Ethnobotanical study of medicinal plants used in the treatment of post-harvest microbial diseases in strawberry and tomato crops in Morocco

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Research

Abstract

Background: People have long used medicinal and aromatic plants (MAPs) as part of an ethnobotanical tradition that combines health, food preservation and cultural heritage. In Morocco, local communities have exploited the natural antibacterial and antioxidant properties of these plants to prevent fruit and vegetables from spoiling and extend their shelf life. This ancestral knowledge, passed down from generation to generation, demonstrates a deep understanding of the functional value of local plants. Recent scientific research is beginning to confirm the validity of these traditional practices and reveal that many medicinal and aromatic plants commonly used by Moroccans, contain highly preservative bioactive compounds.

Methods: In this context, a survey was conducted across three regions in Morocco, involving 250 participants who provided insights via questionnaires on potential MAPs with bio preservative characteristics. The data was analysed using SPSS software, with the chi-square test being applied to assess differences in plant use, preparation methods, and application techniques. JMP Pro version 17 software was used to analyse the contingency of the relationships between the profession of the respondents and the types of protection used, as well as multiple correspondence analysis to study the relationships between the identified plant species and the parts of the plants used. Quantitative ethnobotanical indices, including Use Value (UV), Family Use Value (FUV) and Fidelity Level (FL), were applied.

Results: Lamiaceae family, particularly rosemary, emerged as the most prominent, with FUV = 27.8, UV =0.24 and FL = 100. Leaves were identified as the primary source of bioactive compounds, with essential oils and hydrolats being the most utilized forms.

Conclusion: The study underscores the potential of MAPs as eco-friendly bio-preservatives for post-harvest food protection, especially plant species belonging to Lamiaceae family.

Keywords: Medicinal and Aromatic Plants in Morocco, Ethnobotanical study, Tomato, Strawberry, Post-harvest food preservation.

Background

Morocco has a large and diverse range of medicinal and aromatic plants (MAP) that are deeply rooted in local knowledge systems and lifestyles. Ethnobotanical studies conducted in different regions of Morocco show the widespread use of medicinal and aromatic plants not only in health, but also in cosmetics, cooking and income-generating activities, reflecting their social, economic and cultural importance (Ait Bouzid *et al.* 2024, Benali *et al*., 2017, Bencheikh *et al*. 2024). Among these traditional uses, the use of MAPs to protect and preserve food is widespread and of considerable cultural importance. Ethnographic studies and surveys conducted in Moroccan cities such as Fez have documented numerous types and domestic practices used to delay the deterioration of fruits, vegetables, grains, and other foods (such as drying, aromatic fumigation, paper compresses, and simple extracts), demonstrating longstanding practical knowledge of plant preservation (Ez zoubi *et al*. 2022a).

Morocco offers an exceptionally rich flora, home to approximately 5 200 plant species, of which 22% are endemic This makes it the second most biodiverse country in the Mediterranean region, after Turkey (Ait Bouzid *et al*. 2024, El-Alami *et al*. 2022). A wide range of 743 plant species, covering 101 families and 371 genera, have been recorded in traditional Moroccan phytotherapy. The most abundant species include Asteraceae (10.92%), lamiaceae (10.78%), Fabaceae (5.93%) and Apiaceae (5.12%). Notably, 40 of these taxa are endemic for both aromatic and medicinal properties, accounting for 5.39% of the total. Lamiaceae plants alone account for almost half of these endemics, followed by Asteraceae (16.66%) and Brassicaceae (4.76%), this diversity holds significant potential for developing plant-based pesticides (Ait Bouzid *et al*. 2024, Amrati *et al*. 2021, Jamaleddine *et al*. 2017). For generations, Moroccan farmers and indigenous communities have relied on various plant-based solutions for both pest control and food preservation. This traditional knowledge continues to offer valuable insights into low-impact agricultural practices (Ez zoubi *et al*. 2022a). Plant-derived preservatives are not only effective but also biodegradable, less toxic to non-target organisms, and accessible in terms of raw material availability (Abate *et al*. 2000, Nath & Puzari 2022, Saravanan 2022). Integrating this local expertise into modern food conservation management systems provides a meaningful step toward sustainable and environmentally responsible agriculture (Kamanula *et al*. 2010).

Fez-Meknes region is very well known for its diversity in flora (Tlemcani *et al*. 2023), drawing from ethnobotanical investigations into the utilization of aromatic and medicinal plants in Fez (Amaghnouje *et al*. 2020, Ammor *et al*. 2020), it becomes evident that the region has upheld a rich legacy centred on the incorporation of plants and spices for traditional culinary preservation methods(Ez zoubi *et al*. 2022b). An examination of Moroccan medicinal literature reveals a fragmented and scattered dataset regarding medicinal plants in the region of *Tanger-Tetouan-Al Hoceima*, largely attributable to the vast array of plant species exceeding several thousand. Within this abundance, the documented medicinal species represent a mere fraction, totalling no more than 600 species, equivalent to approximately 14.28% of the entire Moroccan flora (Chaachouay *et al*. 2022). The region of *Rabat-Sale-Kenitra* boasts extensive forest coverage, spanning approximately 125 000 hectares, with natural forests comprising 28% of this area. It serves as a sanctuary for significant natural and biological reserves, including renowned areas like Maamora Forest, and Sidi Boughaba, making this region rich and diverse in terms of flora (Bouayyadi *et al*. 2015). These are the reasons why these three regions have been chosen for the investigation.

Modern scientific research increasingly highlights the potential preservative effects of MAP-derived substances. Systematic reviews and experimental studies conducted since 2022 indicate that plant extracts and essential oils possess antimicrobial and antioxidant properties that suppress microbial spoilage, prevent oxidation, and delay quality deterioration in fresh produce (Gharby *et al*. 2022). These bioactive properties have been successfully incorporated into edible packaging, sprays, and formulations for fruits and vegetables like tomatoes and strawberries (Yadav *et al*. 2022). Furthermore, recent studies have begun evaluating practical application methods (e.g., water/alcohol extracts, essential oils, incorporation into biopolymer films, post-harvest spraying) and identifying their effectiveness against damaging organisms and food matrices (Ahmadi *et al*. 2024, Shahbaz *et al*. 2022). These knowledge transfer initiatives bridge ethnobotany and post-harvest applied science, creating opportunities to develop plant-based preservation technologies that leverage the unique biodiversity of Morocco's MAP region.

