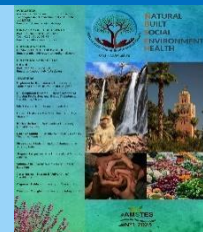




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Terroir Products in Morocco: A review of Challenges, Development Strategies, Biotechnology for Sustainable Valorization

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Graphical abstract

Morocco has a rich and diverse Agri-food heritage, with over 200 terroir products such as Argan oil, Saffron, and Olive oil. These products are both a cultural pillar and a socio-economic driver for rural areas, supporting local communities and preserving traditional knowledge. National strategies, such as the Green Morocco Plan (2008) and Generation Green (2020-2030), aim to enhance these products through cooperatives, official labels, and new technologies. Official quality labels like AOP, IGP, and Agricultural Label help ensure traceability, protect geographical origin, and build consumer trust. These initiatives also promote the development of structured marketing channels and the adoption of innovative processing techniques. Despite these efforts, technical, organizational, and environmental challenges remain, including limited resources and climate constraints. It is important to strengthen the value chains of these products. They are a major opportunity for sustainable rural development and economic inclusion.



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Abstract: Moroccan terroir products represent a significant wealth, stemming from the country's biological diversity, local production conditions, and the traditional knowledge of rural communities. These products play a key role in the economic and social development of rural areas. Yet, their valorization remains limited by several constraints, including the lack of suitable technologies, the weak structuring of value chains, and the impacts of climate change. This study comprehensively surveys scientific work on the valorization of Moroccan terroir products, with a focus on the contribution of biotechnology as a tool for improving quality, preservation, and sustainability. A systematic literature review was conducted following the PRISMA method, covering the period 2001-2025. The selected publications were analysed to identify the main sectors studied, the technological approaches used, and research trends, in order to ensure the sustainable valorization of Moroccan terroir products and support the development of rural areas.

Keywords: Terroir products, Valorization, Biotechnology, Sustainable Development.

Introduction

Over the past two decades, Morocco has undergone a profound structural transformation, marked by a transition from a historically agriculture-based economy to an increasingly industrialized and export-oriented economy [1]. This shift is part of a national strategy aimed at modernization and integration into the global market, driven by structuring programs such as the National Pact for Industrial Emergence (2009-2015) and the Industrial Acceleration Plan (2014-2020) [2]. The gross domestic product (GDP) reflects this evolution, with the growing contribution of industry and services acting as key drivers of national economic growth [3].

At the same time, the promotion of local products complements the industrialization process [4]. Despite Morocco's rich agro-biodiversity encompassing Argan, Saffron, Dates, Cactus, Honey, and Prickly Pear, sustainable valorization remains constrained by several critical challenges [5]. These include limited technological infrastructure, weak integration of biotechnological approaches, and continued reliance on sub-optimal traditional practices such as uncontrolled spontaneous fermentation, inefficient manual extraction methods, poor post-harvest handling, and inadequate storage and packaging conditions. In addition, producers face increasing climate-related pressures, including recurrent droughts, rising temperatures, irregular rainfall patterns, soil degradation, and increased incidence of pests and diseases, which affect yield, quality, and biochemical composition of raw materials. For instance, prolonged drought episodes in recent years have significantly affected argan fruit yield and saffron productivity in semi-arid regions of Morocco. The need to balance ecological sustainability with economic and social viability remains a major concern, as these constraints negatively impact market competitiveness and reduce resilience to climate change [6].

The first major challenge lies in the limited diversification of technological tools used for the processing, preservation, and valorization of local resources [7]. Many cooperatives continue to rely on inadequately optimized traditional methods, which can lead to quality losses, low processing yields, and significant variability in the final product. In addition, the lack of modern storage and processing facilities restricts producers' access to high-value and international markets [8].

A second challenge relates to the weak integration of green biotechnologies within terroir-based value chains [9]. Although such approaches can enhance extraction efficiency, enrichment, and stabilization of bioactive compounds, their adoption remains marginal. Enzymatic technologies, controlled fermentation, bioconversion, and eco-designed extraction processes such as green extraction, the use of natural solvents, or ultrasound-assisted techniques could substantially increase product value and reduce environmental impacts [10].

A third set of constraints operates at the organizational and socio-economic levels. Despite the growth of cooperatives, many still face limited internal structuring, logistical constraints, and weak governance mechanisms [8]. High certification costs remain a barrier for small-scale units, limiting access to official quality labels [11]. Commercialization is often hindered by informal marketing channels, insufficient territorial branding, and limited digital visibility [12].

Environmental challenges also play a central role. Climate change directly affects sensitive value chains such as Argan, Cactus, Saffron, and several medicinal plants. Resource overexploitation, desertification, and the ecological fragility of certain rural areas necessitate a rapid transition toward sustainable production systems that are more efficient in using water and energy [13].

Innovation is required for sustainable valorization, Eco-designed biotechnological processes offer significant opportunities to improve product quality, extend shelf life, increase added value, and reduce post-harvest losses. These technologies enable optimized extraction of bioactive molecules, conversion of by-products into functional ingredients, reduction of natural or microbiological contaminants, and the implementation of circular processes that minimize waste generation. They also contribute to enhanced standardization and reproducibility, which are essential for accessing international markets [10].

In parallel, digital transformation represents a powerful lever for improving value-chain performance. The deployment of e-commerce platforms, the use of geographic information systems (GIS) for mapping production areas, and the development of digital certification tools can significantly enhance market access, traceability, and transparency [14].

Finally, the sustainable valorization of terroir products in Morocco represents a multidimensional strategic challenge, as summarized in Figure 1. It relies on the ability to integrate biotechnological innovations, strengthen value-chain organization, protect biodiversity, and promote inclusive economic models. The convergence of traditional knowledge, modern technologies, and sustainable resource management can ensure the long-term preservation of Morocco's agri-food heritage within an increasingly competitive and demanding market environment [4,14].

The present review aims to examine the main scientific, technological, and socio-economic challenges associated with the sustainable valorization of terroir products in Morocco, through a systematic review of the literature conducted in accordance with the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [15].

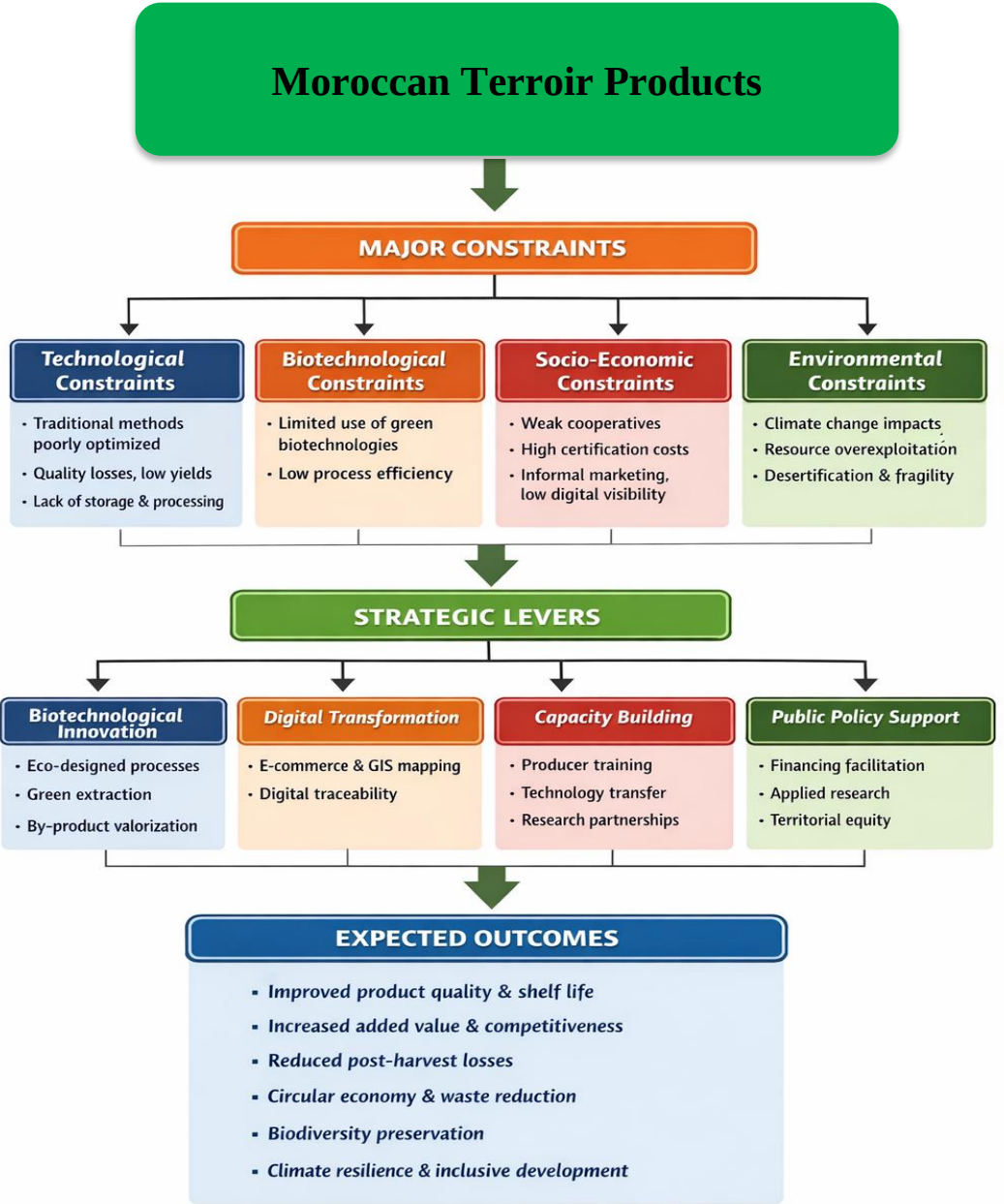


Figure 1. Framework for the valorization of Moroccan Terroir products. (Source: Authors)

