined olive oil: oil obtained from virgin olive oils through refining, with free acidity not exceeding 0.3 g per 100 g, and meeting the other specifications for this category (IOC, 2011).

Olive oil: a blend of refined olive oil and virgin olive oils other than lampante oil, with free acidity not exceeding 1 g per 100 g, and meeting all other standards for this category (IOC, 2011).

Crude olive-pomace oil: obtained from olive pomace by solvent extraction or other physical methods (IOC, 2011).

Refined olive-pomace oil: obtained by refining crude olive-pomace oil, with free acidity not exceeding 0.3 g per 100 g, and complying with the category's specifications (IOC, 2011).

Olive-pomace oil: a blend of refined olive-pomace oil and virgin olive oils other than lampante, with free acidity not exceeding 1 g per 100 g, and meeting the required standards for this category (IOC, 2011).

3.2.4 Uses of the olive fruit

Olive cultivation in Boyacá has emerged as a relevant productive alternative for the department's agricultural sector, despite not being traditionally associated with it. In recent years, olive farming has gained importance in certain areas of the Andean region, particularly in locations with favorable agroclimatic conditions for its

establishment (García-Molano, 2010). However, the lack of technical and scientific information on varieties with better adaptive performance in the high Andean tropics, along with limited infrastructure for product processing and commercialization, are among the main challenges to consolidating this value chain (García and Jaramillo, 2012). Currently, production remains small-scale, established on family farms that seek to diversify their agricultural systems through high-value perennial crops, especially in areas where other crops fail to adapt an observation supported by numerous studies on olive production systems conducted by the Juan de Castellanos University Foundation (García-Molano et al., 2013).

From a future-oriented perspective, olive farming in Boyacá has the potential to become a strategic productive sector within the department's agri-food economy. Research on cultivar identification and selection, adaptation of European varieties, and the establishment of sustainable management practices could foster its expansion (Beghé et al., 2015). Several research-oriented institutions have already begun to study the phenological and agronomic performance of olives in the Andean highlands, generating essential information for decision-making on crop management (Ruiz et al., 2019). Additionally, the growing demand for olive-derived products such as oils and preserves creates opportunities for value chain development that could generate employment and stimulate local economies. These efforts can be supported by coordinated agricultural promotion activities and collaboration with academic and scientific institutions, which will be crucial to ensuring the sector's competitive development in the medium and long term (Jaramillo, 2018).

To consolidate olive cultivation as a relevant activity in Boyacá's rural development, it is essential to establish technical, financial, and commercial support strategies that enable its scaling and sustainability. The strengthening of productive initiatives, access to differentiated markets, and implementation of small and medium scale agroindustrial models could enhance its impact on the regional economy (García-Molano, 2012). In this regard, universities, research centers, and agricultural organizations play a key role in farmer training and the generation of knowledge on olive varieties, phytosanitary management, and oil extraction techniques. Furthermore, the development of rural extension programs will ensure that farmers adopt appropriate practices for efficient and competitive olive production in the territory. In this way, integrating olive farming into rural dynamics will not only strengthen food security and local economies but also promote a development model based on sustainability and productive resilience.

3.3 Prospective olive production in Colombia

Understanding the momentum of olive cultivation in Colombia requires a careful examination of the research efforts that have contributed to characterizing its behavior under the specific conditions of the regions where the species is currently being grown. Despite being a relatively recent crop in the national agricultural landscape, various studies have emerged focusing on phenological adaptation, interactions with edaphoclimatic conditions, germplasm composition, and soil management processes. Most of these studies have been conducted in the central region of Colombia, particularly in Boyacá, reflecting both institutional interest and the agroecological

potential of this crop in the area. However, the approaches adopted by these studies have been diverse, responding to specific academic agendas and illustrating the different phases of understanding the crop. In this context, constructing a chronological systematization of the research carried out makes it possible not only to organize the existing body of knowledge but also to identify thematic trends and areas requiring further investigation. Accordingly, Table 3 compiles the most representative studies on olive cultivation in Colombia, classified according to thematic focus, in order to reflect the evolution of scientific learning over time.

The trajectory of olive cultivation in Colombia, although recent when compared to Mediterranean regions and other Latin American countries, has progressively established itself as an emerging agricultural research field, particularly in the department of Boyacá. Several studies in this region show a gradual shift from initial descriptive and adaptive explorations to more specialized approaches in genetics, phenology, soil science, and microbiology (García-Molano, 2010). This evolution has enabled a more technical understanding of olive cultivation under non-conventional conditions, such as those found in the Cundiboyacense high plateau. However, the thematic concentration on agronomic and microbiological aspects contrasts sharply with the limited academic production on the economic, commercial, and social dimensions that determine the long-term sustainability of the olive value chain in the country.

Since 2014, studies by García-Molano et al. (2013) on the phenological behavior of olives in the Alto Ricaurte region, and Beghé et al. (2015), who conducted a molecular analysis of local germplasm, have offered valuable insights into the adaptive dynamics of *Olea europaea* L. under tropical high-altitude conditions. These were complemented by research from Bello et al. (2016) and García-Molano et al. (2013), who delved into the olive rhizosphere, revealing complex interactions between root microbiota, pruning systems, and the physicochemical properties of soils. This scientific focus on the rhizospheric environment and crop biology has been key to demonstrating that olive cultivation in Colombia is not only agronomically feasible, but also ecologically strategic, particularly in the framework of climate-smart agriculture.