Among the crops most vulnerable to postharvest deterioration are strawberries and tomatoes, both widely consumed and of high nutritional and economic value. Strawberries, rich in antioxidants and essential nutrients, are particularly susceptible to mechanical damage and fungal infections during storage and transport (Bautista *et al*. 2014, Li *et al*. 2021, Oliveira *et al*. 2019, Unal *et al*. 2023, Zhao *et al*. 2022). Similarly, tomatoes, holding high economic value and ranked as the second most consumed vegetable worldwide, face significant postharvest losses due to their perishable nature and increasing production demands (Darfour *et* al 2018, FAO 2020, Peña *et al*. 2022, Pozharskiy *et al* 2022). Both crops are commonly treated with chemical fungicides, yet prolonged use has contributed to pathogen resistance and concerns over pesticide residues (Zhang *et al*. 2018, Zhao *et al* 2022).

Based on Morocco's rich ethnobotanical heritage, this study examines the potential of medicinal and aromatic plants (MAPs) traditionally used by local communities to preserve food quality and prevent spoilage. Focusing on strawberry and tomato cultivation in three Moroccan regions, this study evaluates and records a variety of local medicinal and aromatic plants with potential applications in preservation. By linking traditional knowledge and scientific evaluation, the study seeks to identify promising plant-based solutions that can improve sustainable food preservation and increase environmental resilience.

Materials and Methods

Study area

The study was conducted in 3 regions in Morocco, as shown in Figure 1.

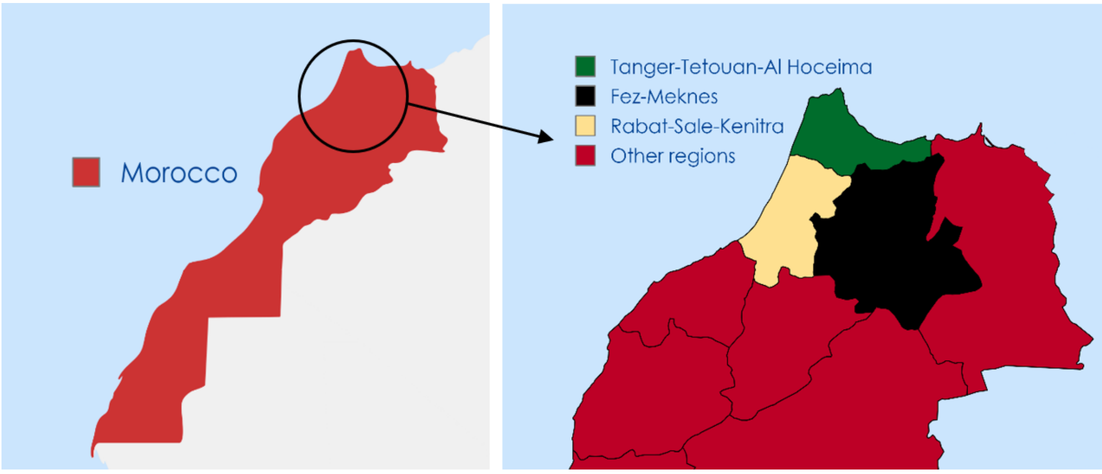

Figure 1. Regions of *Fez-Meknes*, *Rabat-Sale-kenitra* and *Tangier-Tetouan-Al Hoceima* in Morocco, where the study was conducted

There was a total of 15 areas distributed across the 3 study regions (Table 1):

Table 1. Geographical distribution of the study areas across the three Moroccan regions

Region of study	Area	Coordinates (Latitude, Longitude)
Fez-Meknes	*Fez*	34°01'59" N, 5°00'01" W
	Meknes	33°53'36" N, 5°32'50" W
	El Hajeb	33° 41' 16.30" N, -5° 22' 15.60" W
	Sefrou	33° 49' 54.70" N, -4° 49' 40.80" W
	Taounate	34° 32' 11.80" N, -4° 38' 24.32" W
	Zrizer	34.603062 N, -4.787508 W
	Kariat Ba Mohammed	34.368410 N, -5.212713 W
	Khlalefa	34.671467 N, -4.623120 W
	Sidi El Mekhfi	34.603312 N, -4.787609 W
	Rhafsai	34.630354 N, -4.911015 W
	Tafrant	34.623390 N, -5.121560 W
	Tahar Souk	34.651761 N, -4.278917 W
Rabat - Salé - Kenitra	*Kenitra*	34°15'39" N, 6°34'48" W
	Moulay Bousselham	34°52'42.96" N, -6°17'35.99" W
Tangier - Tetouan - AL Hoceima	*Larache*	35°11'00" N, 6°09'00" W

Geographically, the *Fez-Meknes* region covers an area of about 40 075 km2, or 5.7% of the country's land area, and has a population of 4 236 892 (Amrati *et al*. 2021). The climate varies from Mediterranean to continental, with annual rainfall varying between 300 and 800 mm (Amrati *et al*. 2021, Directorate-General for Local Authorities 2015). The region of *Fez-Meknes* is one of the most recognized destinations in the country for traditional use of plants, therefore, it was selected as one of the study regions (El Ghazal *et* al. 2025, Amrati *et al*. 2021).

The region of *Rabat-Sala-Kenitra* is located northwest of Morocco. The climate is semi-arid Mediterranean, with maritime or continental influences. Winters are mild and humid; summers are wet and mild. Hot and dry days are frequent. The region is characterized by a well-developed irrigation system, diversified agriculture (crops, grains, oilseeds, and legumes), a large dairy cattle population, and a concentration of large farms (including strawberry farms) (Elhachimi *et al*. 2022), reason why this region is one of the chosen areas to conduct this study.

