Integrated survey of crop diseases and pest management practices in the Beni Mellal-Khenifra region, Morocco

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Research

Abstract

Background: To promote natural alternatives that could help reduce excessive pesticide use, an ethnobotanical survey was conducted to better understand and document the traditional uses of plant extracts for managing phytopathogenic diseases among farmers in the Beni Mellal-Khenifra region.

Methods: A total of 150 farmers were interviewed from five rural communes in the Beni Mellal-Khenifra region about their knowledge and use of plant extract for crop protection and their pesticide-use practices. The quantitative data were analysed using appropriate statistical tests. A correspondence analysis (CA) was performed to determine the relationships between respondents' treatment practices for crop pests and diseases and the studied parameters.

Results: The survey revealed that 90.67% of the farmers used pesticides to control phytosanitary problems. These products included 61.11% insecticides, 33.33% herbicides, and 5.55% fungicides. Moreover, 2% of the farmers relied exclusively on plant extracts, mainly from *Urtica dioica* L., *Capsicum annuum* L., and *Allium sativum* L., to manage diseases, particularly those affecting citrus crops. These extracts were used alone, in combination with other plant extracts, or together with chemical pesticides, with farmers reporting that the combined use improved treatment effectiveness. Farmers also reported a reduction in disease symptoms following the use of plant-based extracts.

Conclusions: The survey highlights the predominance of chemical pesticide use in the region, while revealing a limited adoption of plant-based pest control methods. Nevertheless, the use of plant-based extracts may contribute to more sustainable crop protection strategies in the future. However, their use as natural complementary alternatives for sustainable pest management requires further investigation.

Keywords: Ethnobotanical survey, plant extracts, disease symptoms, Beni Mellal-Khenifra region.

Background

For several decades, modern crop protection strategies have relied predominantly on the use of chemical pesticides, which have long been considered vital assets for agricultural development (Carpentier 2010). This approach has led to a growing dependence on phytosanitary products aimed at maximizing agricultural yields. Despite their agronomic benefits, the intensive and prolonged use of chemical pesticides has raised serious environmental and health concerns. Numerous studies have reported their negative impacts on soil quality (Zhao *et al.* 2020), water resources (Rissouli *et al.* 2017), and food safety (Abbou *et al.* 2021). In addition, repeated pesticide applications have promoted the emergence of pest resistance (Georghiou 1986), leading to a continuous increase in application rates and the introduction of new active substances to maintain their effectiveness (Carvalho 2006).

Globally, 3.7 million tons of pesticides are applied annually, mainly in agriculture, to reduce crop losses (FAO 2025). Designed to be biologically active, pesticides can also affect non-target organisms, including humans. These negative impacts also threaten ecosystem integrity and the provision of essential ecosystem services, such as water supply, food production, and ecotourism, which are vital to both human well-being and economic sustainability (Carriquiriborde *et al.* 2014; Tanaka *et al.* 2008).

In Morocco, the annual use of formulated pesticides is estimated at 17,000 tons (Benaboud *et al.* 2021). The agricultural sector, which accounts for nearly 17% of the national gross domestic product (MAPM 2014), remains strongly dependent on chemical inputs to maintain crop productivity. However, this growing reliance further exacerbates environmental degradation and public health risks, emphasizing the urgent need to develop and adopt sustainable and environmentally friendly alternatives to conventional chemical pest control strategies.

Despite the increasing interest in plant-based pesticides as sustainable alternatives to synthetic chemicals, there is limited information regarding current pest management practices, farmers' awareness of botanical control methods, and the potential use of local plant resources for crop protection in the Beni Mellal-Khenifra region. This gap in baseline knowledge hampers the development and promotion of locally adapted, sustainable pest management strategies. Therefore, the main objective of this ethnobotanical study was to characterize crop protection practices in the Beni Mellal-Khenifra region, with particular emphasis on the major crops, pests and diseases affecting agricultural production, the pest management practices adopted by farmers, and the local plant species used or perceived as potential botanical alternatives for pest control. The study also aimed to assess the potential role of plant extracts as natural alternatives for reducing or partially replacing the use of synthetic pesticides in the Beni Mellal-Khenifra region.

This ethnobotanical survey documents traditional knowledge in the region and identifies plants used by farmers to address phytosanitary problems. The information collected constitutes a valuable database, offering significant potential for scientific research, the promotion of natural plant protection strategies, and the development of more sustainable and environmentally friendly agricultural practices.

Materials and methods

Study area

The Beni Mellal-Khenifra region covers an area of 28,374 km² (representing 3.99% of the national territory) and has a population of approximately 2.5 million inhabitants, 49% of whom live in urban areas. Following the 2015 administrative territorial reform, the region comprises the provinces of Azilal, Beni Mellal, Fquih Ben Salah, Khenifra, and Khouribga (Fig. 1). Agriculture plays a major role in the region, with a utilized agricultural area of 948,426 hectares, including 187,483 hectares of irrigated land, making it one of the country's main agricultural hubs (Local Authorities, General Directorate, 2015).

Study population

The target population consisted of farmers from the Beni Mellal-Khenifra region. Data collection was carried out using questionnaires, which served as the primary tool for collecting information on farmer's practices and traditional knowledge. To ensure adequate sample representativeness, a random sampling method was implemented. The sample was distributed across five stations: one in the province of Khouribga and four in the province of Fquih Ben Salah (Fig. 1). The paper-based questionnaires were administered by a single interviewer to ensure consistency throughout the data collection process. The interviewer asked the questions and recorded the farmers' responses directly on the questionnaires. The farmers were invited to respond voluntarily and anonymously.