Nevertheless, from a critical and forward-looking perspective, it is evident that scientific production in Colombia has not yet managed to link technical findings with a broader territorial development agenda. There remains a notable absence of studies addressing the socio-economic development of olive production, the organizational dynamics of producers, the creation of territorial brands, or public policy frameworks needed for scaling up. Despite technical progress, most research remains embedded in experimental frameworks with limited projection toward social innovation or inclusive market access, reducing its potential to drive structural transformations in rural contexts.

TABLE 3 Scientific research on olive cultivation in Colombia.

Title	Year of publication	Study area	Focus
Overview of olive cultivation in Boyacá	2010	Boyacá	General review of olive cultivation in the tropical highlands of Colombia, including historical background, adaptation processes, and early challenges.
Molecular study of olive germplasm in Colombia	2012	Alto Ricaurte, Boyacá	Field identification of local olive cultivars using SSR molecular markers; highlighted varietal homonymy and genetic divergence.
Phenological behavior of olive (<i>Olea europaea</i> L.) in Alto Ricaurte (Boyacá)	2014	Alto Ricaurte, Boyacá	Analysis of the phenological stages (sprouting, flowering, fruit set) of olive trees under tropical highland conditions.
Olive biodiversity in Colombia. A molecular study of local germplasm	2015	Villa de Leyva, Boyacá	Molecular analysis of local germplasm; identification of genetic variability and potential for cultivar selection.
Flower and fruit development of olive (<i>Olea europaea</i> L.) under tropical conditions	2016	Alto Ricaurte, Boyacá	Study of floral development and fruit growth patterns of olives in a non-Mediterranean tropical environment.
Olives and olive oil production in the Alto Ricaurte climate region in Boyacá, Colombia	2019	Alto Ricaurte, Boyacá	Evaluation of agronomic performance of olive cultivars and quality parameters of virgin olive oil under Colombian conditions.
Climatic differences between traditionally olive-producing regions and the Alto Ricaurte region in Colombia	2020	Alto Ricaurte, Boyacá	Comparative study between global olive-producing climates and Colombian highland conditions to assess viability and limitations.
Quantification of diazotrophs in the rhizosphere of olive (<i>Olea europaea</i> L.) grown in Boyacá, Colombia	2022	Villa de Leyva and Sutamarchán, Boyacá	Microbiological analysis of nitrogen-fixing bacteria associated with olive rhizosphere in volcanic soils.
Microbial community in the rhizosphere of olive (<i>Olea europaea</i> L.) in Boyacá-Colombia	2022	Villa de Leyva and Sutamarchán, Boyacá	Characterization of microbial diversity in olive rhizosphere and its ecological role under tropical highland farming systems.
Can olive pruning forms influence the olive rhizosphere? The root microbiota and rhizosphere properties in Alto Ricaurte (Colombia)	2022	Alto Ricaurte, Boyacá	Evaluation of how different pruning techniques affect root-associated microbial communities and soil biochemical properties.

Source: Authors (2025).

From this perspective, it becomes essential to expand the research and development pathway of the sector, integrating olive cultivation into an agroecological framework that values situated knowledge and the role of smallholder farming. The accumulated experience reflected in studies such as Ruiz et al. (2019), which assessed oil quality and cultivar performance under Alto Ricaurte conditions, points to the possibility of developing differentiated products with potential access to specialized markets, both nationally and internationally. However, consolidating this scenario requires a shift toward diversified production models, short commercialization circuits, strong associative processes, and public policies that recognize olive cultivation as a strategic pillar for sustainable rural development in Colombia.

4 Conclusion

Integrating olive cultivation into a rural development strategy based on agroecological principles requires moving beyond the boundaries of experimental science and engaging with the social processes that shape rural life. The reviewed experiences show significant progress in understanding the crop, particularly in relation to its phenological behavior, interactions with soil microorganisms, and adaptability to non-traditional climates. However, important gaps remain in understanding its role as a catalyst for social and economic transformation in the Colombian countryside. For olive growing to become more than just a promising species, it is essential to build institutional, organizational, and commercial conditions that link it to collective rural development projects with a strong territorial identity. This task demands applied research, community participation, and public policies that recognize the strategic value of the olive tree within a new agri-food paradigm rooted in sustainability, equity, and cultural diversity.

The advancement of olive cultivation in Colombia should be understood as an opportunity to reconfigure the productive dynamics of rural areas that face edaphoclimatic constraints and structural challenges in their agricultural economies. Although research conducted in the Cundiboyacense highlands has made it possible to identify the agronomic and adaptive potential of the olive tree under tropical conditions, this crop should not be viewed solely from a technical or substitution-oriented perspective. Agroecology, conceived as a transdisciplinary and territorial approach, provides the necessary framework to grasp the complexity of olive cultivation, acknowledging the relationships among rural actors, local knowledge, ecosystems, and long-term sustainability goals. In this sense, olive growing does not merely represent an agricultural innovation, but a path to strengthen productive autonomy, economic diversification, and ecological resilience within rural territories.

Data availability statement

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

Author contributions

AB-S: Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. AT: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. RC-C: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. NM-L: Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization.

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Conflict of interest

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

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