The region of *Tangier-Tetouan-Al Hoceima* is one of the twelve regions of Morocco established by the territorial division of 2015 (Chaachouay *et al*. 2019, Bulletin Officiel 2015). The *Tangier-Tetouan-Al Hoceima* region has a total area of approximately 11,570 km^2 and a population of 3 549 512, with an average residential density of 222.2 persons/km^2. The study area has a Mediterranean climate, with maximum temperatures above 45°C in summer (July and August) and below 0°C in winter (December and January), and annual precipitation of about 1 000 mm (Chaachouay *et al* 2020, HCP 2018). The region's economy heavily relies on subsistence agriculture, livestock rearing, and to a lesser degree, utilization of forest resources, it also exhibits significant diversity in lithology, structure, biology, and flora, due to its topography and geographical positioning (Chaachouay *et al* 2022), making it our third region for this study.

Data collection

An ethnobotanical survey was conducted in the above areas from April 2022 to April 2023. During this period, 250 individuals (local botanists and farmers) from different urban and rural areas were selected as informants. They were asked to respond face-to-face about Medicinal and Aromatic Plants used for preserving fresh strawberries and tomatoes (multiple responses per informant were possible), regarding the part of the plant used, method of preparation, form of application and method of administration. Issues relating to the usage of chemical pesticides by farmers were also addressed. The duration of each interview ranged from 15 to 30 minutes. The study was conducted in full compliance with ethical research standards and in accordance with the Nagoya Protocol on access to genetic resources and the fair and equitable sharing of benefits arising from their utilisation. Data on the usage of these plants was collected from informants through a semi-structured questionnaire (Gary 1985, Nath & Puzari 2022). Interviews were conducted separately and in the local language, Moroccan Darija, spoken by all participants. The plants that were verbally catalogued in the study were then collected for botanical identification. The nomenclature of plants was updated using the Catalogue of Living Things (COL | The Catalogue of Life), and The WFO Plant List | World Flora OnlineANP.

Data and statistical analysis

Data analysis was based on a combination of qualitative and quantitative statistical approaches. The ethnobotanical survey was designed using SPHINX Plus V5 software, while data entry and storage were carried out using Microsoft Excel 2021. Several tools were used for statistical processing: IBM SPSS Statistics 27.0.1 was used to apply the Chi-square test, used to assess the significance of differences observed in the distribution of types of post-harvest protection, plant parts used, preparation methods, and forms and modes of application.

Multivariate analyses were also carried out using JMP Pro version 17 software. First, a contingency analysis was used to examine the relationships between respondents' occupation and the types of protection used, visualized through mosaic diagrams. Next, a simple correspondence analysis was conducted to represent the distribution of practices in a two-dimensional factorial space. Finally, a multiple correspondence analysis (MCA) was used to explore the links between the plant species identified and the plant parts used. The graphical representations resulting from these analyses served as a basis for interpreting the results, revealing empirical trends and traditional logics structuring uses in post-harvest conservation.

Use Value

The frequency of use of each plant in the study areas was measured using the formula of: $UV = N_{pu} / N_i$, where N_{pu} relates to the number of declarations of plant use in the study area, while N_i concerns the total number of informants interviewed (Phillips *et al*. 1994).

Family Use Value

This parameter is obtained by the following formula: $FUV = UV_s / N_s$, where UVs is the use value of each species, while Ns relates to the total number of species within the same family (Sreekeesoon & Mahomoodally 2014). This parameter is used to identify the significance of plant families.

Fidelity level

The following formula was used: $FL = (I_p / I_u) \times 100$, to determine which plant species were preferred by the informants for the treatment of a particular encounter (Nawash *et al*. 2013), where I_p is the number of informants mentioning a plant use for a particular category, I_u is the total number of any use reports per plant species. In our case, the encounter we have is bio-pesticidal usage. The closer FL value of a plant to 100%, the stronger the preference of the informants to use that plant as bio-pesticide. FL was calculated for only two reports per plant at least.

Results

Data on the respondents

Geographic distribution of respondents

Out of 250 respondents surveyed, the distribution across 15 cities and villages was as follows: *Fez* (33.6%), *Meknes* (7.2%), *El Hajeb* (29.6%), *Taounate* (4%), *Karya Ba Mohammed* (2.8%), *Khlalfa* (1.6%), *Sidi El Mokhfi* (2.4%), *Sefrou* (1.6%), *Tafrant* (2.4%), *Ghafssay* (1.6%), *Tahar Souk* (2%), *Zrizer* (1.2%), *Kenitra* (2%), *Moulay Bousselham* (5.2%), *Larache* (2.8%), as detailed in Table 2.

Table 2. Distribution of respondents by city

City	Number of participants
Fez	84
El Hajeb	74
Meknes	18
Moulay Bousselham	13
Taounate	10
Karya Ba Mohammed	7
Larache	7
Sidi El Mokhfi	6
Tafrant	6
Tahar Souk	5
Kenitra	5
Sefrou	4
Khlalfa	4
Ghafssay	4
Zrizer	3

Sociodemographic characteristics

In all survey areas, 226 respondents were men and 24 were women (Figure 2).

