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The Difficult Decision of Using Biopesticides: A Comparative Case-Study Analysis Concerning the Adoption of Biopesticides in the Mediterranean Region

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Abstract: The adoption of biopesticides in Mediterranean agriculture is shaped by environmental, economic, and socio-cultural factors. This study explores the push and pull factors influencing farmers' decisions in Spain's Ebro Delta, Tunisia's Nabeul region, and Turkey's Adana province. Through qualitative fieldwork and comparative analysis, key barriers to adoption are identified, including high costs, limited market availability, skepticism about efficacy, and reliance on conventional pesticides. However, this study also highlights opportunities driven by regulatory changes, increasing market demand for sustainable products, and the potential of biopesticides to improve ecological sustainability. The research follows a comparative case-study approach and was conducted between January and November 2024. The methodology included a literature review, two rounds of qualitative interviews with farmers, and thematic analysis to identify barriers and enabling factors, ensuring methodological rigor and cross-validation. Findings indicate that farmers' professional ethos and economic conditions significantly limit biopesticide adoption. Perceived inefficacy, high production costs, and low profit margins reinforce reluctance. Spain struggles with skepticism, Tunisia faces economic and informational barriers, and Turkey's reliance on traditional practices slows innovation. Despite these obstacles, key drivers facilitate adoption, including improved agricultural education, cooperative support, and increasing consumer demand for sustainable products. Legal frameworks, particularly the EU's "Farm to Fork" strategy, play a crucial role, though top-down policies risk local resistance. This study outlines a model for biopesticide adoption based on seven key factors, with legal frameworks and farm structure emerging as primary drivers. Addressing economic and educational barriers is crucial for widespread adoption. By implementing targeted policies, Mediterranean agriculture can become a model for sustainable practices, balancing productivity and environmental stewardship.

Keywords: biopesticides; Mediterranean agriculture; sustainable farming; push and pull factors; ecological transition; science and technology studies

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1. Introduction

The question of sustainability in agriculture is of tantamount importance. Farming practices, as they emerged from the twentieth-century green revolution, are causing environmental degradation, biodiversity loss, and soil and water pollution [1]. In this respect, international organizations, such as the United Nations Food and Agriculture Organization [2], have pointed out the necessity of changing tools and approaches. In this respect, a key issue is reducing and substituting conventional pesticides with new products, such as biopesticides. Biopesticides are substances of biological origin obtained from microorganisms (bacteria, fungi, and viruses), plants or plant extracts, or natural biochemical compounds capable of acting more selectively and less harmfully on non-target organisms and the environment [3,4]. Despite their market share still being limited (around 2.5% of the global total of plant protection products) [5], their use is steadily, but slowly, increasing, supported by international guidelines for sustainable development, regulations aimed at reducing the use of synthetic chemical substances, and consumers increasingly sensitive to the origin and safety of products [4,6]. Despite the promises, these remedies often appear at the margin of the current agricultural practices, finding it hard to become the mainstream. Recent studies have started exploring the causes of this limited implementation and indicate that bottlenecks attain the availability in the market, as other institutional and socio-cultural issues [7,8]. Overall, however, the dynamics of implementation appear to be limitedly studied.

The Mediterranean region, with its diverse cultural, political, and environmental characteristics and its high crop diversification, proved to be a particularly relevant case study for understanding the underpinning dynamics concerning the implementation of biopesticides. In effect, the region has become a focal point for the international community as a testing ground for the ecological transition in agriculture [9] due to the new and severe challenges posed by climate change and the introduction of new pests and pathogens that are transforming the agricultural landscape [10]. While synthetic pesticides—traditionally used to prevent, control, or mitigate the action of harmful organisms on plants—are showing their limitations and harmfulness in terms of environmental and biodiversity preservation, raising concern and creating a demand for change [11,12], navigating agriculture through new, more sustainable forms of agriculture appears still complex [13]. Despite the attempt of the European Union to drive agriculture to abandon synthetic pesticides [14], they still dominate farming practices. Technical limitations [15], economic factors seem to limit the popularization of new, alternative remedies [16–18], and other socio-cultural factors [19,20]. However, while single case studies shed light on the specific dynamics affecting single regions, the literature does not provide comparative analysis that can help to understand what common threads can be found in a region that is particularly diverse in terms of institutional and political organization and what are the actual specificities that differentiate EU and non-EU developed and developing areas.

This article aims to fill this gap and provide insight into how farmers in the Mediterranean region perceive these new products and what are the key push and pull factors that affect their choices in a comparative perspective. Considering the different institutional environments and different approaches to climate and environmental protection that characterize EU and non-EU countries, this article moves on a basis of a qualitative comparative study conducted in Spain (EU country), Tunisia (non-EU country), and Turkey (non-EU country negotiating access to the EU); the article aims to answer the following three main research questions:

- What are the main limitations and opportunities perceived by the farmers that affect the use of biopesticide in the region?
- What are the specific and more general trends that characterize the adoption of biopesticides within and without the EU?
- What are the possible areas of intervention to facilitate the implementation of these products?

In so doing, it indicates what intervention could be implemented to support the dissemination of biopesticides in the face of the contemporary challenges farmers face in the Mediterranean region.

The article opens by introducing this study conducted in the region and its methodology. It presents the key findings from the research. Their comparative analysis allows them to highlight the key factors that influence the specific trajectories in the three sites and in the region in general.

2. Materials and Methods

This article results from comparative case-study research [21] focused on the following three agricultural sites in the Mediterranean region: the Ebro Delta in Spain, the Governorates of Nabeul and Ariana in Tunisia, and the province of Adana in Turkey (Figure 1). This form of research is a strong approach for contextualized understanding because it offers valuable insights by identifying patterns, differences, and broader trends across the different contexts [22]. It extends qualitative insights beyond a single case and enables cross-case learning [23]. However, this approach also presents challenges, such as the complexity of analysis, the need for a rigorous framework to ensure meaningful comparisons, and potential limitations due to variations in data quality and availability [24]. Additionally, while cases may share similarities, their unique historical, cultural, and economic contexts can complicate direct comparisons and risk overgeneralization [25]. Despite these challenges, a well-structured comparative case-study analysis remains an effective method for examining social, economic, and policy-related phenomena [23].

Figure 1. Localization of the fields: Ebro Delta, in orange; the Governorates of Nabeul and Ariana, in red; and Province of Adana, in yellow. Visualization: Fontefrancesco, 2025.