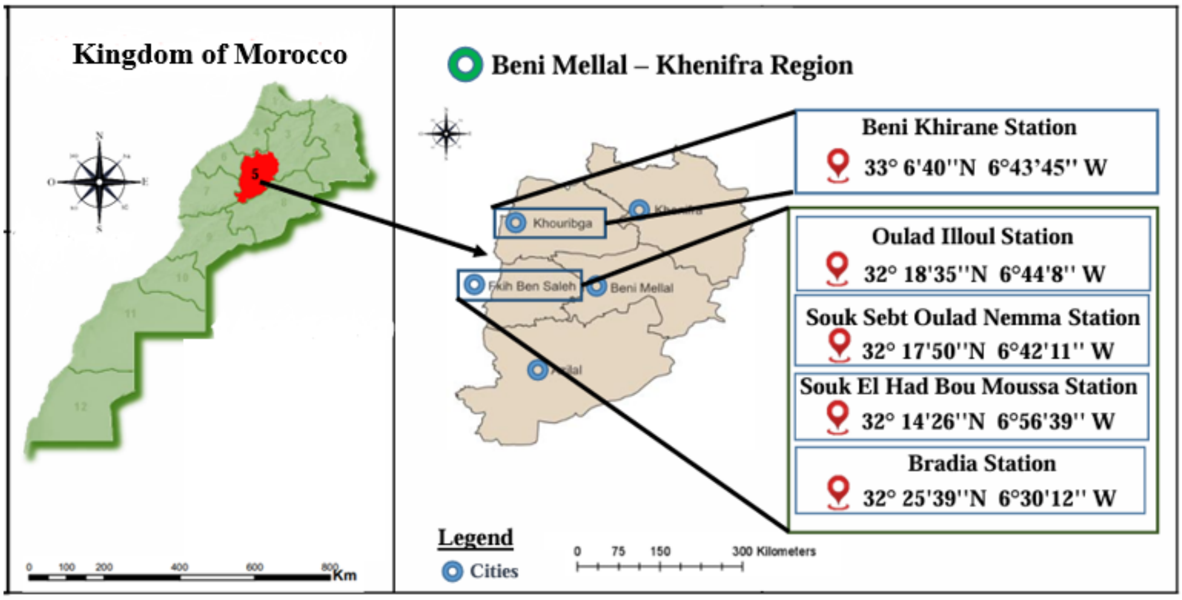


Figure 1. Presentation of the two provinces selected for the study

Data collection

This survey-based study was conducted in August 2024. The questionnaire was organized into several sections comprising a range of questions covering the following aspects: the sociodemographic profile of the respondents, the types of crops cultivated, crop pests and diseases, the use of pesticides and the frequency of their application, the use of plant extracts, the plant species employed, the methods of preparation and application of these extracts, and the effects observed after their use.

Sample size index

The sample size index (SSI) for this study was determined by administering questionnaires to informants via a proportional stratified random sampling approach. The estimation was carried out according to the equation proposed by Charan & Biswas (2013):

$$N = t^2 \times p\,(1-p)/m^2$$

where:

- n = required sample size
- t = value of the statistic corresponding to a 95% confidence level (typical value = 1.96)
- p = estimated prevalence of informants (set at 20%)
- m = margin of error (set at 6.4% = 0.064)

The total number of farmers in the Beni Mellal-Khenifra region is approximately 255,920 (Agrimaroc 2026), which was used as the total population (N) for the finite population correction factor. This large agricultural population supports the sampling approach adopted and the use of the adjusted margin of error.

Using the above equation, the calculated sample size was 150 respondents, which corresponds to the number of questionnaires collected. This sample size was considered adequate for the study population and allowed the investigation of local agricultural and crop protection practices, despite the slightly higher margin of error than the conventional 5%.

Frequency of citations and the relative frequency of citations

The frequency of citation (FC) refers to the number of informants who reported using a particular plant species (Najem *et al*. 2019), whereas the relative frequency of citation (RFC) indicates the relative importance of each cited plant species. It was calculated via the following formula (Najem *et al*. 2019):

$$RFC = FC/N$$

where N is the total number of informants interviewed.

Family use value
The family use value (FUV) was used to identify the importance of plant families. It was calculated via the following formula (Flouchi *et al*. 2023; Najem *et al*. 2019):

$$FUV = RFC/Ns$$

where Ns is the total number of species present in each family.

Fidelity level
The fidelity level (FL) corresponds to the percentage of informants who mentioned the use of a specific plant species for treating of phytosanitary problems in the study area. The FL index is calculated using the formula proposed by Chaachouay *et al*. (2020):

$$FL\ (\%) = Np/N \times 100$$

where Np is the number of informants reporting the use of a given plant species to treat a specific crop pests and diseases, and N is the total number of any use reports per plant species (Bessi *et al*. 2025).

Statistical analysis
The results obtained from the completed questionnaires were analyzed via Microsoft Excel. Frequencies and percentages were calculated for the sociodemographic characteristics. To assess the pairwise associations between categorical variables, Cramér's V coefficient derived from the Chi-square statistic was calculated with values ranging from 0 to 1. Correspondence Analysis (CA) was performed to determine the relationships between respondents' treatment practices for crop pests and diseases and the studied parameters. These statistical analyses were conducted via R version 4.3.3 within the RStudio integrated development environment (Posit Team 2024).

Legal considerations
The farmers were informed that the questionnaire would be completed anonymously and the collected data would be used exclusively for academic research purposes.

Results and Discussion

Study population
The survey was carried out among farmers from five selected stations in the provinces of Khouribga and Fquih Ben Salah, within the Beni Mellal-Khenifra region. A total of 150 farmers were interviewed. The respondents represented the farming population in the selected study areas and provided information on their agricultural practices, crop protection practices, and traditional knowledge related to the use of plants for managing phytosanitary problems.

Pest management practices
The results revealed a strong predominance of chemical control practices among the surveyed farmers. Only three farmers (2%) relied exclusively on aqueous plant extracts, whereas eleven respondents (7.33%) combined plant extracts with chemical pesticides (Table 1). In contrast, most farmers (90.67%) depended solely on synthetic pesticides. Overall, only 14 respondents (9.33%) reported using plant-based preparations, either exclusively or in combination with synthetic pesticides.

The predominance of chemical pesticide use observed in this study is consistent with findings reported by Naamane *et al.* (2020), who found that 100% of the surveyed farmers in El Gara (Berrechid Province, Casablanca-Settat region, Morocco) reported using pesticides. This finding further highlights the marginal role of plant-based alternatives in current phytosanitary practices. In contrast, Bessi *et al.* (2025) reported that 55.18% of farmers used plants, whereas only 18.89% employed chemical pesticides as potential crop protection methods in the Fez-Meknes, Rabat-Sale-Kenitra, and Tangier-Tetouan-Al Hoceima regions of Morocco. The differences among these studies may be related to regional and agroecological conditions, cropping systems, farmers' knowledge, and differences in agricultural practices.

In the present study, the predominance of synthetic pesticide use may be associated with farmers' perception of their rapid action, effectiveness, and availability. The limited adoption of plant-based preparations may also be related to insufficient technical knowledge regarding their preparation and application, as well as limited access to extension services promoting botanical alternatives. These factors may contribute to the continued reliance on conventional chemical control methods.

The limited use of plant-based preparations observed in the surveyed area highlights the need for further research and extension activities aimed at improving farmers' knowledge of botanical alternatives. Integrating locally available plant resources into integrated pest management strategies, supported by experimental validation of their efficacy, could contribute to more sustainable crop protection practices.

Respondent profiling

Age

The study population had a mean age of 52.44 ± 13.8 years, with a median age of 52 years. The farmers' ages ranged from 25 to 76 years, indicating a relatively broad age distribution among the respondents.

The use of plant-based remedies was predominantly observed among individuals aged 41-60 years, accounting for 66.67% of the users, whereas farmers aged 20-40 years accounted for 33.33% (Fig. 2).