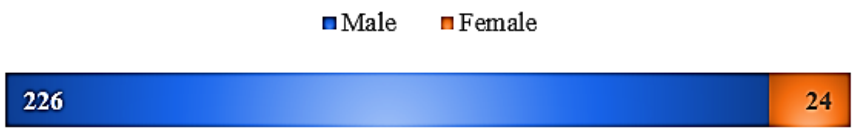

Figure 2. Distribution of respondents by gender

This survey targeted various age groups, with half of the respondents being between the ages of 40 and 59 (Figure 3)

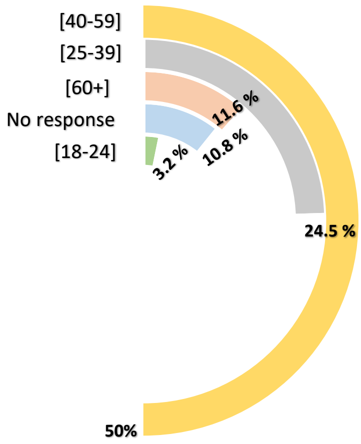

Figure 3. Percentage of the demographic profile of respondents by age

Professional status of respondents

Out of these 250 respondents, 156 were farmers and 94 were herbalists (Figure 4)

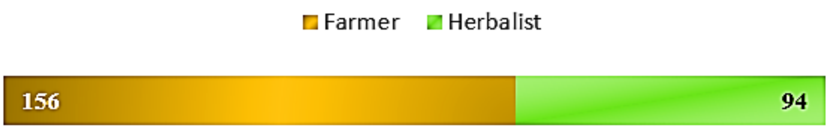

Figure 4. Distribution of respondents by profession

These 156 farmers cultivate various types of crops (with individual farmers potentially growing more than one type), as depicted in Figure 5.

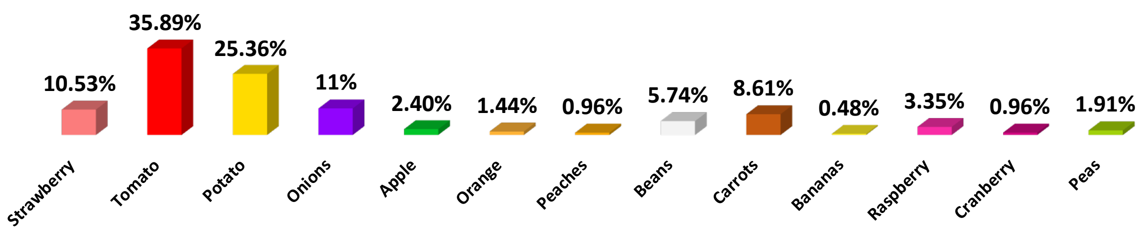

Figure 5. Distribution of cultivated crops among farmers

Educational background and knowledge acquisition

Figure 6 indicates that, among the 250 respondents, 80 possessed either primary or secondary education, a university degree, or a non-university qualification or diploma. In contrast, 144 respondents were illiterate and had acquired their occupations through inheritance. The remaining respondents chose not to disclose their educational background.

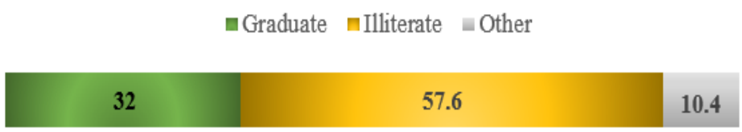

Figure 6. Percentage of the distribution of respondents by type of job acquisition

Crop protection practices among respondents

During the survey, 55.18% of responses identified plants as potential crop protection methods. In contrast, 30.75% of responses addressed alternative protection strategies, such as chemical pesticides and sulfur, while 14.07% of respondents did not provide an answer to this question (Figure 7). The results from the Chi-square test show statistical significance, with $\chi^2 = 851.966$ and $p < 0.001$. Therefore, we can reject the null hypothesis and conclude that there are statistically significant differences in the preference for plant-based protection methods (N = 149), compared to the use of chemical products (N = 51) and other methods (N = 32).

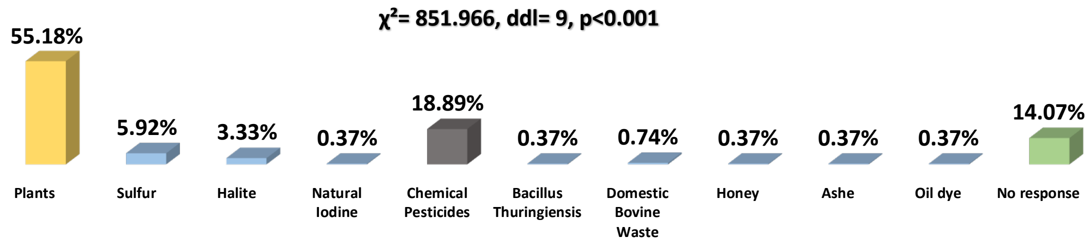

Figure 7. Varied approaches to crop protection used by the informants

Relationship between profession and type of protection used

Figure 8 reveals, statistically, a structured distribution of the relationship between respondents' professions (herbalists and farmers) and the types of postharvest protection known or used, using two complementary tools: the mosaic plot (Figure 8a) and the correspondence analysis (Figure 8b).

The mosaic plot (Figure a) shows a strong differentiation in practices between the two professional groups. Herbalists are more associated with natural preservation methods, particularly the use of plants, while farmers exhibit a higher proportion of conventional methods, especially chemical pesticides and techniques derived from industrial agriculture. The correspondence analysis (Figure b) further supports this differentiation. In the factor space, herbalists are clearly positioned on the right side of the plot, near modalities such as "Plants", "Plants, Sulfur", or "Halite, Sulfur", indicating a strong association with traditional and natural protection strategies. Conversely, farmers are positioned on the left side of the plot, close to modalities like "Chemical pesticides", "Domestic cattle waste", or "Plants, Chemical pesticides", suggesting a preference for conventional or mixed approaches.

Data on the recorded plants

Throughout the survey, a total of 23 plant species were recorded, with respondents citing multiple plants. Tables 3 and 4 detail the plants identified. Rosemary emerged as the most frequently mentioned species, with 60 use reports, a use value (UV) of 0.24, and a fidelity level (FL) of 100%. It was followed by thyme, with 42 use reports, a UV of 0.168, and an FL of 100%, and lavender, which had 32 use reports, a UV of 0.128, and an FL of 100%.

Various parts of the plant, including leaves, flowers, roots, fruits, and occasionally the entire plant, can be utilized across different applications. Figure 9 categorizes the plant parts used in this study in descending order. The most frequently used part was the leaves, comprising 39.63% of the total.