The research was conducted between January and November 2024 within the framework of the research project "SAFWA—Alternative Biopesticides for Safe Integrated Pest and Water Management around the Mediterranean", funded by the EU Partnership for Research and Innovation in the Mediterranean Area program. This study was based on the collaboration of 5 research institutions across the area (the UNISG-University of Gastronomic Sciences in Italy, the IRTA-Institute of Agrifood Research and Technology in Spain, CTA-Citrus Technical Center and the CBS-Centre for Biotechnologies in Sfax in Tunisia, and BBP-Biyans Biological Products in Turkey). The three regions were selected based on the presence of similar crops, particularly olive trees and citrus fruits, and the shared agricultural profile of the local economy. Additionally, the three areas have comparable climatic conditions, which have made them suitable for experimental research on the development of biopesticides [26–28].

The research was structured into three main steps (Figure 2). Phase I involved a targeted literature review aimed at identifying the key areas of concern that the current literature pointed out as limiting factors for the implementation of biopesticides in the Mediterranean area [29]. This preliminary phase was followed by fieldwork conducted in the three sites through two rounds of interviews with farmers. This particular articulation of qualitative research is supported by several key principles evident in the qualitative research literature and aligns well with the standards of qualitative inquiry, where flexibility and responsiveness to participant narratives lead to richer insights [30]. The first round of interviews allows researchers to explore foundational themes and build rapport with participants, since early insights gained from a limited number of participants can help refine subsequent interview guides and encourage deeper and more relevant discourse in later rounds [31]. Following this preliminary analysis, the second round involves a broader participant pool, allowing for validation and refinement of emerging themes. In effect, engaging more participants in subsequent rounds not only increases the diversity of perspectives but also allows researchers to corroborate findings and identify commonalities across distinct experiences and narratives, thereby enhancing generalizability [32]. In both the rounds, for each location, it was aimed at interviewing a minimum of 12 participants. Qualitative studies utilizing semi-structured interviews commonly settle on a sample size of approximately 15 $\pm$ 10 participants to ensure that saturation is attained [33]. Thus, 12 respondents are within the optimal range to explore key themes and reach saturation, particularly for focused case studies such as the one in this research [34].

Field research was conducted by IRTA (Spain), CTA together with CBS (Tunisia), and BBP (Turkey) under the supervision of UNISG, which developed the methodology and tools for data collection (Appendix A). The first round of interviews investigated the use and selection of pesticides, the learning processes related to their application, the forms of awareness concerning biopesticides and their potential use, and the socio-economic and cultural factors influencing or limiting the use of biopesticides. A final question was dedicated to gathering the participants' conceptions and perspectives on the future of their work and agriculture in general. In total, 26 interviews were completed in Spain, 15 in Tunisia, and 12 in Turkey. UNISG analyzed the data to identify convergences, divergences, and the emergence of any new elements not previously addressed in the studies. The interviews were subject to a thematic analysis aimed at understanding the main divergences or convergences between data emerging from the literature and what was experienced on the ground. Moreover, based on these results, the researchers developed a second, more extended interview guide (Appendix B) that was used to conduct semi-structured interviews with farmers in the three target areas between June and October 2024. Overall, 22 interviews were conducted in Spain (by UNISG researchers in collaboration with IRTA), 15 in Tunisia (by CTA together with CBS), and 15 in Turkey (by BBP). These

interviews enabled the placement of specific information on pest management within a broader agricultural context, considering the cultural, social, historical, economic, and territorial dimensions of food production practices. The interviews were then transcribed, translated, and coded. UNISG researchers thematically analyzed the results and then compared them with those resulting from Phases 1 and 2 to identify enabling or limiting factors in the choice of different pest management approaches to provide an in-depth understanding of the pattern of innovation related to the personal histories of the farmers and one of their farms.

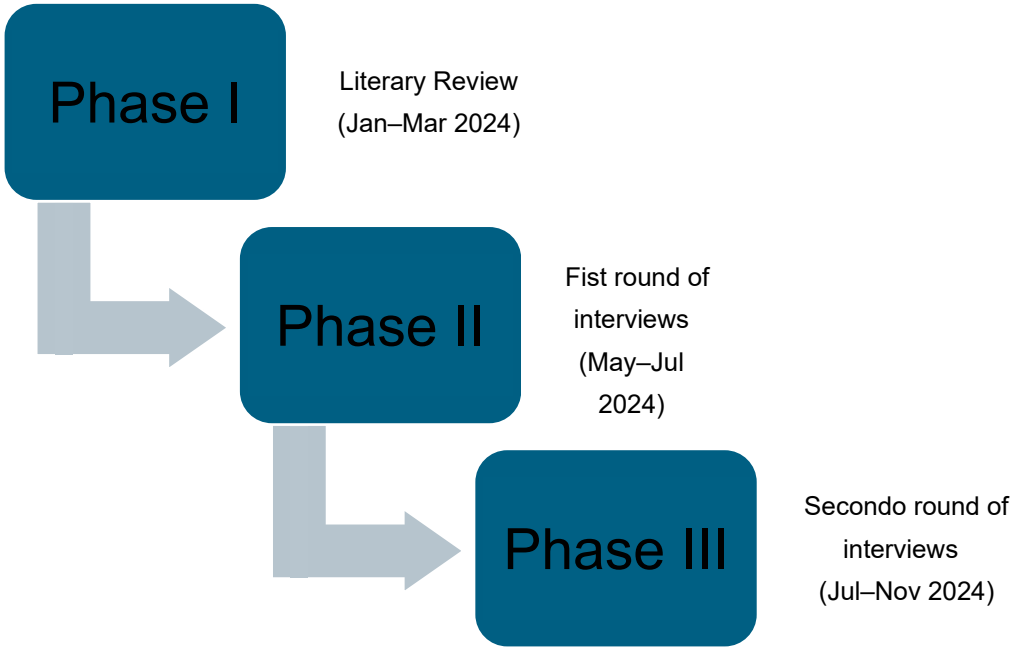

Figure 2. Visual representation of the different phases of research. Visualization: Fontefrancesco, 2025.

For the research, informants were chosen covering individuals involved in the cultivation of predominant crops, with a variety of production systems (e.g., integrated, conventional, and organic) to capture different management practices, particularly for crops requiring specific agronomic interventions. A balance of enterprise sizes is maintained by including farms of different scales, ensuring diversity in production capacity. Additionally, a range of professional roles is represented, incorporating farm owners, technicians, and advisors while also considering varying levels of training and expertise to minimize bias. These criteria are commonly followed in studies with interests aligned with the one conducted [35]. All informants participated freely and willingly in their native language thanks to the researchers of the local partners who were trained by the UNISG researchers in advance.