The exclusive use of pesticides has been widely reported across all age categories. The 41-60-year age group was the most represented group, accounting for 49.27% of pesticide users, followed by individuals over 60 years of age (31.62%) and those aged 20-40 years (19.11%).

Finally, the combined use of plant extracts and pesticides was reported exclusively by individuals in the 41-60-year age group, representing 100% of respondents adopting this integrated practice.

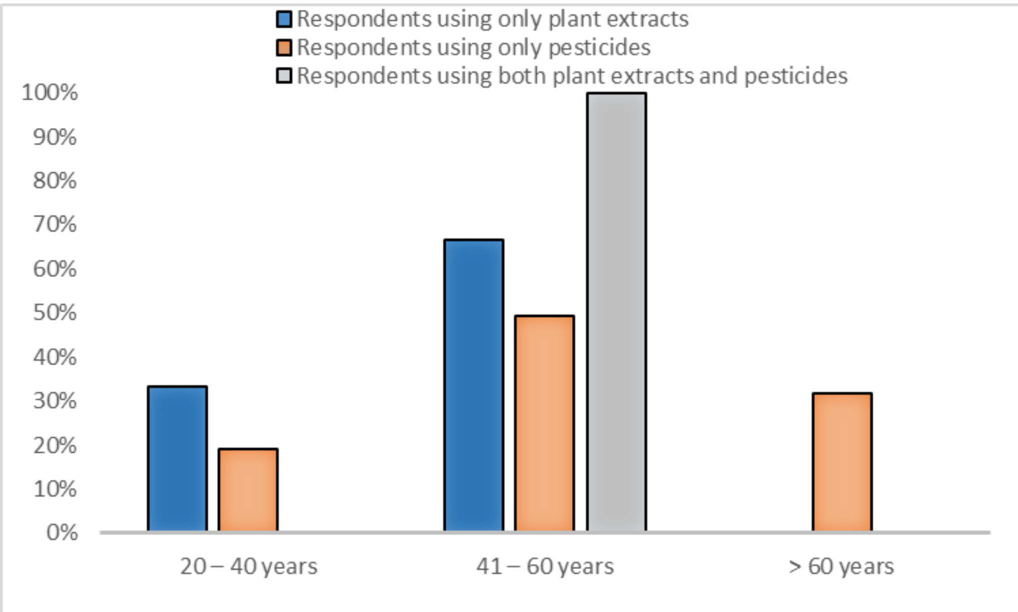


Figure 2. Distribution of respondents according to their age

Sex

The respondents were predominantly male (98.67%) (Table 1). The respondents were distributed across the different pest management practices: some rely exclusively on aqueous plant extracts, others use only chemical pesticides, and a third group combines both approaches. In contrast, the female respondents reported using only chemical pesticides.

This predominance of male respondents may be explained by the fact that the majority of farmers in the Beni Mellal-Khenifra region are men. These results are consistent with findings from other studies conducted by Errahmani & Zahir (2024), Benkhaira *et al*. (2021), and El Alami *et al*. (2020).

Educational level

Most users of plant extracts had primary-level education (67%), followed by those with university-level education (33.33%), while no users were represented among illiterate or secondary-level respondents. Pesticide users are distributed across all educational categories, with a high proportion having primary-level education (54.41%) and being illiterate (31.62%). Respondents with secondary-level education (11.03%) and university-level education (2.20%) were less represented.

Respondents using both plant extracts and pesticides were found exclusively among illiterate respondents (55%) and those with primary-level education (45%), with no representation from other educational levels (Fig. 3). Notably, primary-level education was the most represented category among users of plant extracts, which is an unusual result compared with the findings of other ethnobotanical studies, in which the majority of respondents were reported to be illiterate (Hamamouch 2020; Naamane *et al*. 2020; Salhi *et al*. 2019).

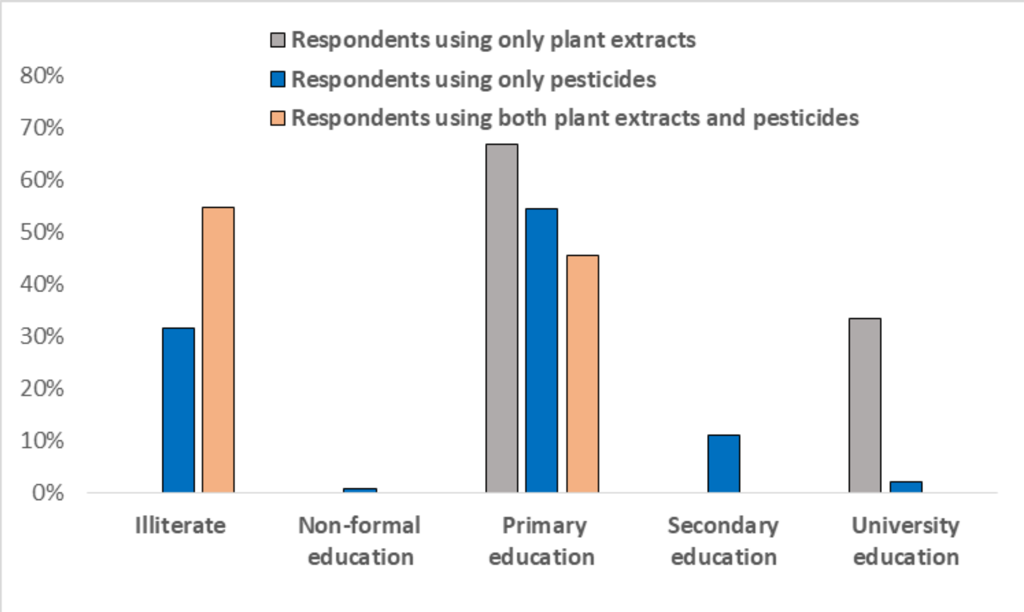


Figure 3. Distribution of respondents according to their educational level

Table 1. Sociodemographic details of the respondents in the study region

	Category	Total Population		Respondents using only plant extracts		Respondents using only pesticides		Respondents using both plant extracts and pesticides	
		Number of informants	(%)	Number of informants	(%)	Number of informants	(%)	Number of informants	(%)
Province	**Station**								
Fquih Ben Salah	Oulad illoul	30	20%	3	100%	16	11.76%	11	100%
	Souk Sebt	29	19.33%	0	0%	29	21.32%	0	0%
	Souk Lhad	31	20.67%	0	0%	31	22.8%	0	0%
	Bradia	38	25.33%	0	0%	38	27.94%	0	0%
Khouribga	Beni Khirane	22	14.67%	0	0%	22	16.18%	0	0%
	Total	150	100%	3	100%	136	100%	11	100%
	Age group								
	20 - 40 years	28	18.67%	1	33.33%	26	19.11%	0	0%
	41 - 60 years	79	52.67%	2	66.67%	67	49.27%	11	100%
	> 60 years	43	28.66%	0	0%	43	31.62%	0	0%
	Total	150	100%	3	100%	136	100%	11	100%
	Sex								
	Women	2	1.33%	0	0%	2	1.47%	0	0%
	Men	148	98.67%	3	100%	134	98.53%	11	100%
	Total	150	100%	3	100%	136	100%	11	100%
	Educational level								
	Illiterate	49	32.67%	0	0%	43	31.62%	6	54.54%