Bibliometric Analysis: History and definition

Bibliometric analysis emerged in the early twentieth century as a response to the growing need to quantify and understand the production and dissemination of scientific knowledge. Its foundations were shaped by classical bibliometric laws proposed by Lotka, Bradford, and Zipf, which described patterns of author productivity, journal dispersion, and term frequency within scientific literature. A major milestone occurred in the 1960s with the development of citation indexing, notably through the work of Eugene Garfield and the establishment of the *Science Citation Index*, which significantly enhanced the ability to trace scientific influence and knowledge flows. With the

subsequent expansion of bibliographic databases and advances in computing technologies, bibliometric analysis produced more sensitive approaches, including co-citation, co-authorship, and keyword co-occurrence analyses. Today, bibliometric analysis is widely recognized as a valuable methodological tool for mapping research fields, identifying trends, and examining the structural dynamics of scientific domains [16].

Bibliometrics applies statistical and mathematical methods to the analysis of scientific publications in order to quantify and interpret the processes of written scientific communication. The discipline is based on two fundamental principles: first, scientific writing is regarded as an objective product of thought that reflects the research activity of the author; second, scientific publications represent a convergence of individual and collective ideas, thereby linking the work of different researchers. Through the quantitative analysis of publications, bibliometrics makes it possible to identify schools of thought and to trace their evolution over time. Bibliometrics is distinct from scientometrics, which focuses on the quantitative aspects of the production, dissemination, and use of scientific information [16].

Materials and Methods

Research strategy

To understand the state of scientific research on terroir products in Morocco and identify trends, we conducted a bibliometric analysis. This study is based on a systematic literature review, carried out in accordance with the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [15]. This methodological framework, as illustrated in figure 2, ensures transparency, reproducibility, and scientific rigour in the study selection process, minimizing biases related to the identification and analysis of publications.

The first step of our analysis is constructing a database that includes all scientific publications relevant to the study. In this context, a keyword-based search was conducted using the Scopus and Web of Science databases, which are concerned with publications which meet serious criteria. These databases have extensive coverage and can provide a large volume of relevant records. The selection of keywords was guided by the research question and refined through several iterative trials. Following this process, the keyword combination:

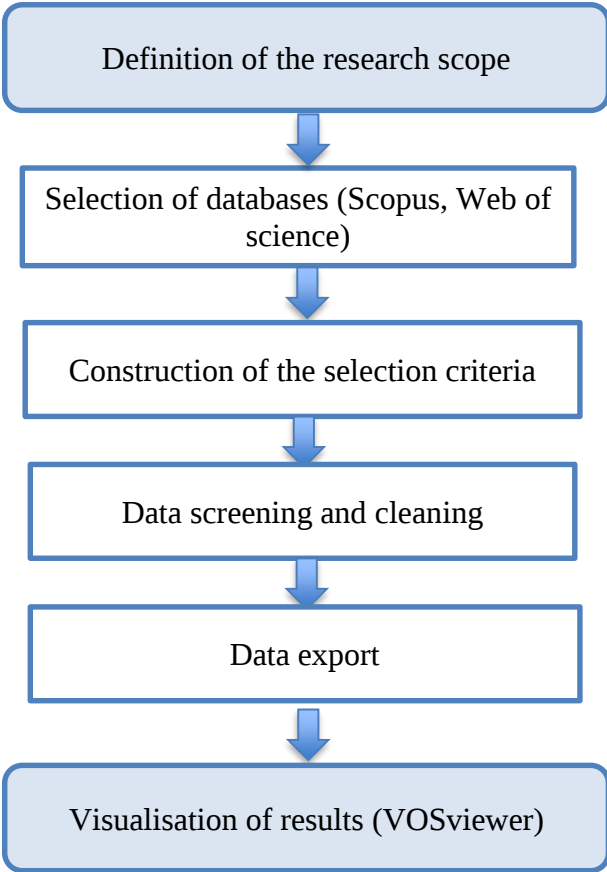


Figure 2. Methodological Framework of the Study. (Source: PRISMA 2020 guidelines [15])

Selection Criteria

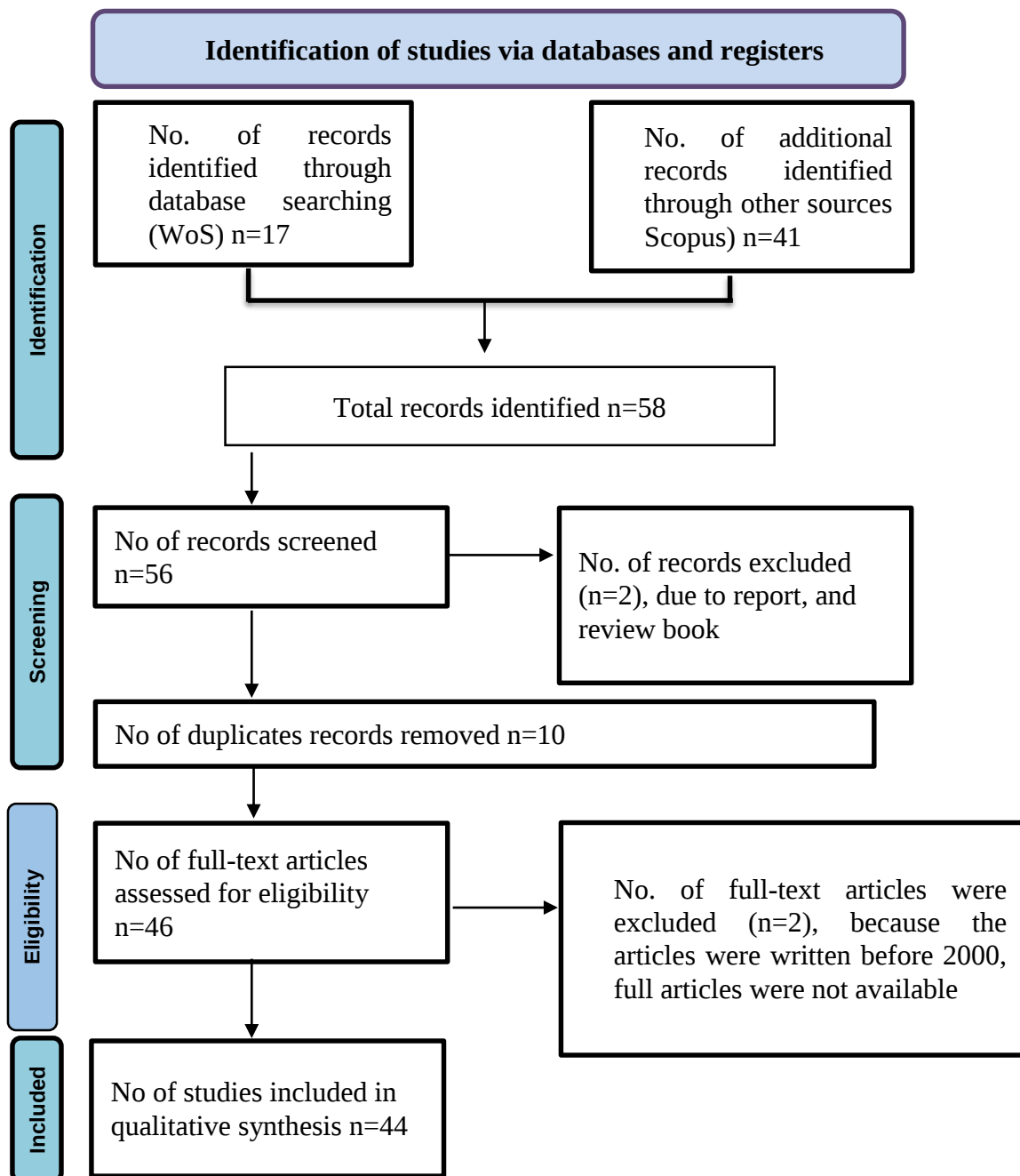
The initial search retrieved a substantial number of articles (58), which were subsequently screened for relevance by evaluating them. A total of 44 documents were considered relevant for our study. Table 1 shows the selection criteria.