3. Results

3.1. The Trends in the Literature

Since the publication of Rachel Carson's Silent Spring in 1962 [36], intensive agriculture has been widely recognized as a major contributor to global pollution and toxicity [37]. Yet, as the evidence presented here demonstrates, the issue remains as urgent today as it was then. A critical point in the ongoing debates and practices surrounding chemical plant protection products lies in their deep connection to ecological and socioeconomic policies [38]. This precarious intersection is reflected in the broader perception of the agricultural sector as being caught in a vicious cycle of new pest outbreaks, restricted availability of plant protection products, climate change, and economic crises.

The state of the art in the literature, highlights the main challenges related to pest management and sustainable agriculture. Overall, limitations are primarily due to the agricultural production system's strong dependence on conventional plant protection products, with a persistent reliance on chemical pesticides to manage difficult-to-eradicate infestations. The biopesticide market remains a niche sector, characterized by low demand and limited product availability. This condition is difficult to overcome due to the presence of numerous regulatory and institutional barriers, such as fragmented or inadequate legislation and poor enforcement of existing laws. Another factor contributing to stagnation is the limited access to adequate and in-depth knowledge of the nature of biopesticide products, compounded in cases where it is paired with a general lack of technical and agronomic expertise among farmers. In contrast, opportunities arise from favorable regulatory developments, particularly in the European Union context, where stricter restrictions on synthetic pesticide use are being implemented. These measures also encourage public–private collaborations to foster investment and innovation, which is driving market expansion.

In this context, however, the review conducted during the research emphasizes specific dynamics characterizing Spain, Tunisia, and Turkey (Table 1). From these data, the empirical research set sail.

Table 1. Summary table of the main limiting factors and opportunities for biopesticide deployment in the scientific literature.

Country	Key Characteristics	Challenges	Opportunities	Main References
Spain	- Biopesticide market still niche but growing - Collaboration between public and private sectors - Stricter regulations on synthetic pesticides	- Slow, widespread adoption of biopesticides - Pressure from the conventional market regarding production costs	- Ongoing increase in the supply of authorized active substances (38 in 2020) - Potential to expand public–private collaboration for research and development	[4,39,40]
Tunisia	- Widespread use of traditional pest management methods - Increasing reliance on chemical pesticides - Regulations aimed at limiting excessive pesticide use	- Traditional methods are insufficient to address the wide range of infestations - Increased use of chemical pesticides despite existing restrictive regulations	- Strengthening sustainable alternatives by leveraging existing regulations - Enhancing traditional knowledge along with modern methods	[41–45]
Turkey	- Dominance of small and medium-sized farms - Fragmented regulatory system - Recent reduction in chemical pesticide production	- Limited access to modern agronomic knowledge - Difficulty adapting to regulations due to fragmentation	- Growing adoption of biopesticides (facilitated by the reduction in chemical pesticide production) - Potential training programs and technical support for SMEs	[46–48]

3.2. Dynamics in the Ebro Delta

3.2.1. Characteristics of Producers and Agricultural Enterprises

The research in the Ebro Delta region in Catalonia (Spain) involved farm owners located in the provinces of Montsià, Baix Ebre, and Baix Maestrat. The interviewees were mostly men aged between 28 and 85 (average of 54). They own farms with an average size of 11.8 hectares, ranging from 1 to 40 hectares. Their educational levels vary, from basic education to university degrees, with a prevalence of those holding intermediate technical training (over 40%). Technical and agronomic training is particularly widespread, with almost all participants having agricultural engineering qualifications and direct and family-based field experience. Often, farmers supplement their agricultural management with

other activities, such as consulting or providing agricultural services to others. Most express satisfaction in having expanded inherited land or aspire to further expand their properties. Some farms also use rented land to increase the cultivated area. These farms are often family-run, a source of pride but also economic uncertainty, especially for smaller properties.

3.2.2. Cultivated Crops, Pests, and Products Used

The main crops cultivated by the informants were citrus fruits and olives. The most frequent pests in this area are California red scale, aphids, whiteflies, mealybugs, the two-spotted mite, Mediterranean fruit fly, Texas citrus mite (in some specific contexts), olive fruit fly, olive moth, peacock leaf spot, olive psyllid, red mites, and scale insects. About 80% of producers report using conventional pesticides, often within an Integrated Pest Management approach. In particular, the most commonly used active substances are insecticides (acetamiprid, pyriproxyfen, and spirotetramat); acaricides (hexythiazox and pyridaben); herbicides (glyphosate); and fungicides (copper oxychloride and copper sulfate). Mineral and paraffinic oils, authorized in organic agriculture, are used by some producers to reduce scale insect and aphid infestations.

3.2.3. Criteria for Choosing Products and Plant Care Methods

Among the various factors influencing product and method selection for crop protection, the most prominent and frequently mentioned in the interviews is the guidance provided by a pest advisor, partly because, under Spanish law, this figure (whether private or cooperative) must supervise that the correct application of treatments is based on their technical expertise. Without such supervision, crop products cannot be allowed to be commercialized. Cooperative membership can be binding but provides technical stability and support. Other criteria are personal/family experience and technical knowledge from training courses or study. In particular, the Phytosanitary Applicator Certificate is mandatory for agriculture, and all people interviewed attended the corresponding training. All the "younger farmers" (under 40) also attended specific training programs to obtain subsidies. Some farmers also mentioned occasional collaborations with research centers to test mass-trapping devices and other sustainable control strategies.

3.2.4. Biopesticides and Knowledge

Nearly all participants report being aware of biopesticides' characteristics and potential, although the depth of understanding varies considerably. About one-third of those interviewed correctly link biopesticides to biologically derived active substances. Only a few have no knowledge of biopesticides. About half of the respondents confirmed having used biopesticides or currently using them, often as an addition to traditional chemical products. Among the most frequent solutions mentioned are copper sulfate, copper oxychloride, sulfur, *Bacillus thuringiensis*, and mineral or paraffinic oils.

3.2.5. Reasons Limiting the Adoption of Biopesticides

Many farmers believe that biopesticides are less effective and more expensive than conventional chemical products, particularly when facing new infestations. Limited market availability, the need for repeated treatments, and a lack of information or technical support from cooperatives or specialized retailers fuel additional skepticism. Most citrus production in this area is devoted to fresh-market consumption, which imposes very high requirements on fruit quality standards. For this reason, some producers believe products grown under this approach would not gain full acceptance from consumers and could increase field waste due to possible cosmetic imperfections. Counterintuitively, in some cases, legislative limits lead many farmers to request the reintroduction of currently non-authorized pesticides rather than invest in solutions perceived as less effective. Finally, there are some producers

who claim that their crops do not require any kind of pesticides, including biopesticides (especially in olive crops).