Non-formal education	1	0.67 %	0	0%	1	0.74%	0	0%
Primary education	81	54%	2	66.67%	74	54.41%	5	45.46%
Secondary education	15	10%	0	0%	15	11.03%	0	0%
University education	4	2.66%	1	33.33%	3	2.20%	0	0%
Total	150	100%	3	100%	136	100%	11	100%

The analysis of Cramer's V coefficient revealed a moderate association between crop diseases and farmers' age, sex and educational level. A strong association was observed between diseases and crops, indicating that the occurrence of specific diseases was associated with the crops cultivated (Table 2). In contrast, the associations among the remaining variables were weak ($V<0.30$). These findings suggest that certain crops may be more susceptible to specific diseases, highlighting the importance of crop selection in developing disease management strategies.

Table 2. Cramer's V coefficient of association between different parameters study ($V>0.30$).

	Sex	**Educational level**	**Crops**	**Diseases**
Age	0.1251	0.2276	0.2923	0.4074
Sex		0.0766	0.2370	0.3451
Educational level			0.2451	0.3727
Crops				0.6317

A correspondence analysis (CA) was conducted to provide a structured representation of the relationships between respondents' treatment practices for crop pests and diseases and the studied parameters, including age, educational level, crop type, and disease category. This analysis revealed that two dimensions (Dim 1 and Dim 2) explained 100% of the total variance. The first axis (Dim 1) represents the main axis of differentiation, showing high inertia (89.5%, 81.5%, 99.9%, and 97.3%) in graphs A, B, C, and D, respectively (Fig. 4).

In the factorial plane, pesticide treatment (P) appears in all the graphs near the origin and to the right of the discriminant plot (Dim 1), indicating that it is not strongly associated with any particular modality. A relatively narrow confidence ellipse for this treatment was observed around respondents aged 20-40 years (class 1) and >60 years (class 3) (Fig. 4A), and it was associated with non-formal, primary, and secondary educational levels (Fig. 4B). It was also represented mainly by wheat (Fig. 4C). This treatment was positioned near modalities related to phytopathogenic diseases such as fungal, insect, and nematode-related diseases (Fig. 4D).

The plant extract treatment (E) was characterized by a wide confidence ellipse, indicating greater variability. It was associated with age classes 1 and 2 (Fig. 4A), primary- and university-level education (Fig. 4B), citrus cultivation (Fig. 4C), and diseases of fungal origin (Fig. 4D).

The combined plant extract + pesticide treatment was represented by a confidence ellipse of intermediate size between those observed for treatments E and P. It was associated with age class 2 (Fig. 4A), illiterate respondents (Fig. 4B), citrus cultivation (Fig. 4C), and diseases of fungal origin (Fig. 4D).

Dominant crops in the studied region

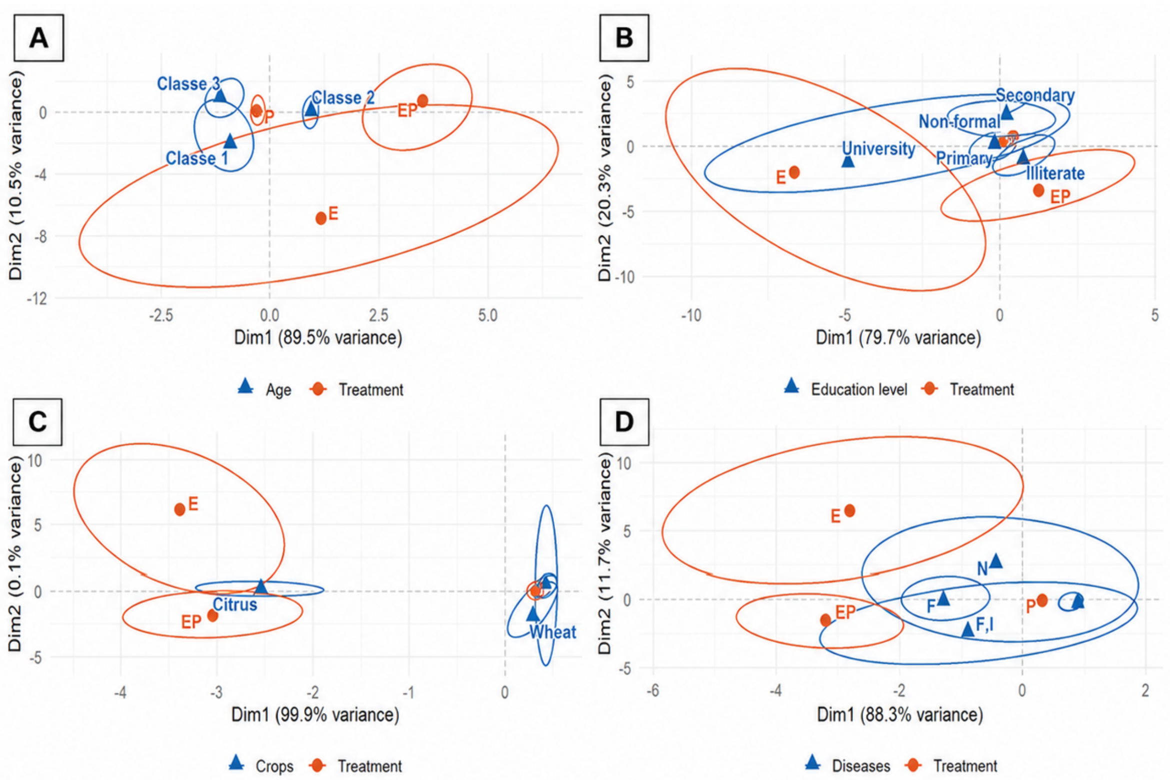
The present study shows that the most dominant crops in the investigated region are olive trees, accounting for 35.60%, followed by wheat at 25.40%, citrus at 11.40%, sugar beet at 9.60%, Capsicum at 6.80%, pomegranate at 4%, barley at 2.80%, sesame at 2.30%, onion at 1.10%, and tomato at 0.60% (Fig. 5). These crops provide an important context for interpreting the phytosanitary problems reported by farmers and the crop protection practices documented in this study, as the type of crop may influence the pests, diseases, and control methods.