Quality Assessment

The PRISMA flow diagram (Figure 3) visually represents the study selection process followed in this bibliometric analysis. The diagram illustrates the four main stages recommended by PRISMA: identification, screening, eligibility, and inclusion. The eligibility stage consisted of assessing the full texts against predefined inclusion and exclusion criteria. Finally, the included studies represent the curated dataset used for the bibliometric analysis, providing a transparent and reproducible foundation for mapping research trends, collaboration networks, and emerging themes.

Table 1. The selection criteria of documents. (**Source:** PRISMA 2020 guidelines)

Inclusion Criteria	Exclusion Criteria
Publications released between 2001 and 2025	Publications outside the topic
Documents addressing terroir products, local products, or traditional foods in Morocco	Documents written in other languages
Document types: scientific articles, review articles, and book chapters	Conference proceedings, technical reports, and non-peer-reviewed documents
Languages: English and French	Duplicates across databases
Full-text documents available	

**Figure 3.** The PRISMA 2020 flow diagram illustrating the different stages of the selection process. (**Source:** Based on Prisma 2020 flow diagram for systematic reviews [15]).

After making the selection, the data were exported for bibliometric processing using VOSviewer, as shown in Figure 10 enabling the creation of visual maps to identify the main research themes and emerging topics, and detect patterns of collaboration within the Moroccan context. offering a comprehensive view of the scientific landscape in this field.

Results

Results of the search conducted on Scopus and Web of Science

Before proceeding to the bibliometric analysis of the documents extracted from Scopus and Web of Science, it is appropriate to present a summary of the extracted database.

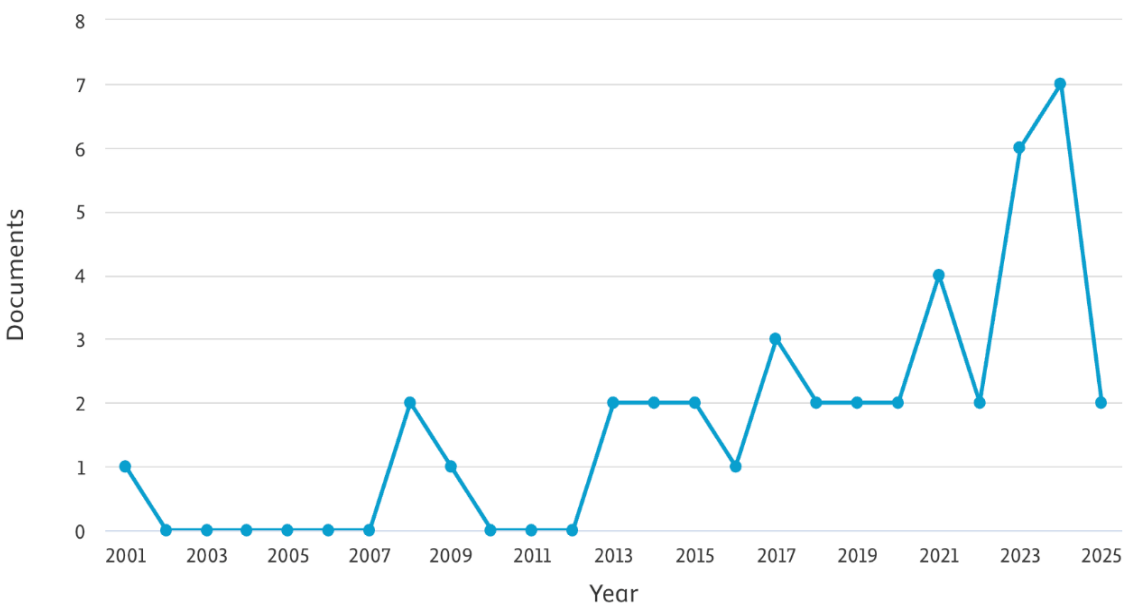


Figure 4. Distribution of Reviewed Articles by Year. (Source: Scopus)

Figure 4 illustrates the temporal evolution of scientific production related to terroir between 2001 and 2025. Three distinct phases can be identified:

- A latency period (2001-2012): For more than a decade, academic interest in this topic remained marginal, with several years showing no recorded publications.
- A phase of emergence and instability (2013-2022): From 2013 onwards, research activity began to take shape, with a regular but fluctuating output, generally ranging between two and four articles per year.
- A recent acceleration (2023-2024): A very marked exponential growth is observed over the last two years, reaching a peak of seven documents in 2024.

This progression indicates that the valorization of Moroccan terroir products has become a major research priority, driven by recent challenges related to sustainability and food security. The apparent decline in 2025 can be explained by the fact that it was the current year when the data were collected.

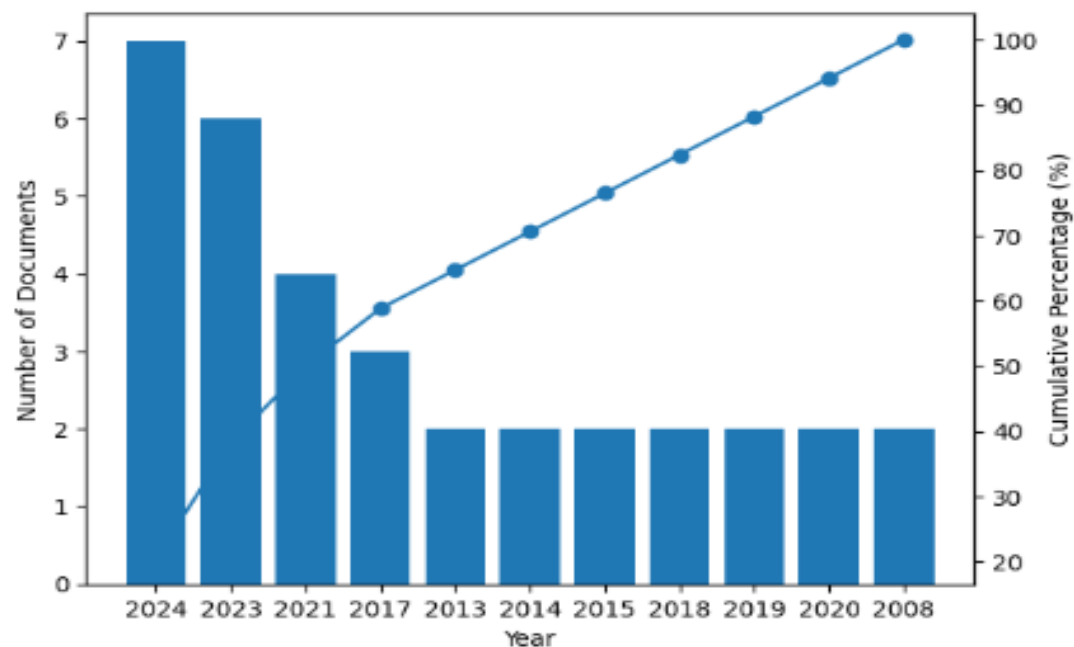


Figure 5. Pareto Diagram of publications by Year (**Source:** Scopus)

The Pareto diagram (Figure 5), illustrates a clear trend in the temporal distribution of publications, showing that the majority of research output on this topic is concentrated in recent years. Specifically, more than 80% of the documents have been published after 2017, indicating a significant acceleration in scholarly attention. This surge reflects a growing interest in the field, probably because of emerging scientific, technological, or societal challenges that make the topic increasingly relevant. The pattern also suggests that the research area is developing, with new findings, methodologies, and applications being introduced at a faster pace than in earlier periods. Such a concentration of publications in the last few years highlights both the contemporary relevance of the subject and the dynamic nature of investigations, signalling that the field is likely to continue expanding in the near future.

The geographical distribution of scientific production, as illustrated in Figure 6, shows that Morocco dominates research in this field with more than 27 indexed publications, confirming its position as the centre for the study of its own terroir products and their sustainability. This strong national concentration highlights the commitment of local researchers to the valorization of their natural heritage. An international dimension is also evident, with collaborations or studies conducted by European countries such as Spain, Italy, and France, as well as Canada. This shows

that issues related to Moroccan terroir particularly health, natural product chemistry, and sustainable development attract scientific interest beyond national borders.