3.2.6. Reasons Favoring the Adoption of Biopesticides

From a middle- and long-term perspective, the main driver is the progressive reduction in the availability of synthetic pesticides due to legal and market restrictions. Less, but existing, is the interest in addressing ecological considerations for human and plant health. Some producers declare the aim to align with markets increasingly focused on sustainability, tapping into potential niche segments like zero-residue production. In millenary olive crops, another biopesticide/ecological agricultural driver is the development of territorial promotion projects, based on the emotional bond to the land. Certain farmers are experimenting with integrated or organic farming methods and "do-it-yourself" solutions (e.g., producing natural substances independently) to reduce reliance on synthetic active substances without compromising yields.

3.3. Dynamics in the Tunisian Northeastern Regions

3.3.1. Characteristics of Producers and Agricultural Enterprises

The research was conducted in the Nabeul region (Tunisia), with some farms also located in the Ariana area. The interviewees are primarily men, aged between 30 and 78 (with an approximate average of 55). In some instances, women manage the farm in the spouse's absence. There is a generational continuity up to the third generation for many farms; only in a few cases are there recent acquisitions by professionals from non-agricultural sectors. They own farms with an average size of around 15 hectares, ranging from less than 2 to 180 hectares. The organizational structure is often small, family-run businesses, but there are also larger enterprises with both permanent and occasional workers. In general, family labor is a notable use. Their educational levels vary from primary school to university and postgraduate degrees, with many holding specialized agronomic qualifications. Technical and agronomic training is particularly common, and several participants also possess direct, family-based field experience. Frequently, farmers integrate their agricultural activities with other professional roles, such as mechanics, citrus wholesaling, or consultancy.

3.3.2. Cultivated Crops, Pests, and Products Used

The main crops considered are citrus, often accompanied by olives, fodder, vegetables, occasional greenhouse vegetables, and organic roses. Citrus is traditional in the region, but concern about the economic viability of citrus has led some farmers to replace or supplement their citrus groves with more drought-resistant olives.

Various insects and pathogens affect crops, including aphids, mites, leaf miners, *Ceratitis capitata* (Mediterranean fruit fly), whiteflies, scales, mealybugs, carob moths, *Prays citri*, and the Tristeza virus. Newer threats, such as California red scale (*Aonidiella aurantii*) and fungi like *Botryosphaeria dothidea*, have emerged, partly due to climate change, which extends pest activity periods and heightens their aggressiveness.

The most applied treatments include insecticides (e.g., abamectin, acetamiprid, deltamethrin), fungicides, herbicides, and preventive winter treatments (oil and copper) or sulfur application. Intensive and prolonged pesticide use has led to resistance development, necessitating more frequent treatments or costlier products, thereby increasing production expenses. Some farms employ targeted interventions for specific pests (e.g., aphids), whereas others practice non-selective chemical management covering several key pests.

3.3.3. Criteria for Choosing Products and Plant Care Methods

The decision-making process results from practical experience, professional advice, and formal/informal education. Many producers rely on direct observation and personal

expertise to identify and manage pest species and prefer independent agronomy technicians or peer-to-peer learning networks because of limited availability of specialized technical support and concerns about conflicts of interest, particularly when guidance comes from pesticide sellers. The majority of the interviewed farmers mentioned consultation with trusted neighbors to bridge advisory gaps. Only in very few cases is the decision-making fully delegated to external consultants. The information is searched through official references (phytosanitary guides and CTAB for organic farmers), internet resources, and training courses. Key factors for pesticide selection are efficacy and price (reduced toxicity just for pollinators). Balancing economic viability with effective pest management is a persistent challenge. Only a few farmers have specialized training (e.g., university-level studies, Citrus Technical Center). Self-taught methods predominate, with trial-and-error and label reading as common practices. There is widespread acknowledgment of the importance of updated, reliable guidance, yet barriers exist in accessing and adopting new knowledge.

3.3.4. Biopesticides and Knowledge

Most interviewed producers define biopesticides as natural-origin products with minimal toxicity, suited for organic agriculture. Still, one-third are completely unfamiliar with the term or provide only a generic "no" when asked about biopesticides. Some producers report using biopesticides, such as Spinosad (for *Ceratitis capitata* control) and Bactospeine (based on *Bacillus thuringiensis*) for carob moth or *Prays citri*. It quite diffused the usage of copper, sulfur, and mineral oil—permitted in organic farming—without resorting to specific biopesticide products.

3.3.5. Reasons Limiting the Adoption of Biopesticides

Many respondents cite the high cost of biopesticides as the primary barrier to their broader use. Price concerns are compounded by limited availability and a lack of information or training. Moreover, some farmers explicitly state they do not practice organic farming and therefore perceive biopesticides as unnecessary or unaligned with their current conventional approach. These findings align with broader observations regarding satisfaction with conventional pesticides as follows: despite complaints of high costs and resistance issues, many producers still rely on chemical products to secure yields and marketable quality. Additionally, minimal technical support, insufficient incentives to switch, and economic constraints all reinforce the sense that biopesticides remain a less accessible option.

3.3.6. Reasons Favoring the Adoption of Biopesticides

Around half of the interviewees are interested in trying biopesticides, provided they become more affordable and readily available. A small number emphasize plans to transition to organic farming in the near future, holding organic certification. Some also point out their interest in lower residue levels for export-oriented production. In line with these motivations, certain farmers mention that additional training or technical guidance could facilitate a shift. This openness reflects an underlying awareness of the drawbacks of conventional agriculture (e.g., resistance development and environmental impact) and the potential benefits of integrating more sustainable practices.

3.4. Dynamics in the Turkish Province of Adana

3.4.1. Characteristics of Producers and Agricultural Enterprises

The research was conducted in the Adana region (Turkey) and involved all male farmers, between 29 and 72 years old (with an approximate average of 46). Most farms cover areas between 5 and 242 hectares, although most do not exceed 15 hectares, directly managed by owners, with limited task delegation. Producers declare that they are personally in charge of planting, pruning, irrigation, and pest control. Their educational levels

vary from primary school to university, but up to 50% of people interviewed hold only the primary school degree. Many of them are second- or third-generation farmers, exhibiting a strong family heritage and pride in continuing the work of fathers and grandfathers. Concretely, they often rely on traditional farming techniques. However, uncertainties are expressed about the interest of the younger generation.