Crop pests and diseases reported by farmers

The main phytosanitary problems affecting various crops in the studied region are summarized in Table 3. In citrus crops (orange and lemon), the phytosanitary issues reported by farmers are primarily of fungal origin, including blue mold (100%)

and Mal Secco (69.6%). A viral disease, *citrus tristeza virus* (CTV)**,** was also commonly reported (65.2%). In olive trees, several bacterial and fungal diseases were reported, such as olive knot, verticillium wilt (60.3%), and scab (peacock spot) (54.0%), along with insect attacks, notably by the olive fly and the olive psyllid (73.0%).

Our study is consistent with the findings of a study conducted by Barguigua *et al.* (2020), which focused on the prevalence of microbial diseases in olive trees in the Tadla-Azilal region. They reported that, based on disease prevalence, olive leaf spot disease (91.3%) was the most predominant disease in the region, followed by verticillium wilt (65.2%) and olive bacterial tuberculosis (13.0%). Wheat is affected mainly by fungal diseases such as rust and *Fusarium*, whereas weeds such as poppy, bromes, milk thistle, and ryegrass exert significant pressure. Barley also is affected by fungal diseases (*Fusarium* and rust), with poppy as the dominant weed. Sugar beet is affected by the southern root-knot nematode and the cutworm. In pomegranate, fruit rot, a fungal disease**,** the southern root-knot nematode, and insects such as aphids and the Mediterranean fruit fly are observed. Tomato plants are affected by necrotic fungal spots, whereas sesame plants mainly suffer from the presence of poppy as a weed. Finally, onion and chili pepper are affected by viral diseases, notably leaf curl virus.



Groups	Age	Education level	Crop type	Diseases
Overall	0.2589	0.0058	1.00E-04	0.5844
E*EP	0.1538	0.2143	1	0.6703
E*P	0.1765	0.4258	0.01305	0.8389
EP*P	0.5233	0.0043	4.49E-07	0.3463

Figure 4. Biplot with 95% bootstrap confidence interval (B=1000) for the treatments used and the parameters studied in axes 1 and 2 with p-values for all associations.

A. Relationships between treatment type and respondent age classes. B. Relationships between treatment type and education level. C. Relationships between treatment type and crop type. D. Relationships between treatment type and the disease category. (E) plant extract; (EP) plant extract + pesticide; (P) pesticide only.

Class 1: 20-40 years, Class 2: 41-60 years, Class 3: > 60 years.

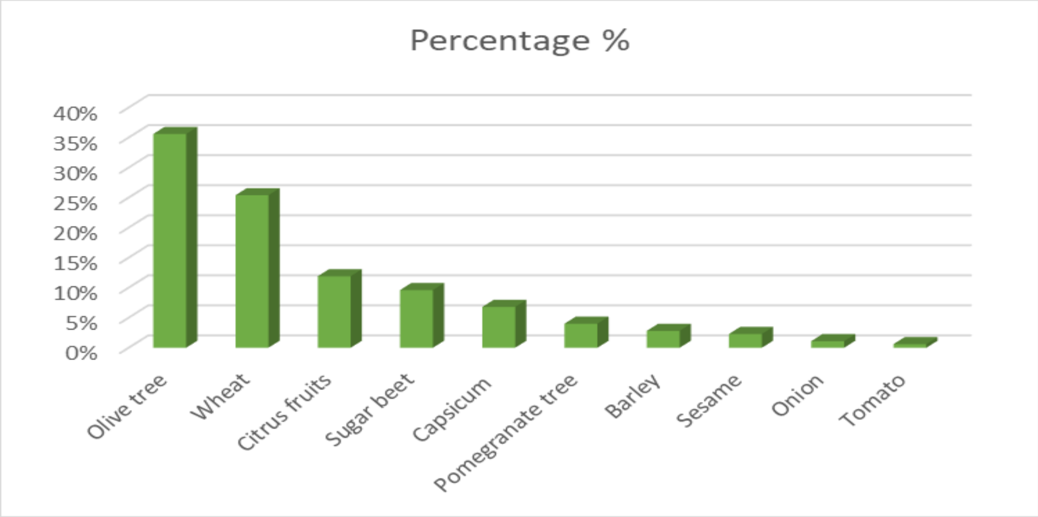


Figure 5. Different crops cultivated in the studied region

Table 3. Pests and diseases affecting crops in the studied region

Crop	Bacterial Diseases	Fungal Diseases	Viral Diseases	Nematode Diseases	Insect Pests	Weeds
Citrus (Orange, Lemon)	-	Blue mold (100%) Mal Secco (69.6%)	*Citrus tristeza virus (* 65.2%)	-	-	-
Olive	Olive knot (60.3%)	Verticillium Wilt (60.3%) Scab (peacock spot) (54.0%)	-	-	Olive fly (73.0%). Olive psyllid (73.0%).	-
Wheat	-	Rust (84.84%) *Fusarium* (30.30%)	-	-	-	Poppy (42.42%) Bromes (21.21%) Milk thistle (6.06%) Ryegrass (3.03%)
Barley	-	*Fusarium* (75%) Rust (25%)	-	-	-	Poppy (25%)
Sugar beet	-	-	-	The southern root-knot nematode (81.25%)	Cutworm (62.5%)	Poppy (6.25%)
Pomegranate	-	Fruit rot (33.33%)	-	The southern root-knot nematode (50%)	Aphids (66.66%) Mediterranean fruit fly (33.33)	-
Tomato	-	Necrotic spots (fungal origin) (100%)	-	-	-	-
Sesame	-	-	-	-	-	Poppy (100%)

Crop	Bacterial Diseases	Fungal Diseases	Viral Diseases	Nematode Diseases	Insect Pests	Weeds
Onion	-	-	Leaf curl virus (100%)	-	-	-
Capsicum	-	-	Leaf curl virus of pepper (100%)	-	-	-

The denominator is the number of citrus farmers who reported diseases, not all farmers.

The pesticides most commonly used in the studied region for plant disease management

The results of the survey concerning pesticide use are presented in Figure 6 and Table 4. These results show that farmers in the studied region mostly use insecticides, which account for 61.11% of the products applied. These insecticides include several types, depending on their active ingredients. They are followed by herbicides, which account for 33.33% of pesticide use and are also divided into different categories according to their active ingredients. Finally, fungicides represent 5.55% of the pesticides used. Among these, the most widely used products in the region are REX DUO® and TACOS®. The low use of fungicides despite the presence of several fungal diseases reported by farmers may be explained by the fact that disease diagnosis is often based on visual observation of symptoms rather than laboratory confirmation. As a result, some fungal diseases may be misidentified as insect-related damage, leading to a greater reliance on insecticides. However, another study conducted by El Bouzaidi *et al.* (2020), in the Gharb plain of Morocco, and based on the quantification of environmental nuisances caused by pesticides, showed that farmers predominantly use fungicides (50%), followed by insecticides (32%) and herbicides (18%).