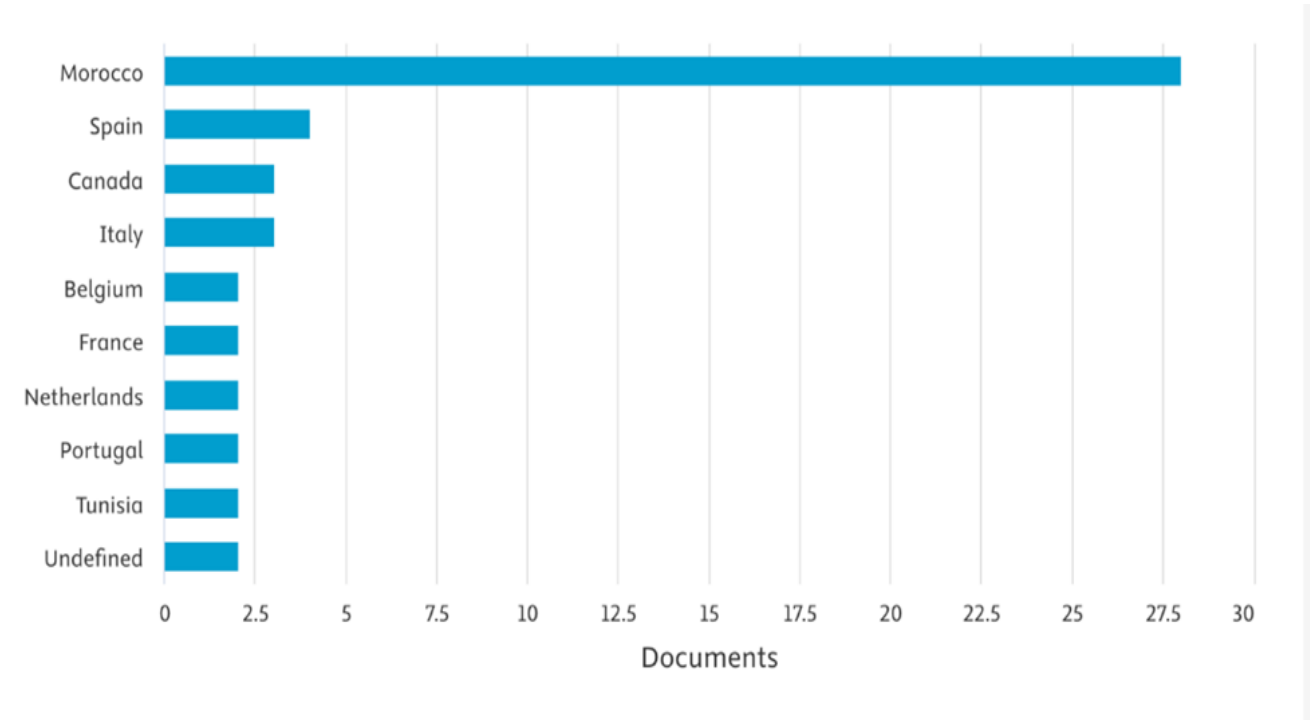


Figure 6. Publication distribution of reviewed articles by country. (Source: Scopus)

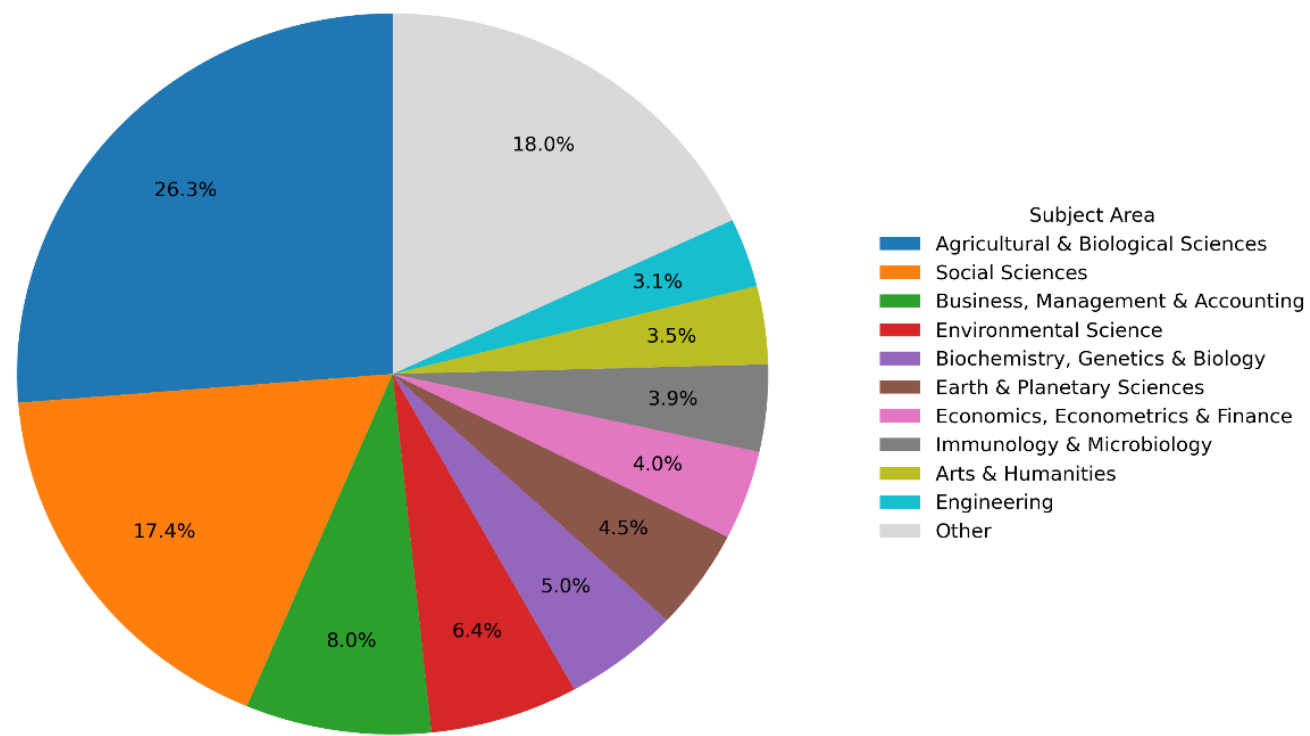


Figure 7. Distribution of Documents by Discipline. (Source: Authors from Scopus)

The distribution of documents by subject area (Figure 7) highlights the strongly multidisciplinary nature of the analysed research. Agricultural and Biological Sciences represent the largest share of publications (26.3%), reflecting the central role of terroir products within agri-food systems and the associated challenges related to production, processing, and local resource valorization. This predominance is consistent with the core objectives of these studies, which focus on improving product quality, sustainability, and competitiveness.

Social Sciences rank second (17.4%), emphasizing the importance of socio-economic, cultural, and territorial dimensions. This significant contribution indicates a growing interest in consumer behaviour, rural development, heritage valorization, and public policies related to terroir products.

Contributions from Business, Management and Accounting (8.0%) and Environmental Sciences (6.4%) demonstrate the increasing integration of sustainability, governance, and economic performance considerations in terroir-related research. These findings suggest a shift toward more holistic approaches that balance economic development with environmental responsibility.

Furthermore, the presence of Biochemistry, Genetics and Molecular Biology (5.0%) and Earth and Planetary Sciences (4.5%) reflects the scientific interest in compositional, physico-chemical, and geographical factors influencing product characteristics. The relatively lower representation of Engineering, Economics, and Arts and Humanities indicates that technological innovation and analytical economic perspectives remain underexplored areas.

Finally, the substantial proportion of publications classified under “Other” disciplines (18.0%) confirms the diversity of scientific fields involved. This disciplinary diversity is advantageous. Integrated and sustainable strategies can enhance the valorization of terroir products within territorial development and agro-ecological transition frameworks.

The tree map represented in Figure 8, illustrates the diversity of the publications included in this study. Food Science and Technology is a central field, highlighting the focus on food quality, processing, safety, and innovation in terroir-related research. This emphasis reflects the technical and scientific efforts dedicated to improving characteristics of products which preserve traditional attributes.

Business-related studies also occupy a notable position, indicating increasing attention to market dynamics, value chain organization, and economic performance of terroir products. This trend suggests a growing recognition of the importance of commercialization strategies and governance mechanisms in enhancing the competitiveness of local products.