3.4.2. Cultivated Crops, Pests, and Products Used

The main crops farmed among considered producers are oranges, tangerines, lemons, grapefruits, and mandarins, with lemons and oranges being the most common species. Most farmers stick to citrus due to land suitability, tradition, and established markets. The prevalent pests that threaten the crops are citrus red mites, citrus rust mites, moths, mealybugs, and Mediterranean fruit flies. Many farmers underline how Mediterranean fruit flies and moths have become significant pests, possibly due to climate changes or reduced pesticide efficacy. Pest control relies on chemical pesticides overall. Some producers mention specific formulations but often refer to them with general labels. Rising pesticide costs, resistance issues, and limited access to alternative methods may pose future challenges.

3.4.3. Criteria for Choosing Products and Plant Care Methods

The two main key influences in the decision-making process in pesticide selection and use are consulting agricultural engineers and, overall, following prescriptions and recommendations of pesticide dealers of pharmaceutical companies and shops. Relying almost entirely on outside experts is inevitable, especially because over 80% of people interviewed lack formal training in pesticide use, and by consequence, they lack overall modern pest management innovations. These two information sources are completed through personal experiences, based on years of farming and trial-and-error, and recommendations from other farmers recognized as experts, because information sharing among neighbors and producers is common.

3.4.4. Biopesticides and Knowledge

Of farmers lack complete awareness of biopesticides and have heard the term for the first time during the interview. Only a few farmers are familiar with the concept or have tried biopesticides in the past. Moreover, 100% of respondents practice conventional farming, without mentioning organic, integrated, or alternative farming methods. is that they believe that conventional farming is the only viable option, even though there is no real exploration or motivation to discover alternative practices.

3.4.5. Reasons Limiting the Adoption of Biopesticides

The most important limitations to biopesticide adoption are the lack of information and understanding of what biopesticides are and how they function and the absence of accessible training opportunities to prevent adoption. In this context, chemical pesticides are viewed as necessary and the only viable option. The conditions under which people would be interested in trying and exploring biopesticides are determined by economic constraints because price is a critical barrier for most respondents. Conservative factors are also the continuation of traditional practices learned from family and passed through generations, and the belief that conventional farming is easier and more economical; reliance on routines inherited from previous generations reinforces continuity, and risk aversion discourages major changes. Indeed, growing pest challenges and uncertainty about long-term sustainability. Last, people rely on agronomists and pharmaceutical advisors and technicians, so limited promotion and availability of biopesticides in the market prevent exploration of alternatives.

3.4.6. Reasons Favoring the Adoption of Biopesticides

Around one-third of respondents are open to trying biopesticides. Their conditional willingness to explore alternatives is based on demonstrated efficacy and affordability. The opportunities for biopesticide adoption are overall situated in addressing an existing dissatisfaction with current practices, motivated by a general growing pesticide resistance. The interviews show not only several conservative factors but also that some farmers are aware of the need to innovate. One emerging trend is the experimentation with new citrus varieties to adapt to market demands. A similar effort to adapt to the increasing organic product demands could determine a biological shift in crop protection.

4. Discussion

4.1. Overview

The results from the three fields can be read synoptically to identify the general trends linked with the introduction of biopesticides in the Mediterranean area (Table 2).

Table 2. Summary table of data provided by fieldwork in Spain, Tunisia, and Turkey.

Section	Ebro Delta (Spain)	Nabeul (Tunisia)	Adana (Turkey)
Characteristics of Producers and Agricultural Enterprises	Farm sizes: Average 11.8 ha, range 1–40 ha. (mix of inherited and rented land) Demographics: Producers mostly male, aged 28–85 years (average 54). Training: High prevalence of agronomic training; most have agricultural engineering qualifications. Additional activities: Many supplement farming with consulting or agricultural services. Farm structure: Family-run farms are common.	Farm sizes: Average 15 ha, range < 2 to 180 ha. Demographics: Producers mostly male, aged 30–78 years (average 55). Training: A mix of formal agronomic training and practical experience. Additional Activities: Farmers often engage in other activities, such as mechanics, citrus wholesaling, or consultancy. Farm structure: Family-run farms with generational continuity (up to the third generation).	Farm sizes: Range 5–242 ha. Demographics: Predominantly male, aged 29–72 years (average 46). Training: Half of the farmers hold only primary education, experience for trial and error Additional activities: Farm structure: Family-run farms with generational continuity
Cultivated Crops, Pests, and Products Used	Main crops: Citrus and olives. Main pests: California red scale, aphids, whiteflies, mealybugs, two-spotted mites, Mediterranean fruit fly, Texas citrus mite, olive fruit fly, olive moth, peacock leaf spot, olive psyllid, red mites, scale insects. Pesticide usage: overall conventional pesticides, often with integrated management approaches (exceptions: no products at all, self-made products, organic products). Common substances: Acetamiprid, pyriproxyfen, pyridaben, hexythiazox, spirotetramat, glyphosate, copper oxychloride, copper sulfate. Biological inputs: Mineral and paraffinic oils used by some producers (approved for biological agriculture).	Main crops: Citrus, olives, fodder, greenhouse vegetables, organic roses. Main pests: Aphids, mites, leaf miners, Mediterranean fruit flies, whiteflies, scales, mealybugs, carob moths, *Prays citri*, Tristeza virus, California red scale, *Botryosphaeria dothidea*. Pesticide usage: overall conventional pesticides Common substances: abamectin, acetamiprid, deltamethrin, general fungicides, herbicides. Biological inputs: oil, copper, sulfur.	Main crops: Citrus (oranges, lemons, mandarins). Main pests: Mediterranean fruit fly, moths, mites, citrus rust mite. Pesticide usage: Heavy reliance on chemical pesticides. Common substances: Algomeg, “Zenk Medicine”, “Rust Medicine”, “Mealybug Medicine”, V-93, PAs, lice medicine. Biological inputs: oil