Figure 10 reveals a Multiple Correspondence Analysis (MCA) carried out on data relating to plants used and plant parts exploited for post-harvest preservation, showcasing significant and structured correlations. It shows that the choice of plant parts is not random, but organized by plant species, reflecting logics of use inherited from empirically transmitted traditional knowledge.

The results show that some plants are clearly associated with the use of leaves, while others are linked to roots, bulbs, seeds or fruits. The MCA also highlights geographical groupings of certain plant species, reflecting a convergence of uses between different localities. When a species clearly stands out in factorial space, this suggests either a central role in local practices, or specific bioactive properties recognized by users.

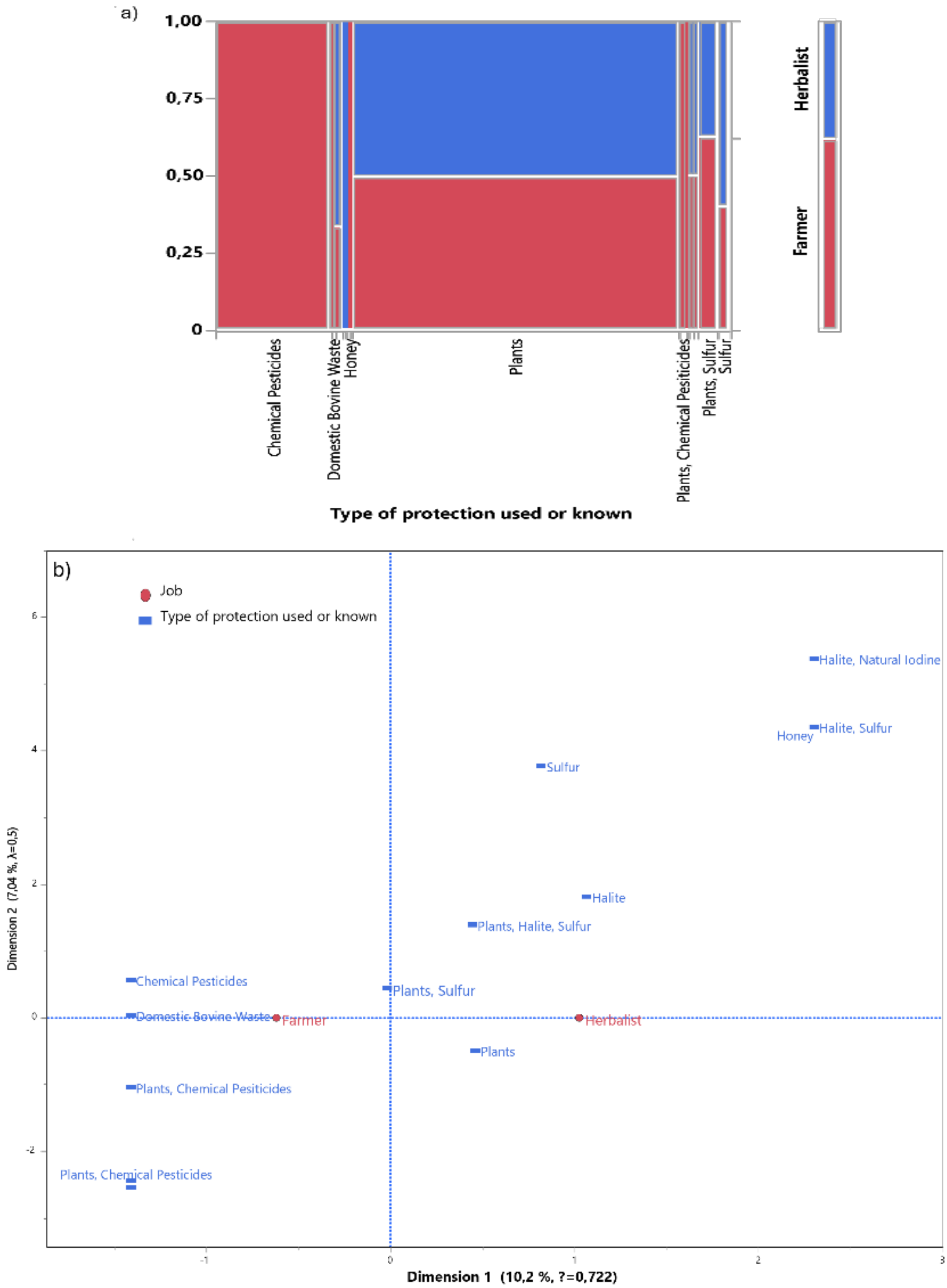

Figure 8. Relationship Between Job Type and Postharvest Protection Methods: Contingency Analysis (a) and Correspondence Analyses (b)

Table 3. List of plants reported by participants in the study

Plant	Use Report
Rosemary	60
Thyme	42
Lavender	32
Eucalyptus	24
Garlic	16
Wormwood	8
Nettle	6
Cornflower	5
Calament	4
Jujube	3
Clove	3
Apple Tree	2
Mugwort	2
Red pepper	2
Bitter Orange	1
Orange	1
Lemon Balm	1
Ginger	1
Rhus	1
Grape tree	1
Onion	1
Olive tree	1
Spinach	1