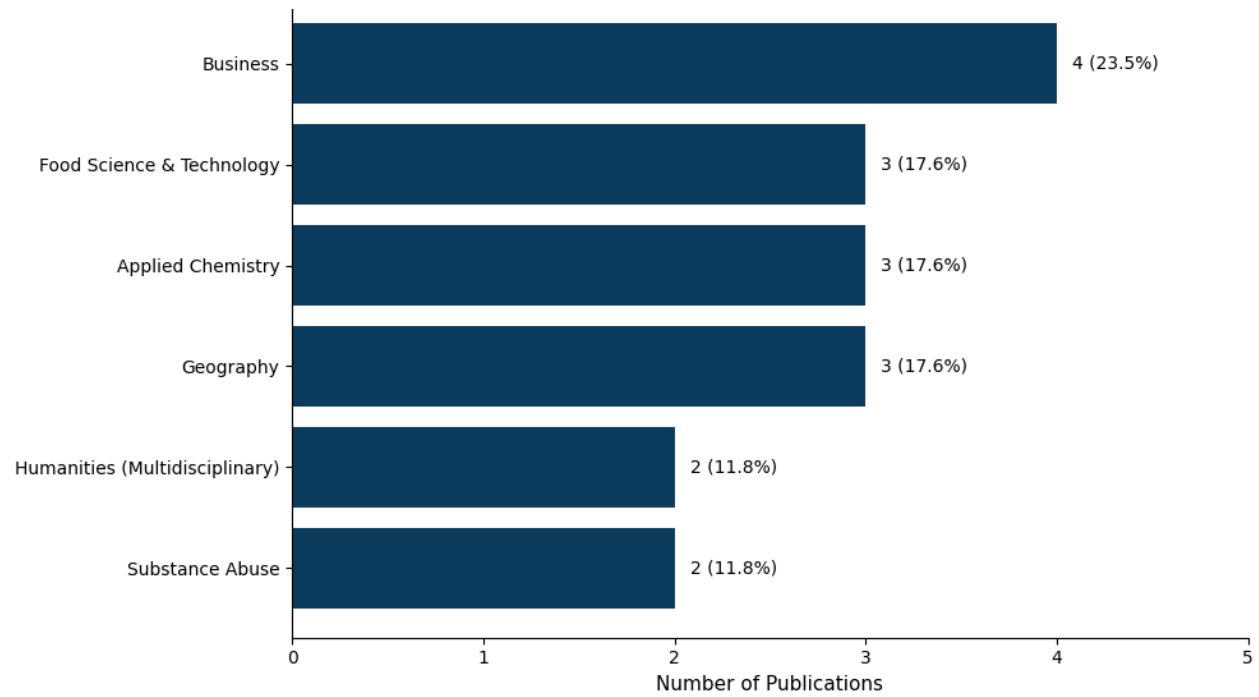


Figure 8. Subject Area Distribution of Publications on Terroir-Related Research. (Source: Authors from Web of Science)

Applied Chemistry contributes to the scientific understanding of terroir products through analyses of composition, authenticity, and quality markers, and Geography plays a key role in linking products to their territorial origins. Geographic approaches help explain how environmental conditions, spatial identity, and local ecosystems shape product specificity and reputation.

The presence of Humanities and Multidisciplinary research highlights the cultural, social, and heritage dimensions associated with terroir products. These studies emphasize traditional knowledge, identity, and consumer perception, reinforcing the non-material value of these products. The inclusion of Substance Abuse as a subject area, although limited, reflects research interest in specific products such as fermented or alcoholic goods, addressing issues related to consumption and regulation.

Overall, terroir research is inherently interdisciplinary. Such diversity is inherently interdisciplinary, combining technical, socio-economic, cultural, and territorial perspectives. Such diversity is essential for developing integrated strategies aimed at sustainable valorization, quality enhancement, and long-term preservation of terroir products.

Figure 9 highlights the multidimensional nature of Moroccan terroir products, demonstrating that their impact extends well beyond a purely commercial framework and is embedded within a

broader sustainability strategy. The strong predominance of SDG 3 (Good Health and Well-being) indicates that the added value of these products is mainly in their nutritional and therapeutic properties. In parallel, the significant contribution to SDG 15 (Life on Land) and SDG 2 (Zero Hunger) shows that these value chains are an essential ecological safeguard for the preservation of Morocco’s biodiversity, and that they strengthen food security and resilience in rural areas. Finally, the presence of goals related to responsible consumption and production (SDG 12) and climate action (SDG 13) confirms that the terroir sector represents a model of the circular and sustainable economy.



Figure 9. Coverage of the Sustainable Development Goals. (Source: Authors from Web of Science)

Bibliometric Analysis using VOSviewer

A bibliometric analysis was conducted to map the scientific output related to terroir products and Moroccan traditional foods. The extracted data included, among others: the number of publications per year, the distribution of publications by document type, the most frequent keywords, and co-occurrence and co-citation networks, VOSviewer software (version 1.6.17) was used to perform analyses of keyword co-occurrence, co-citation, and bibliographic coupling. These analyses allowed the identification of major research trends, dominant themes, and the evolution of scientific work in this field.

This keyword network (Figure 10) reveals that scientific research in Morocco is rooted in the valorization of local natural resources. At the centre of the map, the term *Morocco* acts as a hub connecting several areas of knowledge. A strong link is observed between terroir products and health, with keywords such as *antioxidant*, *anticancer*, *alternative medicine*, and *diabetes*. This confirms that the strength of Moroccan terroir lies mainly in its medicinal and therapeutic qualities.

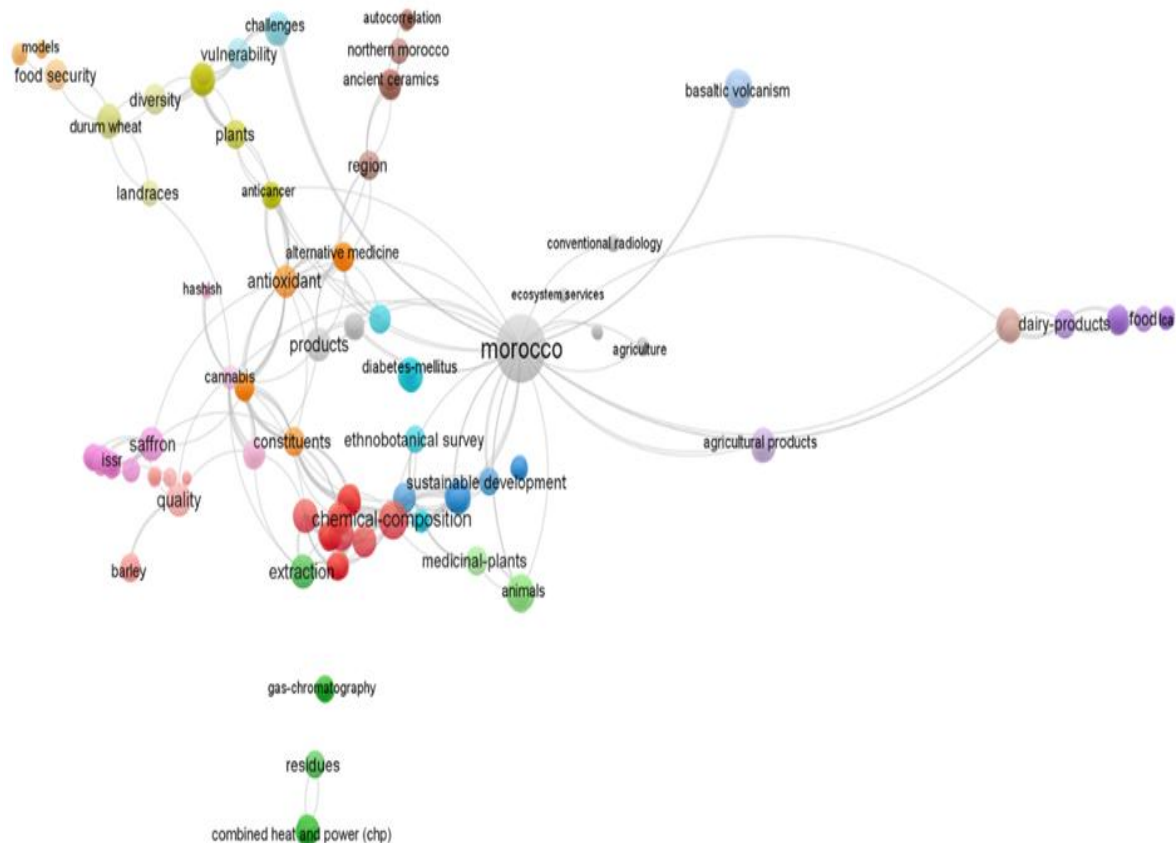


Figure 10. Co-occurrence analysis of author's keyword in VOSviewer. (Source: Developed by Authors from VOSviewer)

Another major cluster relates to chemical composition and extraction, reflecting efforts to ensure product quality and safety, particularly for saffron and medicinal plants. The map also highlights a direct connection with sustainable development, demonstrating that these research efforts are not solely driven by economic profit, but also by the preservation of ecosystems and food security. Overall, this visualization portrays a country that uses science to transform its ancestral traditions into future-oriented solutions for health and environmental sustainability.

Discussion

Terroir products

To quote the Food and Agriculture Organization: “Terroir products are products that are distinguished or can be distinguished based on their local identity or typical characteristics. Their designation through a geographical indication (GI) justifies the specific local context from which they originate, giving them, in the eyes of the consumer, a distinctive characteristic, quality or reputation” [17].

Terroir products can be defined as foods closely linked to a specific geographic area, where they are traditionally produced, consumed, or marketed [18]. They embody not only the agro-ecological characteristics of their region of origin but also the cultural, social, and gastronomic features of the local populations. In this sense, they constitute a tangible expression of the food heritage and worldview of the communities that cultivate or process them [19]. Like France, Italy, Germany or Greece, Morocco produces foods which are culturally and geographically distinctive [20].

There are three questions of origin: the origin of the raw material, the origin of the recipe, and the origin of the product. A terroir product may meet one, two, or all of these conditions [20].