Table 2. *Cont.*

Section	Ebro Delta (Spain)	Nabeul (Tunisia)	Adana (Turkey)
Criteria for Choosing Products and Plant Care Methods	Guidance and support: Guided by agronomists, cooperative membership provides technical stability and support. Selection criteria: Efficacy, price, past experience, market niche, plant care Training: Phytosanitary Applicator Certificate mandatory; younger farmers receive special training for subsidies, school and university, family experience, and occasional collaborations with research centers (e.g., testing mass traps and sustainable remedies). Information sources: Internet, courses, cooperatives, agronomists.	Guidance and support: Limited access to specialized technical support; some consult independent agronomy technicians or neighbors. Selection criteria: Efficacy, price, reduced toxicity for pollinators Training: Limited formal training; reliance on informal learning and self-training. Information sources: Phytosanitary guides, CTAB (for organic farming), and the internet.	Guidance and support: Decisions guided by agronomists, pesticide dealers, and familiar experience Selection criteria: Price, resistance avoiding Training: learning through trial and error and peer recommendations. Information sources: Peer recommendations supplement agronomist and dealer advice.
Biopesticides and Knowledge	Awareness: The great majority is familiar with biopesticides. Biopesticides are associated with biologically derived active substances, but the depth of understanding varies. Usage: The majority use biopesticides or organic products along with conventional products. Frequent biopesticides: Spinosad, *Bacillus thuringiensis*-based products. In addition: Copper sulfate, copper oxychloride, sulfur, and mineral/paraffinic oils.	Awareness: Most producers define biopesticides as natural-origin, non-toxic products suited for organic farming. One-third are unfamiliar with the term. Usage: Some farmers use biopesticides or organic products along with conventional products. Frequent biopesticides: Spinosad (for *Ceratitis capitata* control) and Bactospeine (*Bacillus thuringiensis* for carob moth or *Prays citri*). In addition: copper, sulfur, and mineral oils (allowed in organic farming).	Awareness: The majority lack awareness of biopesticides; the term was often first heard during interviews. Usage: Few have tried and abandoned biopesticides. Frequent biopesticides: None. In addition: oil.
Reasons Limiting the Adoption of Biopesticides	High cost of biopesticides. Limited availability in the market. Lack of information and awareness about biopesticides. Skepticism about their effectiveness. Perception that biopesticides are less effective than conventional pesticides. The need for repeated treatments increases labor and cost. Reliance on chemicals.	High cost of biopesticides. Limited availability in the market. Lack of knowledge and training on biopesticides. Perception that biopesticides are unnecessary for conventional farming. Satisfaction with conventional pesticides. Minimal technical support for adopting alternative methods. Economic constraints reinforce reliance on conventional practices.	Lack of knowledge about biopesticides. Economic constraints. Reliance on conventional methods. Generational practices that favor continuity over change. Risk aversion discourages major innovations. Limited promotion of biopesticides. Market availability of alternatives is insufficient.
Reasons for Adopting Biopesticides	Legal restrictions on chemicals. Market limitations on chemicals. Increased demand for sustainable and environmentally friendly products. Health benefits for humans and plants. Territorial promotion projects. Experimentation with alternative practices. Adoption of integrated or organic farming methods.	Lower residue levels for exports. Alignment with organic market demands.	Addressing pesticide resistance Meet organic market demands.

4.2. Pull Factors

A specific eco-social perspective [49], which encompasses both beliefs and material conditions, appears to hinder the implementation of biopesticides.

First, farmers across the region tend to perceive biopesticides as less effective and reliable than synthetic pesticides. The prevailing belief is that these products are insufficient to combat severe infestations or extreme environmental stress, both of which have become increasingly common in recent years. In a context marked by the treadmill effect—resulting from the continuous use of synthetic pesticides [50]—this negative perception should be understood within a broader cultural framework. Throughout the Mediterranean region, farmers' professional success is closely tied to the quantity and quality of their yields each season. This ethos, which prioritizes agronomic solutions aimed at maximizing productivity, aligns with the logic underpinning global strategies such as those promoted by the UN [51], which advocate for increased agricultural production to keep pace with population growth while avoiding further climate catastrophes [52].

As a result, despite their level of formal education, many farmers grapple with the dilemma of growth versus sustainability [53], questioning whether the best path forward is degrowth [54] and which agrarian technologies are the most effective to implement [55,56] in an unstable economic environment [57]. Within this context, organic farming conversion is often seen as an added burden, especially for small farms already struggling with high production costs and inadequate infrastructure. Specifically, interviews highlight that many farmers experience an ambivalent mix of inadequacy and frustration about their results and future prospects while simultaneously expressing confidence in the skills they have acquired through family and education. Meanwhile, new sustainable products are perceived as expensive and difficult to access.

Economic challenges, in any case, represent the most significant barrier to adopting biopesticides. Small and medium-sized agricultural enterprises, already contending with high costs and narrow profit margins, find it difficult to invest in unfamiliar new technologies. Additionally, costs associated with other aspects of agriculture, such as labor and fuel, necessitate further trade-offs when experimenting with alternatives, fostering a general aversion to innovations perceived as risky.

Furthermore, specific challenges in individual regions shape the local trajectory of biopesticide adoption. In Spain, high costs, limited availability, and widespread skepticism about efficacy hinder their implementation. In Tunisia, economic and informational barriers, coupled with overall satisfaction with conventional pesticides, slow the transition to biopesticides. In Turkey, reliance on traditional practices, risk aversion, and inadequate market promotion continue to reinforce the use of conventional methods, limiting innovation in biopesticide adoption.

4.3. Push Factors

Despite the challenges, the data analysis also reveals positive factors that facilitate the adoption of biopesticides and promote a transition toward more sustainable agricultural practices. Some farmers and producers recognize the potential of biopesticides to reduce environmental impact and improve long-term sustainability. In this respect, where education levels are medium to high and producers have received agricultural education, there is greater openness toward using biopesticides. Together with education, as in Spain, the presence of cooperatives or strong informal social networks among producers in the same localities is a powerful driver of collective innovation; these institutions facilitate the diffusion of information among farmers since individuals rely on the decisions and evaluations of cooperative member assemblies, management boards, cooperative technicians, or the advice of other producers who have demonstrated tangible results. Together with

it, "knowledge key keepers", such as agronomists and traders, can support farmers by providing new insight into products and methods, facilitating the adoption of new products. Moreover, as in Tunisia and Turkey, biopesticides are easily approached when perceived as something closer and complementary to traditional chemical pesticides, becoming a further tool for controlling pests and treating plants.

It is also widely evident that increasingly stringent legislation on synthetic pesticides, aimed at reducing the environmental impact of conventional agricultural practices, is pushing many farmers—willingly or not—to resort to biopesticides as the only available alternatives. In this context, the role of European public policies, such as the "Farm to Fork" strategy, which aims to reduce pesticide use by 50% and make 25% of farming organic by 2030, proves crucial in enforcing sustainable practices [58–61]. This has also emerged in the research, although the interviews show that such "top-down" policies risk generating resistance and friction at the local level. The data produced in the research present alignments and discrepancies with the data in the literature that help better understand the key factors affecting farmers' choice.