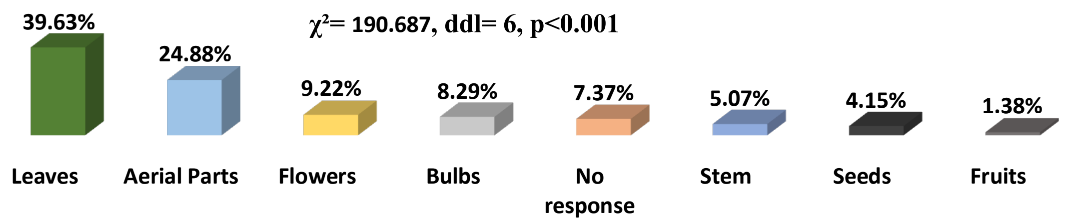

Figure 9. Parts of plants employed by the informants

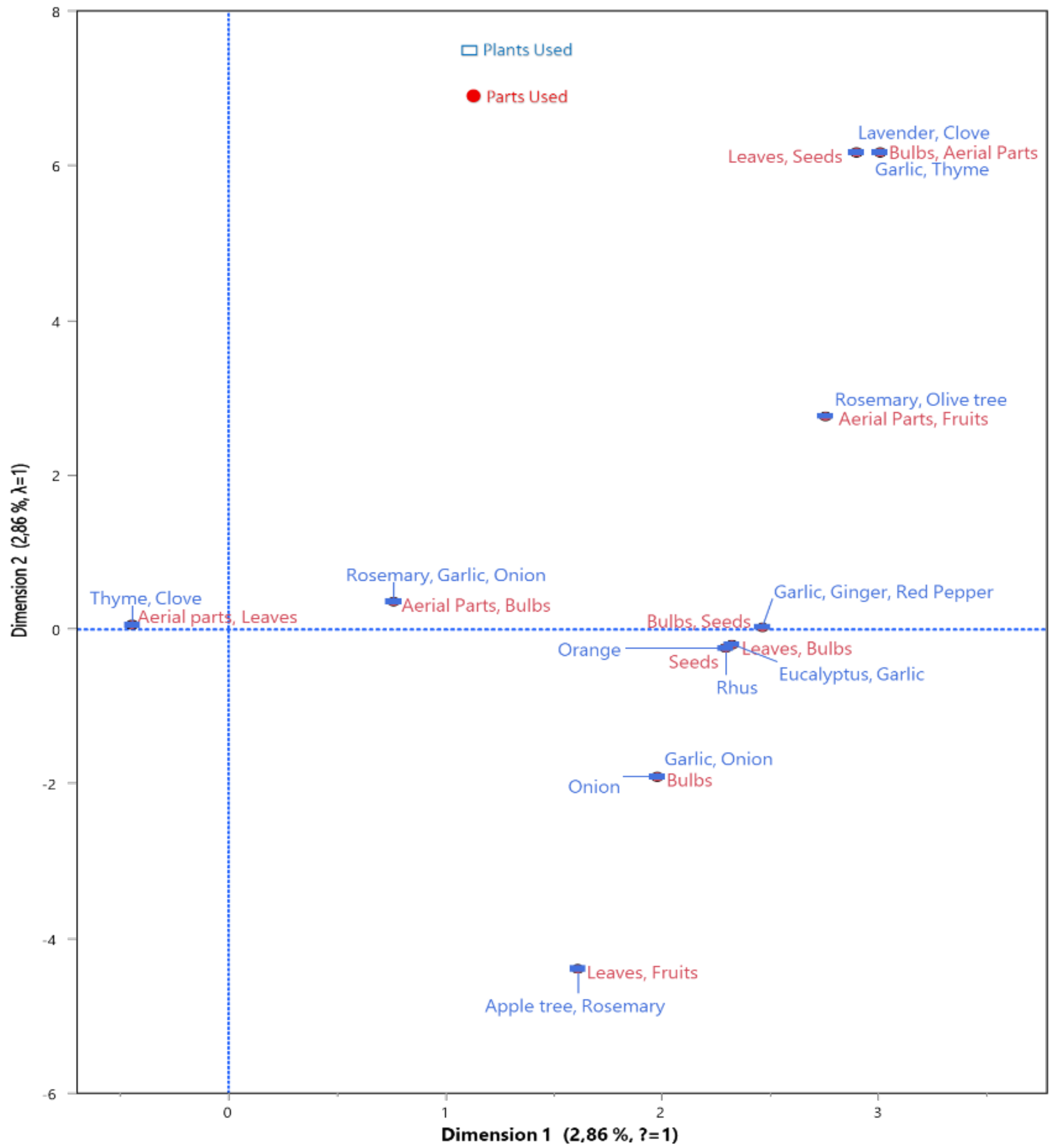

Figure 10. Multiple Correspondence Analysis of plant species and used parts for post-harvest preservation

Methods of preparation

Preparation methods for administering plant's active ingredients include infusing, decocting, distilling, making poultices, and grinding. In this survey, distillation was the most used method, with a frequency of 38.07%, as illustrated in Figure 11.

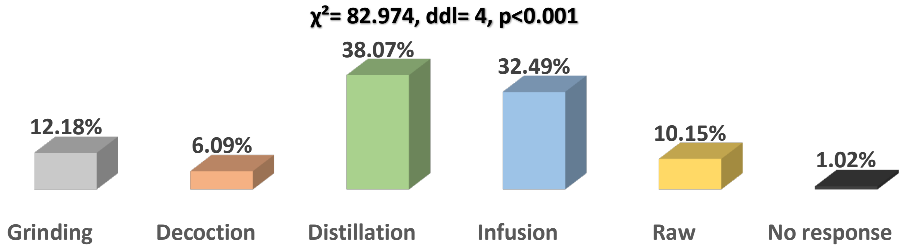

Figure 11. Diversity in plant preparation techniques used by the informants

Forms and methods of application

Essential oils and extracts were the predominant forms of use, with extracts slightly exceeding essential oil, at 31.94% compared to 31.02%, as depicted in Figure 12a. Additionally, spraying emerged as the most frequently employed method for applying herbal products, accounting for 62.96%, as shown in Figure 12b.