Most farmers report using pesticides (90.67%), mainly because of their perceived effectiveness. These chemical products are perceived to provide rapid protection against harmful insects, diseases, and weeds, thus contributing to crop protection and potentially improving yield stability.

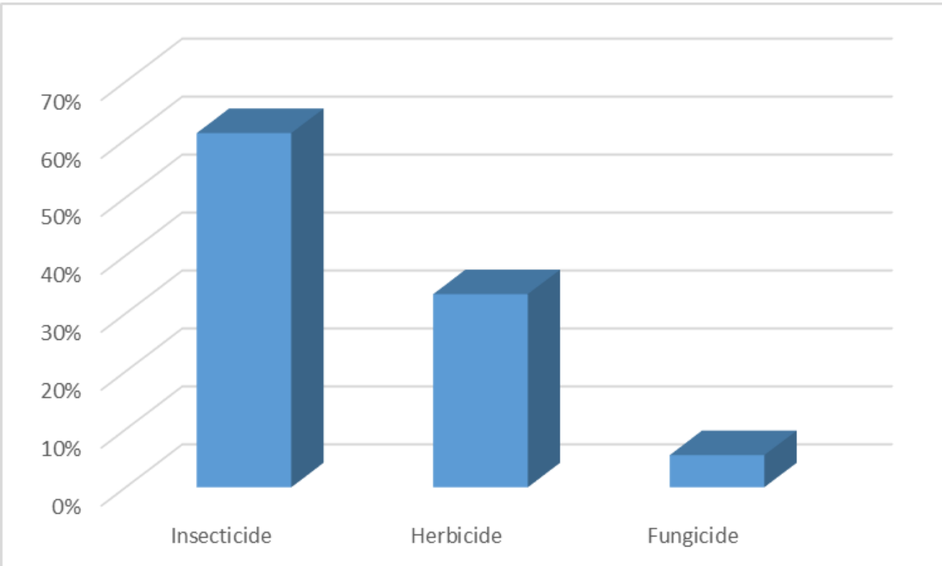


Figure 6. Distribution of the types of pesticides used in the study region

Table 4. Pesticides commonly used in the investigated region and their active ingredients

Category	Commercial name	Active ingredient
	KARATE ®	Lambda-cyhalothrin, pyrethroid
	VALMEC ®	Abamectin
	TRACTOR 25 EC ®	Cypermethrin
	TAIKOK ®	Cypermethrin
	FORCE ®	Tefluthrin
Insecticides	MASTER ®	Cypermethrin

Category	Commercial name	Active ingredient
	AFRITE ®	Pyrethroid
	PIRIMOR ®	Pirimicarb
	PROCLAIM ®	Emamectin benzoate
	HECTOR ®	Emamectin benzoate
	KARTER ®	Pyriproxyfen
Herbicides	PROMETRYN ®	Triazine
	MUSTANG ®	2,4-D + florasulam
	IMAZACURE ®	Likely based on imazapyr/imazamox
Fungicides	REX DUO ®	Epoxiconazole + thiophanate-methyl
	TACOS ®	Tricyclazole

Plant species used for crop pests and disease management

The results revealed that 14 farmers from the Oulad Illoul station reported the use of plant extracts to manage various plant diseases, particularly those affecting citrus crops in the Beni Mellal-Khenifra region. The most frequently cited species belonged to the families Urticaceae (*Urtica dioica* L.), Solanaceae (*Capsicum annuum* L.), and Amaryllidaceae (*Allium sativum* L.). These plants are used to manage crop pests and diseases such as Citrus blue mold, *Citrus tristeza virus*, Mal Secco, and rust. Detailed information on the scientific and local names of the species, their families, plant parts used, preparation methods, potential associations, and their frequency of citation (FC), relative frequency of citation (RFC), and family use values (FUV) are provided in Table 5.

Quantitative analysis

The quantitative analysis based on the relative frequency of citation (RFC) and family use values (FUV) revealed that the species most frequently used by farmers for the management of Citrus blue mold, *Citrus tristeza virus*, Mal Secco, and rust in the Beni Mellal-Khenifra region were *U. dioica* (RFC = 0.046-0.05), *C. annuum* (RFC = 0.02-0.033), and *A. sativum* (RFC = 0.01-0.013) (Table 5). These plants are primarily used in the form of aqueous maceration extracts prepared from leaves, fruits, or bulbs and may be applied individually or in combination with other plants to enhance their perceived effectiveness against phytopathogenic diseases.

The analysis of the fidelity level (FL) made it possible to assess the degree of specificity of plant use among farmers in the Beni Mellal-Khenifra region for the management of citrus diseases. The FL values, mostly ranging between 26.66% and 40%, indicate a moderate degree of specificity in the use of the studied plant species. *U. dioica* had FL values of 33.33% for Citrus blue mold and Mal Secco, reflecting recurrent but non-exclusive use for these diseases, whereas its very low FL for rust (4.16%) indicates a marginal role in treating this disease. *Capsicum annuum* exhibited a slightly higher fidelity level for Citrus blue mold (FL = 40%), suggesting a relative preference for this disease, whereas its use against Mal Secco remained more limited (FL = 26.66%). *Allium sativum* presented similar FL values (33.33%) for several diseases, indicating its versatile use, mainly in association with other plant species.

Overall, these findings highlight that *U. dioica*, *C. annuum*, and *A. sativum* are the most cited and widely used species in the study region, reflecting farmers' traditional knowledge and confidence in these plants for managing phytosanitary problems in the Beni Mellal-Khenifra region.

Scientific evidence and mechanisms of action of medicinal plants against phytopathogens

A bibliographic review was conducted using scientific articles indexed in Google Scholar, PubMed, and ScienceDirect to gather experimental evidence from in vitro and/or in vivo studies investigating the antifungal and antibacterial activities of the aforementioned plants. Table 6 summarizes the main antimicrobial mechanisms of action of the three plant species traditionally used by the surveyed farmers to manage crop diseases.

The plants *A. sativum*, *C. annuum*, and *U. dioica* are recognized for their general antimicrobial properties, including the antibacterial and antifungal activities demonstrated in several *in vitro* experimental studies. However, to the best of our knowledge, no published study has evaluated the effects of these plants against the pathogens associated with the diseases targeted in the present study, namely, *Penicillium italicum*, the causal agent of citrus blue mold; *Citrus tristeza virus* (CTV); *Phyllocoptruta oleivora*, the causal agent of citrus rust; and *Plenodomus tracheiphilus*, the causal agent of Mal Secco. Therefore, further experimental investigations are needed to scientifically validate the efficacy of these plants for managing the crop pests and diseases identified in this study.