4.4. The Model

Overall, the comparison between the literature and three case studies suggests that the push and pull factors influencing the adoption of biopesticides develop according to a complex model emerging from distinct yet interconnected trajectories. These trajectories can be understood as different axes that together form a comprehensive framework. The key axes are as follows:

- Accessibility, which describes the availability of biopesticides in the market, with the extremes being "Limited" and "Wide".
- Cultural Attitude, which reflects farmers' openness to change, ranging from "Conservative Attitude" to "Innovative Attitude".
- Education and Information, which represent the availability of training and knowledge on biopesticide use, with the extremes being "Scarce Information" and "Wide Information".
- Efficacy, which refers to the perceived effectiveness of biopesticides for local crops, ranging from "Low Effectiveness" to "High Effectiveness".
- Farm Structure, which describes the economic and entrepreneurial stability of farms, with the extremes being "Fragile Structure" and "Strong Structure".
- Legal Framework, which assesses the strength of legislative measures enforcing biopesticide use, ranging from "Lax Framework" to "Strong Framework".
- Market Demand, which represents consumer interest in organic or sustainable products, with the extremes being "Low Demand" and "High Demand".

Among these factors, the "Legal Framework" and "Farm Structure" appear to be the primary driving forces, while the remaining five play a secondary role in facilitating decision-making and adoption.

Each locale presents its own unique articulation of these factors, highlighting the specific local conditions that shape biopesticide adoption (Figure 3).

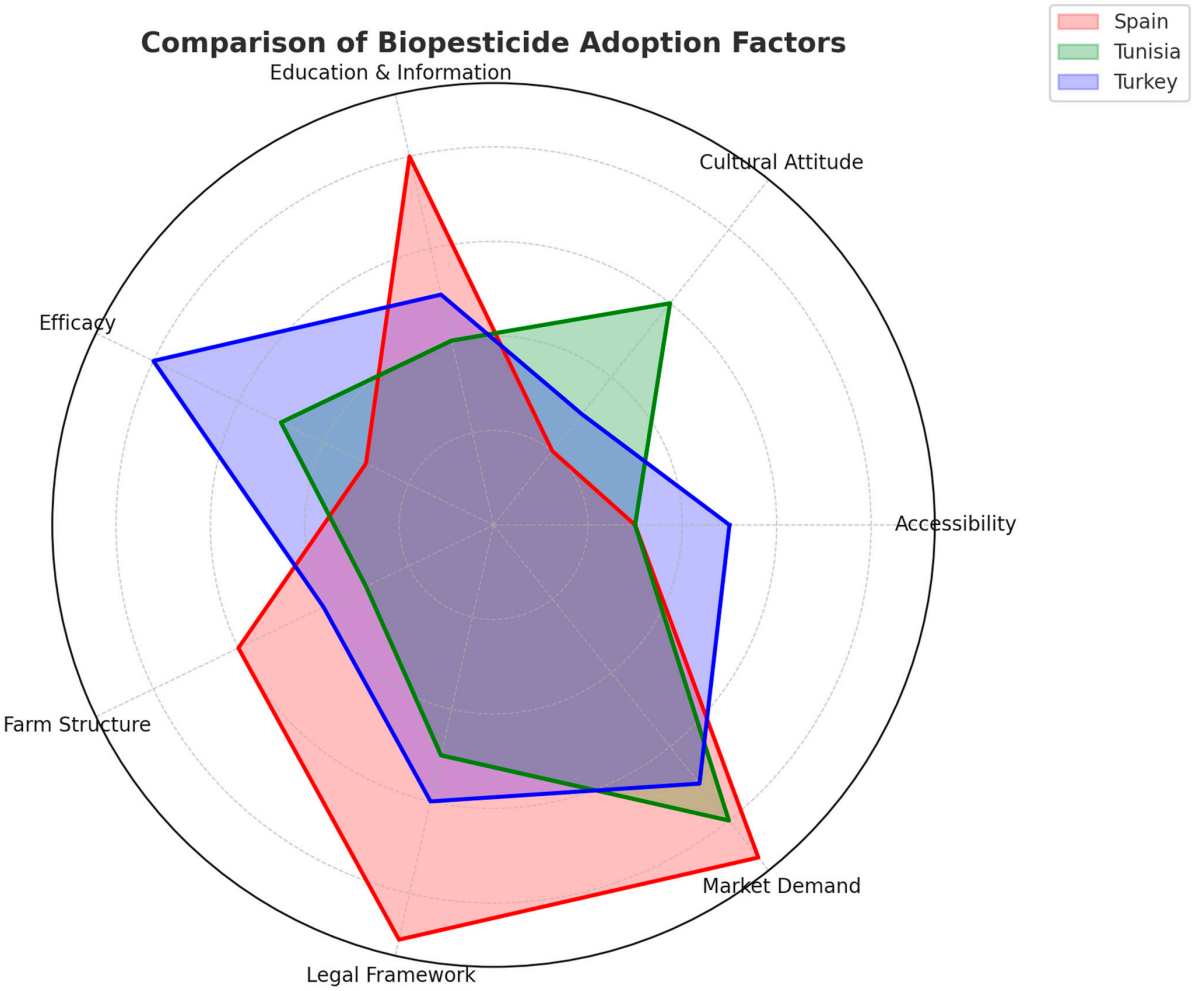

Figure 3. Radar chart comparing Spain, Tunisia, and Turkey based on their respective pull and push factors affecting biopesticide adoption. Each country's profile is represented with different color-coded areas to illustrate the differences in accessibility, cultural attitude, education, efficacy, farm structure, legal framework, and market demand. Quantification was based on the occurrence of the topics in the interviews. Entirely negative attitude codified with value 0; wholly positive with 7, neutral with 3. The quantification follows a structured approach. Pull factors (barriers) were rated higher where adoption was hindered, such as Spain's limited access and Tunisia's fragile farm structures. Push factors (drivers) were rated higher where positive influences existed, like Spain's strong legal framework and Turkey's high efficacy perception. Scores were derived from research, expert insights, and field data, considering factors like market demand, policy impact, and farmers' willingness to innovate. By integrating these elements, the chart offers a comparative analysis of the strengths and weaknesses shaping biopesticide adoption in each country. Visualization: Fontefrancesco, 2025.

5. Conclusions

The adoption of biopesticides in Mediterranean agriculture presents both a significant challenge and a unique opportunity to transform the sector into a more sustainable, resilient, and environmentally friendly system. By examining and comparing the dynamics in Spain, Tunisia, and Turkey, the research has identified the key factors influencing the implementation of these products.

Among the barriers to adoption, the perceived inefficacy of biopesticides remains a dominant issue. Farmers often doubt their reliability, particularly under extreme environmental conditions or severe pest infestations, where traditional synthetic pesticides are seen as more effective. Another significant obstacle is the high cost and limited availability

of biopesticides, further compounded by bureaucratic and economic challenges associated with organic certifications, which small and medium-sized enterprises struggle to afford. Overall, the fragile economic situation of many farms underpins farmers' risk aversion, leading them to view biopesticides as uncertain investments amid financial instability.