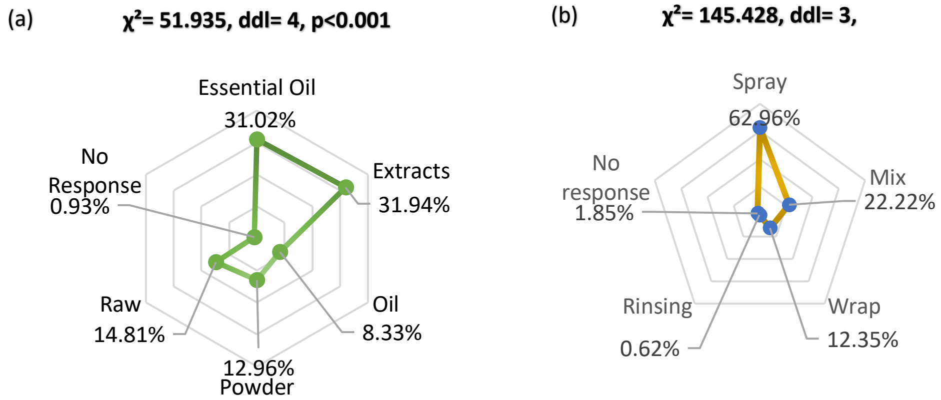

Figure 12. Different applications: (a) Diversity in plant application forms; (b) Diverse modalities of plant application methods

Side effects and mixing recommendations

Among the herbalists surveyed, only two reported potential side effects associated with the use of plants as biopesticides. They noted that Nettle could be harmful if applied in high concentrations. Additionally, one respondent recommended a mixture of garlic, ginger, and red pepper for preserving fresh produce. In contrast, three other respondents suggested that a combination of onion and garlic would be effective for the same purpose.

Data on the other types of protection

As previously noted, 30.75% of the respondents addressed alternative protection methods, as illustrated in Figure 13.

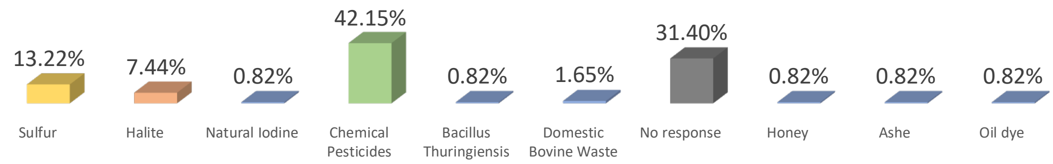

Figure 13. Other types of protection used

The methods of application for these various types of protection employed by farmers are detailed as follows in Figure 14.

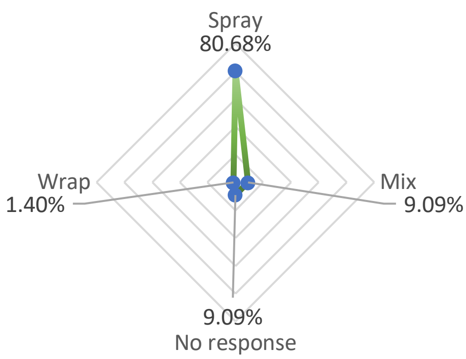

Figure 14. Method of application of the other types of protection

Given that a significant number of respondents used chemical pesticides for crop protection, we extended our questionnaire to include more in-depth questions for 156 farmers

Purpose and selection of chemical pesticides

All respondents indicated that the primary purpose of using chemical pesticides was to safeguard their crops from various types of damage (Figure 15a). The criteria for selecting the appropriate chemical pesticide varied among farmers, as illustrated in Figure 15b.

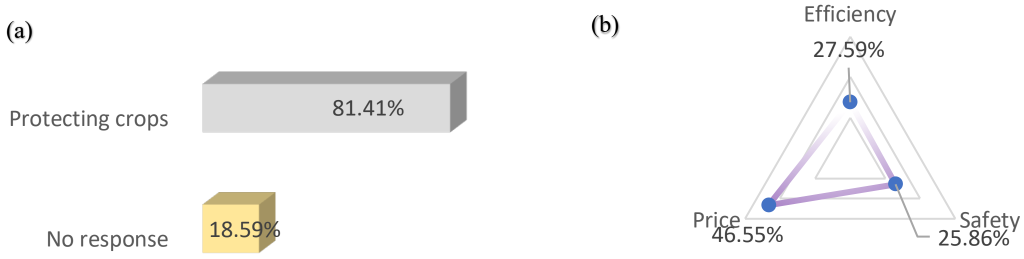

Figure 15. (a) Purpose of chemical pesticides; (b) Motives for ideal pesticide selection

Usage degree and precautions

Farmers exhibit varying degrees of chemical pesticide use, with half employing them moderately, as depicted in Figure 16a. Additionally, some farmers implement safety precautions during pesticide applications, whereas others do not, as shown in Figure 16b.

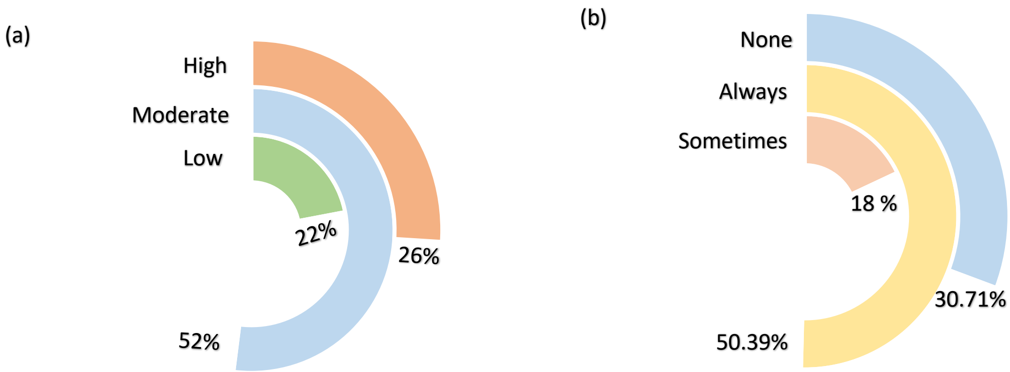

Figure 16. (a) Degree of chemical pesticides usage; (b) Precautions during the application of pesticides

Challenges and ecological crop protection views

Many farmers have faced various challenges at different stages of farming, as depicted in Figure 17a. In contrast, Figure 17b illustrates farmers' views on the adoption of eco-friendly methods for crop protection.