Terroir

The FAO defines terroir as the result of multiple interactions occurring over time between local actors and their environment within a specific geographical area, leading to the development of unique knowledge and the emergence of origin-linked quality. This specific quality encompasses both objective dimensions, such as organoleptic attributes including taste, texture, and shape, and subjective or symbolic dimensions, such as identity values and perceptions of authenticity [17].

A terroir is a defined geographical area where a human community, over time, has developed collective production knowledge through interactions between the physical and biological environment and human factors. The resulting socio-technical practices create originality, confer distinctiveness, and establish a reputation for products originating from that terroir [18].

All this is illustrated in Figure 11 [20]:

- **Territory and geographical space:** boundaries, relief, topography, climate, natural resources, infrastructures.
- **Human community and agricultural production:** know-how, traditions, agrarian and agri-food systems, technical production pathways, technologies, population diversity, governance, and authenticity.

- **Local development and cultural valorization:** typicality, local identity, food culture, marketing, economic and heritage value, sense of belonging.

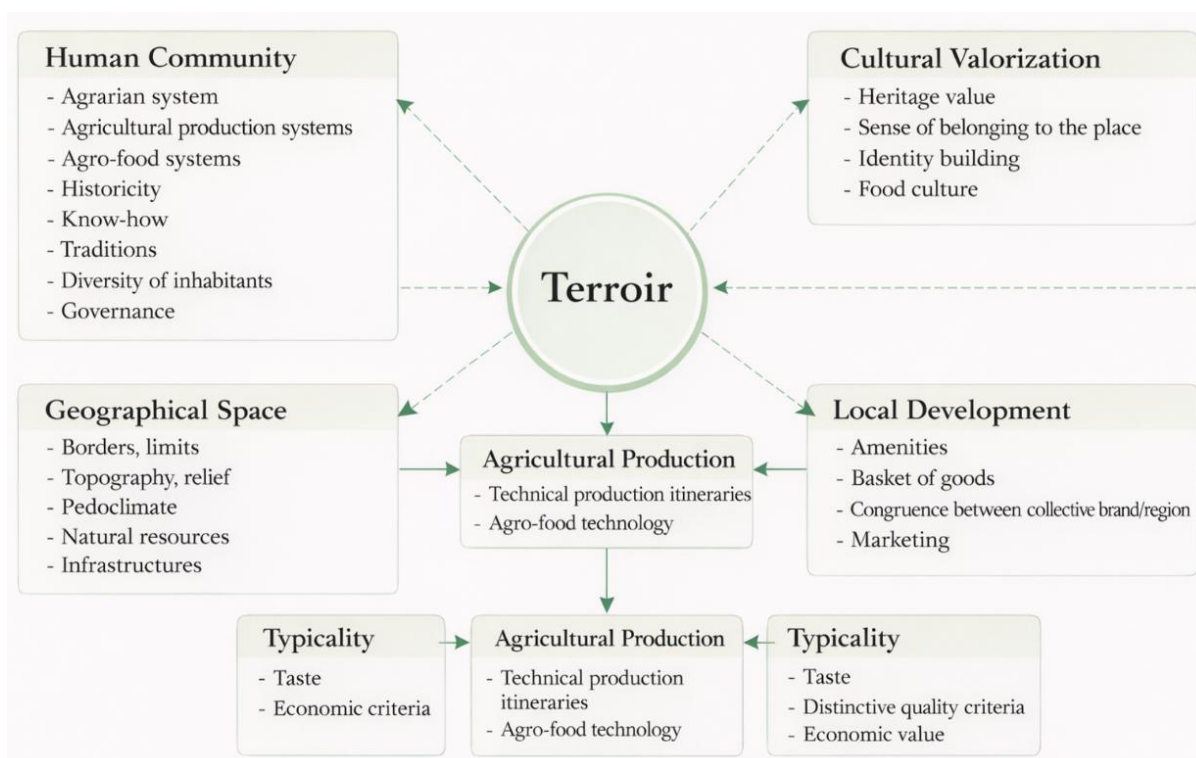


Figure 11. The conceptual field of terroir. (Source : Authors based on *Philippe Prévost et al.* [18])

Morocco has a variety of local products that reflect the richness of its ecosystems and traditional knowledge. In addition to argan oil, saffron from Taliouine, dates from the Tafilalet region, *figue de barbarie* from Aït Baâmrane, and roses from Kelaat M'Gouna, other emblematic products include thyme and euphorbia honey, almonds, carobs, figs, pomegranates from Sefrou, regional olive oils, etc [21].

The scope and depth of scientific studies vary significantly from one product to another. For a few products, such as argan oil, saffron, and certain olive oils, chemical and nutritional analyses exist, but for many others including carob, *figue de barbarie*, and regional honey, these are lacking. This represents a strategic opportunity for researchers and institutions to create comprehensive databases on composition and nutritional values [22].

Terroir, regional, local, and traditional products are interrelated concepts that form a continuum linking geographical origin, cultural heritage, and production practices, as illustrated in Figure 12. Terroir products represent the most integrative category, as they are defined by the interaction between natural factors (soil, climate, biodiversity) and human factors (know-how, traditions, and practices) within a specific geographical area [20].

Regional products can be considered as local products distributed through wider marketing channels, allowing them to travel longer distances to the final place of consumption or to originate from geographically larger areas. The geographical origin of a product confers added value derived from the uniqueness of local cultures, traditions, production methods, as well as the associated geographical and natural conditions. The combination of these human, natural, and production-related factors, which are closely linked to a specific location, differentiates production regions and endows products with distinctive properties and organoleptic qualities that are difficult to replicate elsewhere [20].

Regional products are generally marketed with a strong emphasis on quality. Despite being distributed through short or extended supply chains, and regardless of the number of intermediaries or the distance travelled to reach the consumer, they retain explicit information regarding their geographical origin. This transfer of information mainly occurs through product packaging and labelling, or through the use of protected designations of origin and similar certification systems [20].

Traditional product can be perceived as an ordinary product when it is consumed outside its sphere of influence, whether at the local, regional, or national level, insofar as the geographical, human, social, and cultural context that confers its identity is no longer fully preserved. A traditional product is never exported as such. In other words, the traditional dimension loses part of its substance once it is detached from its territory of origin [20,23].

A traditional product constitutes a heritage transmitted across generations. It is produced according to a specific recipe that embodies cultural identity, represents a distinctive marker of its place of origin, and functions as a catalyst for territorial recognition and promotion. Traditional products are linked to both territory and tradition [20,23].

Local products are defined by the geographical proximity between production and consumption. These products are cultivated, processed, marketed, and consumed within a relatively limited geographical area [20].

From a consumer standpoint, local products are often perceived as authentic, as they stand in contrast to standardized and homogenized market offerings. This perception is reinforced by the authentication of their production processes, through which products are recognized as original, genuine, and trustworthy. The strong association with place may also stem from the social values attached to consumption and, in some cases, from the appropriation or misappropriation of product identity, positioning local products as a medium for self-expression and identity construction [20].

Local products are commonly associated with superior quality and are perceived as fresher, more nutritious, and more flavourful than conventional alternatives. These attributes result from the geographical proximity between production and consumption, which reduces transportation time, allows optimal ripening, and limits the need for preservatives [20].