Moreover, several factors encourage the adoption of biopesticides. Research highlights their positive impact on both human and environmental health. Improved agricultural education fosters openness to alternative practices, supported by enhanced curricula, training programs, and the role of institutional actors such as farmers' cooperatives and associations. Additionally, stringent regulations, such as the EU's "Farm to Fork" strategy, serve as a regulatory push toward sustainable practices, though they are sometimes perceived as restrictive. Lastly, market demand for organic products is increasing, incentivizing producers to align with sustainable practices to access new market opportunities.

These factors are common threads across different regions, though they manifest more prominently in specific areas. Despite regional differences, the research underscores that agricultural innovation in the Mediterranean remains largely market-driven. The growing demand for environmentally sustainable and health-conscious products is generating increasing interest in biopesticides. However, progress is severely constrained by the economic realities of farms, which face low profit margins, high uncertainty, and limited financial capacity to manage production declines or crop failures. This economic fragility stands out as a primary concern that must be addressed to support meaningful change, particularly from an institutional perspective.

To overcome these obstacles and promote the broader adoption of biopesticides, a coordinated approach is essential. Legislative reforms should simplify registration processes, while awareness campaigns should educate farmers on the benefits of these products. However, the highest priority is supporting farms through economic incentives, including subsidies, tax breaks, and targeted grants, to encourage the adoption of biopesticides and mitigate potential agricultural losses. Additionally, further investment in research is needed to develop new solutions and enhance the effectiveness of existing biopesticides, ensuring their wider availability in the market.

This qualitative research highlights the complexity behind the delayed adoption of biopesticides in the region. The collected data allow for an initial modeling of this dynamic. Considering the inherent limitations of the methodological approach, future studies could both bridge the knowledge gap regarding other areas and crops not examined in this study and further explore the issue quantitatively, providing a more detailed analysis of the ongoing trajectories, helping to tailor better policies adhering to the specific characteristics of each region. The successful implementation of these strategies could position the Mediterranean as a model for addressing global challenges related to food security and environmental sustainability.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Gastronomic Sciences (protocol code 6/2023, 12 December 2023). The research was conducted according to the ethical guidelines of the American Anthropological Association (Principles of Professional Responsibility). In this article, the names of the research participants, their sensitive data, and the names of places have been anonymized.

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Appendix A

Table A1. Interview guide developed by UNISG and administered by partners in Tunisia, Turkey, and Spain for the first round of interviews.

Questions
1. Pesticide Selection and Usage
- Do you use pesticides in your agricultural work? If so, which ones?
- How did you choose the pesticides you use?
2. Training and Experience
- How did you learn to use these pesticides?
- Have you received any specific training? By whom?
3. Biopesticides
- What is a biopesticide?
- Have you ever used biopesticides?
If YES:
- Have you received any specific training on how to use it? By whom?
- What are the main factors that limit a more common use of biopesticides?
If NOT:
- Why don't you use them?
- Would you be interested in using them? Why?
4. Future Outlook
- What's the future of agriculture?
- How do you foresee the future of your work?

Appendix B

Table A2. Interview guide developed by UNISG and administered by partners in Tunisia, Turkey, and Spain for the second round of interviews. In bold, the key questions that underpins a series of secondary questions used in the interview.

Question
Name
Surname
Can you introduce your farm?
1.1. What type of crops do you have?
1.2. Have you always cultivated these trees, or have you changed? Do you plan to change? Why?
1.3. How many hectares do you have for each crop?
1.4. What type of business is it (family-run/personal/cultivated on behalf of others, etc.)?
1.5. What type of irrigation do you use (well/canal/river/dry farming, etc.)?
1.6. How is the quality of your land?
1.7. How is the quality of the water available to you?
What are the main difficulties you encounter in your work?
2.1. Do you recall moments of particular difficulty in the past? Did your grandparents or parents tell you about them?
2.2. At present, what causes you the most problems?
What are the main pests affecting your crops?
3.1. Have the pests always been present, or are they recent?
3.2. What remedies did your predecessors adopt against pests?
3.3. What remedies do you use today for different pests?
3.4. What products do you use? How do you apply them?
3.5. How do you decide which products to use and how to apply them?
3.6. What methods do you use besides product application?
3.7. Do you think there are enough tools for pest prevention?
3.8. If yes, why?/If no, why?
3.9. Do you think the products you use have an impact on the environment around you? If yes, what impact?
3.10. Do you think the products you use have an impact on your health? What precautions do you take?
Do you feel the consequences of climate change in this region?
4.1. If yes, what are they?
4.2. If yes, how do you organize to deal with them?
What type of agriculture do you practice (conventional, organic, integrated, etc.)?
5.1. Why did you choose this type of agriculture?
5.2. Are you satisfied with your choice? Would you like to change? Are you making any changes?
5.3. If yes, why?/If no, why?
5.4. Why didn't you choose another type of agriculture?
5.5. Do you have any type of certification for quality/origin/method of cultivation? Does your cooperative have any?

Table A2. *Cont.*

How did you learn your job? From family? Through studies? From personal experience?
6.1. If you studied: Do you think the education you received helped you in the practical work?
6.2. Did you receive specific training for pest control? What kind of pest management was taught in training centers? What was taught in the family?
6.3. Are there differences in farming methods between different generations of your family or in the area?
6.4. Is there an exchange of skills and advice among neighbors and producers in the area?
What happens with damaged products?
7.1. Are they harvested or left in the field?
7.2. Does the quality/price change?
7.3. What do you think about it?
How do you market your products?
8.1. Are you part of a cooperative?
8.2. If yes, why? What agreements do the members have for harvesting? And for selling the product?
8.3. If yes, do you know to whom the cooperative sells the product? Is it for local, national, or international trade?
8.4. If no, why not?
8.5. If no, how do you sell your products? To a wholesale company? To small shops? Online? By word of mouth?
8.6. How much product do you sell annually?
8.7. Are you satisfied with the income in economic terms?
8.8. If yes, why?/If no, why?
8.9. What difficulties do you encounter in the market?
Do you receive any support or subsidies for your work?
9.1. What do you think about current agricultural regulations?
Does your land/your trees hold emotional or symbolic value for you?
10.1. If yes, what is it?
How do you see the future of your business?
11.1. Are there any young people who will continue after you?
How do you see the future of agriculture in this area?
12.1. Why?
12.2. What do you think could improve the conditions of agriculture?

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