Possible associations

In the study region, plant extracts are used either individually, in combination with other plant species, or together with conventional pesticides. *Urtica dioica* is used mainly alone or in combination with *C. annuum* and/or *A. sativum*. Similarly, *C. annuum* is applied either as a single treatment or in combination with other plants.

Furthermore, some farmers reported mixing plant extracts with pesticides to increase treatment effectiveness against pathogens affecting citrus crops. This practice reflects an empirical strategy aimed at improving the management of crop pests and diseases while, in some cases, reducing the quantity of chemical products applied.

Similar practices have been documented in several ethnobotanical studies. For example, Bessi *et al.* (2025) reported that farmers in Morocco frequently combine plant species to improve antimicrobial efficacy in the control of postharvest diseases. Similarly, Eddouks *et al.* (2017) highlighted that traditional agricultural and medicinal practices often involve mixtures of plants to broaden the spectrum of biological activity.

Plant type

The plant species used by farmers in the studied region include both cultivated and wild species. *Allium sativum* and *C. annuum* are exclusively cultivated species that are widely available and easily accessible, which may explain their frequent use in local phytosanitary practices. In contrast, *U. dioica* is a wild plant harvested directly from its natural habitat. This pattern is consistent with findings from many ethnobotanical surveys conducted in the Mediterranean and North African regions, where both cultivated and spontaneous plants are used in traditional agricultural practices (Bessi *et al.* 2025).

State of use

In the investigated region, plant extracts are prepared primarily from fresh or dried plant material. *Urtica dioica* is used either fresh or after shade-drying of the aerial parts, whereas *C. annuum* and *A. sativum* are generally dried before preparation. The drying process allows for long-term storage and helps preserve the plant material until use (Azwanida 2015). Comparable practices have been widely described in the ethnobotanical literature (Silveira & Boylan 2023). Drying plant material is commonly used to ensure long-term preservation and to maintain the availability of plant resources throughout the agricultural season (Van Wyk & Wink 2018). Similar observations were reported by Bessi *et al.* (2025) and Pieroni *et al.* (2005), who reported that drying plant material is one of the most common preservation techniques used in traditional plant-based treatments.

Part used

In the study area, different plant parts were used to prepare the extracts. For *U. dioica*, leaves are collected either fresh or after shade drying. For *C. annuum*, the fruits are harvested and dried before being ground into powder for maceration. *A. sativum* bulbs, which are also dried before preparation, are used. These results are consistent with numerous ethnobotanical studies indicating that leaves, fruits, and bulbs are among the most commonly used plant parts, partly because they contain secondary metabolites such as phenolic compounds, flavonoids, and sulfur-containing molecules. Similar findings were reported by Eddouks *et al.* (2017).

Preparation methods for the plant extracts

In the surveyed region, the preparation of plant extracts is carried out mainly through aqueous maceration. For *U. dioica*, the aerial parts are either fresh or shade-dried, then placed in a 5 L container filled with water and left to macerate for 48 hours at room temperature under light exposure. For *C. annuum*, the fruits were first dried, ground into powder, and macerated in 5 L of water for 48 hours before filtration.

When two or more plants are combined, the different plant materials are added simultaneously to the same 5 L container and macerated under the same conditions. The resulting extracts are then filtered before application.

When plant extracts are combined with pesticides, the extract is used as a substitute for the water normally employed in pesticide dilution, maintaining the same volume. According to the interviewed farmers, this combined treatment was perceived to be more effective is reducing citrus phytopathogenic diseases than either chemical pesticide or the plant extract alone. This reported perception was one of the reasons for combining plant extracts with chemical pesticides in the surveyed area. Such preparation methods are widely reported in ethnobotanical studies because aqueous maceration represents one of the simplest and most accessible extraction techniques for farmers. Similar preparation procedures have been described by Bessi *et al.* (2025).

Table 5. Plants used by farmers in the Beni Mellal-Khenifra region to treat crop pests and diseases, with their families, English and vernacular names, parts used and ethnobotanical indices.

Pests and diseases	Family	Scientific name	English name	Vernacular name in Arabic	Part Used	Type of Plant	State of Use	Single/ Associated	FC	RFC	FUV	FL (%)	E.E./S.E.
Citrus blue mold due to *Penicillium italicum*	Amaryllidaceae	*Allium sativum* L.	Garlic (P 1)	Thouma	Bulb	Cultivated	Dried (shade-dried)	Associated with P 2+P3	2	0.013	0.013	33.33	Choudhary *et al.* 2024
	Solanaceae	*Capsicum annuum* L.	Sweet pepper (P2)	Mnioura	Fruit	Cultivated	Dried (shade-dried)	Single or associated with P1+P3	6	0.04	0.04	40%	Koffi *et al.* 2022
	Urticaceae	*Urtica dioica* L.	Stinging nettle (P3)	Harika	Leaves	Wild	Dried or fresh	Single or associated with P1+P2	8	0.053	0.053	33.33	NR
Citrus tristeza virus	Amaryllidaceae	*Allium sativum* L.	Garlic (P 1)	Thouma	Bulb	Cultivated	Dried (shade-dried)	Associated with P 2+P3	2	0.013	0.013	33.33	NR
	Solanaceae	*Capsicum annuum* L.	Sweet pepper (P2)	Mnioura	Fruit	Cultivated	Dried (shade-dried)	Single or associated with P1+P3	5	0.033	0.033	33.33	NR
	Urticaceae	*Urtica dioica* L.	Stinging nettle (P3)	Harika	Leaves	Wild	Dried or fresh	Single or associated with P1+P2	7	0.046	0.046	29.16	NR
Rust due to *Puccinia triticina*	Urticaceae	*Urtica dioica L.*	Stinging nettle	Harika	Leaves	Wild	Dried or fresh	Single	1	0.006	0.006	4.16	NR
Mal Secco due to *Plenodomus tracheiphilus*	Amaryllidaceae	*Allium sativum* L.	Garlic (P 1)	Thouma	Bulb	Cultivated	Dried (shade-dried)	Associated with P 2+P3	2	0.013	0.013	33.33	NR
	Solanaceae	*Capsicum annuum* L.	Sweet pepper (P2)	Mnioura	Fruit	Cultivated	Dried (shade-dried)	Single or associated with P1+P3	4	0.026	0.026	26.66	NR
	Urticaceae	*Urtica dioica L.*	Stinging nettle (P3)	Harika	Leaves	Wild	Dried or fresh	Single or associated with P1+P2	8	0.053	0.053	33.33	NR

Quantitative indices: FC: frequency of citation, RFC: relative frequency of citation, FUV: family use values, FL: fidelity level. Ethnobotanical/Scientific Evidence (E.E./S.E.), NR: Not reported