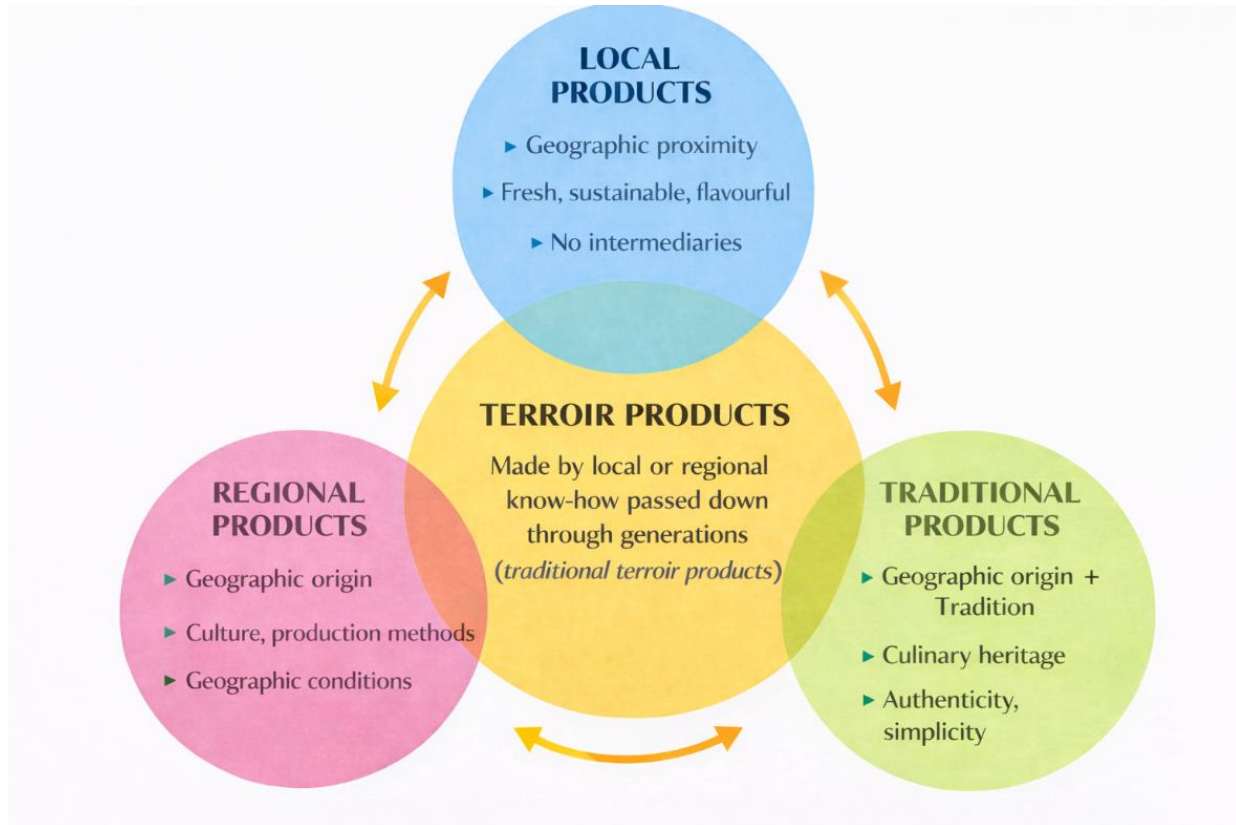


Figure 12. Relationship and interaction between Terroir, Regional, Local, and Traditional products. (Source: Author adopted from Elgozmir et al. [20])

Main Terroir Product Sectors

Morocco's terroir products belong to several major agri-food sectors that reflect the country's rich agro-ecological diversity and cultural heritage, as shown in Table 2. Each sector is closely linked to specific geographical areas, such as argan oil in the Souss-Massa region, saffron in Taliouine, dates in the oases of the Tafilalet, and olive oil across multiple regions including Meknès-Fès and Marrakech-Safi [21]. These terroir sectors rely on traditional know-how combined with local natural resources, contributing significantly to rural development, income generation, and the preservation of cultural identity [24]. Moreover, several of these products benefit from geographical indications or quality labels, which enhance their national and international recognition [2].

Table 2. Main Terroir Product Sectors in Morocco and Their Traditional Uses (**Source:** FAO (2021) [24], Ministry of Agriculture of Morocco (2022) [33])

Sector	Emblematic Product	Main Region	Traditional Uses
Oilseeds	Argan oil	Souss-Massa	Cosmetic, culinary, medicinal
Spices	Taliouine saffron	High Atlas	Cooking, infusion, pharmacopoeia
Dry fruits	Dates from Tafilalet	Drâa-Tafilalet	Direct consumption, pastries
Medicinal plants	Cactus, prickly pears	Southern Morocco, Guelmim-Oued Noun	Juice, jam, cosmetic
Beekeeping	Atlas honey	Middle Atlas, Rif	Tea, traditional remedy
Ancient cereals	Durum wheat, barley, local maize	Rural areas of North and Centre	Couscous, bread, porridge

Strategy for the Development of Terroir Products

The national strategy for the development of terroir products in Morocco is based on the economic, social, and environmental valorization of these products [25,21]. The methods adopted for valorization include the establishment of local cooperatives, quality certification, and support for national and international marketing [26].

The State has undertaken several structuring initiatives, notably through the Green Morocco Plan and the Generation Green 2020-2030 program, which emphasize the sustainability and competitiveness of the sectors [2]. At present, value chains are weakly structured, there is a lack of processing infrastructure, and artisanal practices are not optimized [27]. Protected Geographical Indications (PGI) and Controlled Designations of Origin (PDO) are essential to ensure traceability and international recognition of products [28]. These mechanisms strengthen the competitiveness of Moroccan products in global markets, but more imaginative advertising and promotion (e.g., through international trade fairs) would be helpful, so that Morocco's protected geographical indications (PGIs) and protected designations of origin (PDOs) may become better known [26].

Legislative Framework and Labelling (SDOQ)

Morocco's Agricultural Development Agency (ADA) in line with successive agricultural policies (Green Morocco Plan and then Generation Green), has structured its approach around three main axes: legislation, actor structuring, and promotion [2].

There is a legal framework for the recognition and protection of terroir products [21], Law 25-08 on Distinctive Signs of Origin and Quality (SDOQ). Adopted in 2008, this law introduced a protection system in Morocco similar to European models. It allows products to be registered under specific labels, as illustrated in figure 13, providing added value and protection against counterfeiting [29].

Protected Geographical Indication (PGI): Used for products whose quality is linked to their geographical origin (e.g., Argan Oil, Majhoul Dates) [29,30].

Controlled Designation of Origin (PDO): Offers a higher level of protection, requiring that all production stages occur within a defined geographical area [29,30].

Agricultural Label (LA): Certifies superior quality related to production conditions [29,30].

The ADA registered the collective label “**Terroir du Maroc**” as a collective trademark, together with its rules of use, with the Moroccan Office of Industrial and Commercial Property (OMPIC). The main objectives of this label are to regulate the use of the designation “Moroccan terroir products”, to establish a collective promotional tool at both national and international levels, and to contribute to improving the income of small-scale producers [31,32].

Since the establishment of the legal framework in 2008, a growing number of quality labels have been granted in Morocco under Law No. 25-06 on Distinctive Signs of Origin and Quality. By 2023, the system had recognized a total of 77 quality labels, including 4 Protected Designations of Origin (PDO/AOP) and 7 Agricultural Labels (LA), with the remaining 66 corresponding to Protected Geographical Indications (PGI/IGP) [33]. Examples of labelled products are illustrated in Figure 14.

The award of a Distinctive Sign of Origin and Quality by the Ministry of Agriculture and Maritime Fisheries (MAPM) follows a well-defined and institutionalized process. This process begins with the submission of a recognition application to the Department of Agriculture, accompanied by a detailed product specification. Such applications are generally prepared by organized producer groups, particularly cooperatives and Economic Interest Groups (EIGs) [34].



Figure 13: Official logo of Moroccan Distinctive Signs of Origin and Quality (SDOQ). (Source: Ministry of Agriculture and Maritime Fisheries, Kingdom of Morocco, 2018, *Official logos of the Moroccan Distinctive Signs of Origin and Quality – SDOQ* [34])