Table 6. Scientific evidence on the antimicrobial activities of selected plants used against phytopathogens

Plant	Part used	Form of use	Results	Used method (s)	Reference
***Allium sativum* L.**	Bulbs	Hydroalcoholic extract	Extract showed a strong antibacterial effect against *Agrobacterium tumefaciens*, *Erwinia carotovora*, *Pseudomonas syringae pv. tomato*; inhibition zones proportional to concentration	In vitro diffusion in agar	Curtis *et al.* 2004
		Isolated organosulfur compounds	Compounds exhibited an inhibition of spore germination of *Fusarium* spp. and *Alternaria* spp ; dose-dependent antifungal activity	In vitro spore germination assay	Lanzotti 2006
***Capsicum annuum* L.**	Fruits	Aqueous extract/Methanolic extract	Extracts showed a strong inhibition of fungal growth and spore germination against *Fusarium* spp. - MIC: 100-500 µg/mL;	In vitro growth inhibition/dilution assays	Dorantes *et al.* 2000
		Methanolic extract	The extract showed a significant reduction in mycelial growth of *Fusarium* spp. (>50%); effect dose-dependent	In vitro mycelial growth assay	Omolo *et al.* 2014
***Urtica dioica* L.**	Leaves	Aqueous extract	The extract showed a moderate antimicrobial activity against *Candida albicans* ; concentration-dependent	In vitro agar diffusion and growth assays	Gülçin *et al.* 2004
			The extract showed a moderate antimicrobial activity against *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*; concentration-dependent	In vitro agar diffusion and growth assays	Gülçin *et al.* 2004
		Methanolic extract	The extract displayed an antimicrobial effect observed against *Candida albicans* ; the effect is attributed to flavonoids and phenolics	In vitro growth inhibition	Kregiel *et al.* 2018
			The extract displayed an antibacterial effect observed against *Escherichia coli* and *Staphylococcus aureus* ; the effect is attributed to flavonoids and phenolics	In vitro agar diffusion and growth assays	Kregiel *et al.* 2018
			The extract exhibited an antifungal effect observed against *Fusarium* spp; the effect is attributed to flavonoids and phenolics	In vitro growth inhibition	Kregiel *et al.* 2018

Application method and frequency

In the surveyed region, filtered plant extracts are applied by foliar spraying directly onto trees. Farmers reported that this application is generally performed every 15 days to ensure effective protection against phytopathogens. This practice is followed for single plant extracts as well as for combinations of two or more plants or for mixtures of plant extracts with pesticides, maintaining the same interval between applications. This regular application interval may help maintain the effectiveness of plant extracts, as some bioactive compounds may degrade rapidly under environmental conditions, including exposure to sunlight and precipitation (Isman 2020).

Satisfaction of respondents after applying plant extracts

The survey results indicate that the use of plant extracts for the management of citrus diseases generally led to a moderate or significant reduction in symptoms, depending on the plant species used and the type of association (single plant, combined plants, or plants associated with a pesticide).

Urtica dioica, applied alone or in combination with other plants or pesticides, resulted in a moderate reduction in symptoms in most cases, with a significant reduction observed when combined *C. annuum*.

Capsicum annuum, used either alone or in combination, primarily resulted in a moderate reduction in symptoms, with some instances of significant symptom reduction when it was combined with *U. dioica*.

Allium sativum, although less frequently used, was reported to have moderate effects when associated with other plant extracts.

Overall, these results suggest that combining multiple plants or combining plant extracts with pesticides may enhance their perceived effectiveness. The farmers reported that these practices contributed to noticeable improvements in the control of phytosanitary problems, suggesting that these traditional practices may have practical value in the studied region.

These findings are consistent with previous ethnobotanical research showing that plant-based preparations may represent potential alternatives or complements to synthetic pesticides. Studies conducted by Bessi *et al.* (2025) highlighted the potential of medicinal and aromatic plants as natural sources of antimicrobial compounds capable of controlling microbial diseases affecting crops.

Limitations of the study

The number of plant extract users was small (n = 14), which limits the generalizability of the results. No experimental validation of extract efficacy was conducted, as the data are based solely on farmers' perceptions. In addition, the assessment of effects is subjective and may involve recall bias. Data collection by a single interviewer may also introduce bias, and the study covers only two provinces out of five. Finally, the survey was conducted in a single period (August), which does not account for seasonal variations.

Conclusion

This ethnobotanical survey, carried out among 150 farmers in the Beni Mellal-Khenifra region, documented the use of plant extracts as potential natural alternatives to chemical pesticides. However, this study highlights the continued importance of pesticides in managing crop pests and diseases, while also revealing the persistence of traditional plant-based practices among farmers. The findings indicate that 90.67% of farmers rely on pesticides, including insecticides (61.11%), herbicides (33.33%), and fungicides (5.55%). In contrast, 2% of the farmers used aqueous plant extracts exclusively, mainly from *Urtica dioica*, *Capsicum annuum*, and *Allium sativum*, whereas 7.33% combined them with chemical treatments. The farmers using plant extracts reported a reduction in phytopathological symptoms, suggesting that these extracts may represent potential complementary options for sustainable disease management.

A key contribution of this work is the documentation of the traditional use of these plant species against specific citrus diseases for which, to the best of our knowledge, no specific experimental evidence has been identified in the literature reviewed, particularly against *Penicillium italicum*, *Citrus tristeza virus*, *Phyllocoptruta oleivora*, and *Plenodomus tracheiphilus*. This finding emphasizes the value of local ethnobotanical practices as potential sources of sustainable plant protection strategies.

From this perspective, further in vitro and in vivo studies should be conducted to evaluate antimicrobial activity of these plant extracts against the targeted pathogens or causal agents identified in this study, namely *P. italicum*, *Citrus tristeza virus*, *P. tracheiphilus*, and *P. oleivora*, to identify their bioactive compounds and clarify their mechanisms of action. These investigations are essential for scientifically validating these traditional practices and supporting the development of environmentally friendly alternatives to conventional pesticides.

Declarations

Ethics approval: All participants provided oral informed consent.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Nagoya Protocol Compliance: This study complies with the principles of the Nagoya Protocol on Access and Benefit-Sharing. The research involved only documentation of traditional knowledge, without commercial utilization of genetic resources.

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Author contributions: TS collected the data, compiled the literature sources, analyzed the data, and contributed to the assessment, interpretation, and writing of the manuscript. ZI supervised, investigated, designed, and methodology; contributed significantly to the data analysis; and reviewed, edited, and prepared the final draft. SF analyzed the data. HN supervised the investigation and contributed to the editing and preparation of the final draft. All the authors read and approved the final manuscript.

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