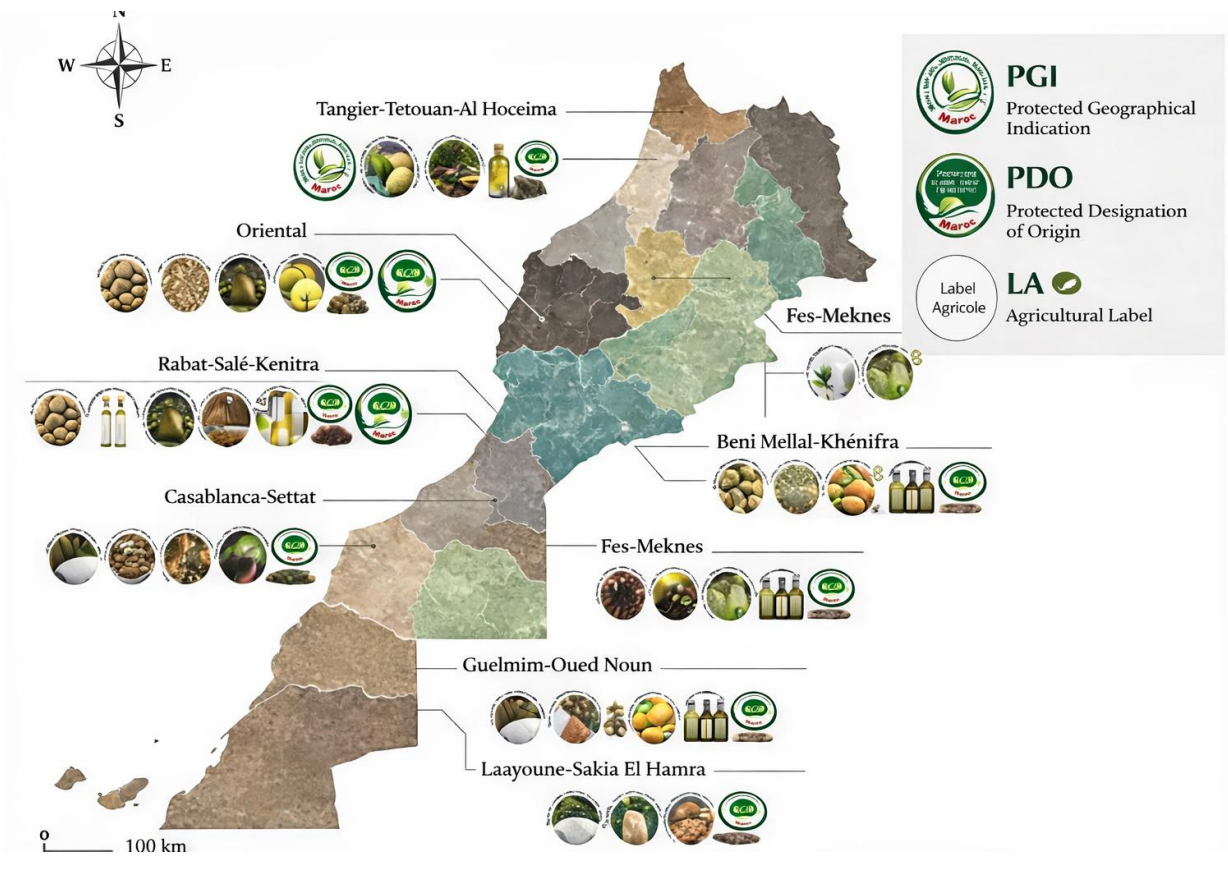


Figure 14: Labelled Terroir Products in Morocco

(Source: Developed by the authors based on Ministry of Agriculture and Maritime Fisheries, Kingdom of Morocco. (2018), *Strategy for the Valorization of Terroir Products and Legal Framework of Distinctive Signs of Origin and Quality (SDOQ)* [33])

Control and Certification

Established accredited bodies, supervised by the Ministry of Agriculture, to monitor the compliance of labelled products with their associated specifications (CDC) [33].

Structuring and Supporting Producers

The State's approach is not limited to regulation; it also includes technical and organizational support:

- Grouping into Cooperatives and Economic Interest Groups (GIE): ADA encourages and subsidizes the organization of small producers into formal economic entities (cooperatives and GIEs). This structuring is often a prerequisite for obtaining an SDOQ label. It professionalizes management, ensures traceability, and improves production techniques [35].
- Technical Support and Training: Programs are implemented to train producers in good agricultural practices (GAP), post-harvest processing methods, and administrative management of labels [36].

Promotion and Marketing

The State invests in platforms and events to connect terroir products with markets:

- Moroccan Terroir Products Competition (CMPT): Organized annually, this competition awards medals that increase the visibility and credibility of labelled products.
- Marketing Platforms: The creation and support of structures such as MAROC TASWIQ (Moroccan Agency for the Marketing of Agricultural Products) a Moroccan public institution operating under the supervision of the Ministry of Foreign Trade, which deals with the promotion, marketing, and export of local products and goods from the social and solidarity economy (cooperatives, small producers, micro-enterprises, unions, and associations) [37].

Principles and Applications of Biotechnology

Biotechnology's applications in daily life range from pharmaceutical development and food production to the treatment of polluting waste. In principle, biotechnology uses living cells to develop or modify products for specific purposes, such as genetically modified foods [38].

Biotechnology is closely linked to genetic engineering and has expanded from the food industry to the fields of medicine and environmental management [39].

It encompasses several key branches, often classified by colour, each with distinct applications, as summarized in Table 3 below:

Table 3. Classification of biotechnology according to application fields [40,45]

Category of Biotechnology	Definition	Reference
Red Biotechnology	focuses on healthcare and contributes to more than 250 vaccines and medicines, regenerative therapies, and the development of artificial organs.	[40]
Green Biotechnology	is applied in agriculture to control pests, enhance crop resilience against microorganisms, and protect against extreme weather conditions such as drought and frost.	[41]
White Biotechnology (Industrial Biotechnology)	aims to improve manufacturing processes, develop biofuels, and promote more efficient and sustainable industrial practices.	[42]
Yellow Biotechnology	focuses on food production, particularly by reducing saturated fats in cooking oils and using genetically improved products to increase food quantity and quality.	[43]
Blue Biotechnology	exploits marine resources for aquaculture, cosmetics, health products, and environmental conservation, including the production of biofuels from microalgae.	[44]
Grey Biotechnology	is dedicated to the conservation and restoration of natural ecosystems contaminated through bioremediation processes	[45]

Review of Existing Processes Applied to Terroir Products

The valorization of terroir products relies on a wide range of traditional and modern processing methods aimed at preserving product identity while improving quality, safety, and market competitiveness [46]. Traditionally, processes such as cold pressing, sun drying, fermentation, and artisanal extraction have been used to maintain sensory attributes and cultural authenticity, particularly for products like olive oil, Argan oil, dairy products, and fermented foods [46,47]. In recent decades, these methods have increasingly been complemented by improved and innovative technologies, including controlled fermentation, membrane filtration, enzymatic treatments, and mild thermal processes, which enhance yield, shelf life, and nutritional value and minimize

environmental impact [48]. Moreover, the integration of quality management systems and geographical indication schemes (PDO, PGI, and national labels) has contributed to standardizing processing practices, ensuring traceability, and protecting traditional know-how [49]. The focus now should be on adapting technologies to small-scale producers, ensuring cost-effectiveness, and maintaining a balance between innovation and preservation of terroir specificity [50]. Therefore, the development of eco-designed and context-adapted processing technologies remains a priority for the sustainable valorization of terroir products [51].

Development of Biotechnological Processes for the Valorization of Terroir Products

The development of biotechnological processes applied to terroir products can enhance the sustainability, competitiveness, and international recognition of local agri-food value chains [52]. Biotechnological processes can be implemented through several complementary approaches; see table 3. First, controlled fermentation represents a key technique for improving the sensory and nutritional quality of terroir products. It allows the standardization of traditionally artisanal productions, such as cheeses, oils, or fermented beverages, by ensuring greater consistency and enhanced food safety [53]. Secondly, the use of selected microorganisms helps optimize yields and reduce post-harvest losses. These microorganisms can be adapted to local conditions, thereby strengthening the resilience of production systems to climatic and environmental constraints [53,54].

Another important approach is bio preservation, which uses lactic acid bacteria or yeasts to extend product shelf life without resorting to chemical additives [55]. This method is particularly relevant for terroir products, which are often marketed through short supply chains where freshness and authenticity are key criteria [56]. In addition, biotechnological processes enable the development of active and biodegradable packaging incorporating natural antimicrobial compounds, contributing to a reduced ecological footprint and enhanced sustainability of local value chains [57].

The valorization of terroir products through biotechnology also includes biofortification, i.e., and enriching foods with essential micronutrients such as iron, zinc, or vitamins. This approach addresses public health concerns, particularly in rural areas where nutritional deficiencies are common [58]. It enhances the nutritional value of local products and preserves their cultural identity. The development of biotechnological processes promotes collective organization among producers, particularly through cooperatives and economic interest groups. These structures facilitate access to technology, allow cost-sharing for certification, and strengthen bargaining

power in national and international markets [59]. The greatest gain may be socio-economic. Biotechnology helps to empower rural women, who play a central role in the processing and marketing of terroir products, by providing them with the means to improve product quality and visibility [60,61].

Yet several challenges remain. The high costs associated with implementing biotechnological processes, the need to train producers in new techniques, and the complexity of international regulations may limit their widespread adoption. It is therefore essential to develop public policies that promote equitable access to innovation, while ensuring the protection of traditional knowledge and local genetic resources [62].

Table 4. Examples of potential applications of biotechnological processes for terroir products

Biotechnological Process	Possible Application	Advantages
Controlled Fermentation	Honey, cactus juice, cereals	Preservation, enrichment
Enzymatic Extraction	Argan oil, saffron	Yield, purity
Bioconversion	Fig residues, dates	Waste valorization
Optimized Solar Drying	Dried fruits, medicinal plants	Energy savings, sustainability

Sources: Summarized from Peron *et al.* [63]

Conclusion

Despite the significant progress, the valorization of terroir products in Morocco continues to face technical, organizational, and environmental constraints limiting their economic potential and competitiveness in both national and international markets. Challenges related to quality standardization, control of processing and preservation methods, structuring of value chains, and conservation of natural resources require innovative and integrated approaches. In this context, eco-designed biotechnological processes represent a major opportunity to improve the sanitary and nutritional quality of products, optimize their shelf life, and reduce the environmental footprint of production processes. The adoption of these approaches, combined with the strengthening of labelling systems, the valorization of local know-how, and the support of territorial stakeholders can ensure the sustainable valorization of Moroccan terroir products, contributing to rural

development, the protection of agri-food heritage, and the transition toward more sustainable and resilient food systems.

Future research should focus on the adaptation of these technologies to small-scale and cooperative-based production systems, ensuring their technical feasibility and market availability. Strengthening collaboration between research institutions, policymakers, and local actors will be essential to foster innovation transfer and capacity building. Finally, the integration of circular economy principles and climate-resilient practices will strengthen the sustainability and competitiveness of Moroccan terroir products in a rapidly changing agri-food landscape.

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