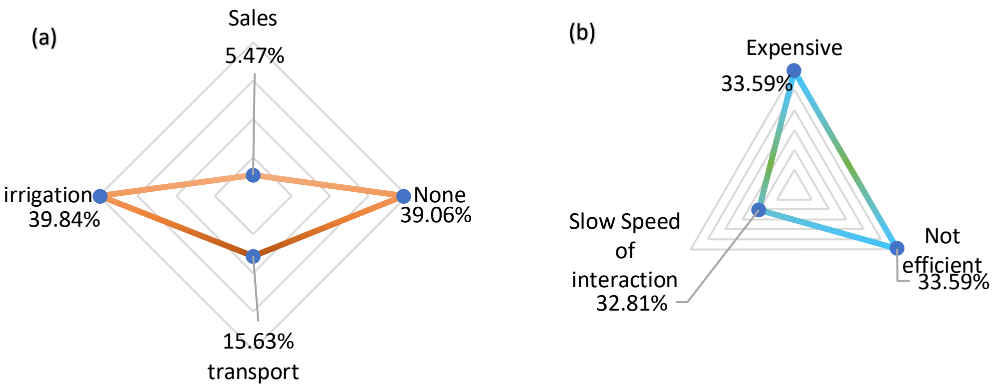

Figure 17. (a) Challenges encountered by farmers; (b) Farmers' Perspectives on Crop Bio protection

Table 4. Data of medicinal and aromatic plants utilized for the treatment of post-harvest microbial diseases in strawberry and tomato crops in the three regions studied in Morocco

Family	Species (Vouchers)	Common names	Local name	Parts used	Mode of preparation	Form of application	Method of application	Use Reports (UR)	Use value	Fidelity level %	FUV
Lamiaceae	*Rosmarinus officinalis* **L.**	Rosemary	Azir	Aerial Parts (Leaves - Stem - Flowers)	Distillation - Decoction - Infusion - Raw	Essential oil - Extracts - Oil - Raw	Wrap - Spray	60	0.24	100	27.8
	Thymus vulgaris **L.**	Thyme	Zeitra	Aerial Parts (Leaves - Stem - Flowers)	Distillation - Decoction - Infusion - Grinding	Essential oil - Extracts - Powder - Oil	Spray - Mix	42	0.168	100	
	Lavandula latifolia **Medik.**	Lavender	Khzama	Aerial Parts (Leaves - Stem - Flowers)	Distillation - Decoction - Infusion - Grinding	Essential oil - Extracts - Powder - Oil	Spray - Mix	32	0.128	100	
	Clinopodium nepeta **(L.) Kuntze**	Calamint	Lmanta	Seeds - Leaves	Distillation - Infusion - Grinding	Extracts - Powder - Oil	Spray - Mix	4	0.016	100	
	Melissa officinalis **L.**	Lemon balm	Mlissa	Flowers - Leaves	Infusion	Extracts	Spray	1	-	-	
Asteraceae	*Artemisia absinthium* **L.**	Wormwood	Chih	Leaves	Distillation - Infusion	Essential oil - Extracts	Spray	8	0.032	100	4.33
	Centaurea cyanus **L.**	Cornflower	Chebba	Aerial Parts (Flowers - Stem - Leaves)	Distillation - Decoction - Grinding	Essential oil - Extracts - Powder - Oil	Spray - Mix	5	0.02	100	
	Artemisia vulgaris **L.**	Mugwort	Chih	Flowers - Leaves	Distillation - Decoction - Raw	Essential oil - Extracts	Wrap	2	0.008	100	
Myrtaceae	*Eucalyptus torquata* **Luehm.**	Eucalyptus	Oukaliptus	Leaves	Distillation - Infusion - Raw	Essential oil - Extracts - Oil	Wrap - Spray	24	0.096	100	13.5

	Syzygium aromaticum **(L.) Merr. & L.M.Perry**	Clove	Krounfol	Seeds	Grinding	Powder	Mix	3	0.012	100	
Amaryllidaceae	*Allium sativum* **L.**	Garlic	Thouma	Bulbs	Grinding - Raw	Powder	Mix	16	0.064	100	8.5
	Allium cepa **L.**	Onion	Bassla	Bulbs	Raw	Powder - Raw	Mix	1	-	-	
Urticaceae	*Urtica dioica* **L.**	Netlle	Houriga	Leaves	Infusion - Raw	Extracts - Raw	Wrap	6	0.024	100	6
Rutaceae	*Citrus aurantium* **L.**	Bitter orange	Ranje	Seeds	Grinding	Powder	Mix	1	-	-	1
	Citrus sinensis **(L.) Osbeck.**	Orange	Limoun	Seeds	Grinding	Powder	Mix	1	-	-	
Solonaceae	*Capsicum annuum* **L.**	Pepper	Lfelfla	Bulbs - Seeds	Grinding	Powder	Mix	2	0.008	100	2
Rhamnaceae	*Ziziphus jujuba* **Mill.**	Jujube	Sedra	Leaves	Raw	Raw	Wrap	3	0.012	100	3
Zingiberaceae	*Zingiber officinale* **Roscoe**	Ginger	Skinjbir	Bulbs - Seeds	Grinding	Powder	Mix	1	-	-	1
Vitaceae	*Vitis vinifera* **L.**	Grapes	Leenab	Leaves	Raw	Raw	Wrap	1	-	-	1
Oleaceae	*Olea europaea* ***L.***	Olives	Zitoune	Fruit	Grinding	Oil	Spray - Mix	1	-	-	1
Anacardiaceae	*Rhus coriaria* L.	Sumach	Al semaq	Seeds	Raw	Raw	Mix	1	-	-	1
Chenopodiaceae	*Spinacia oleracea* **L.**	Spinach	Al Baqoula	Leaves	Raw	Raw	Mix	1	-	-	1
Rosaceae	*Malus domestica* **Borkh.**	Apple	Tefah	Fruit	Grinding	Raw	Spray	2	0.008	100	2

Discussion

During the survey, significant differences were observed between men and women regarding workplace availability and knowledge of locally known pesticide plants. Out of 250 respondents, 226 were male and 24 were female, encompassing various age groups. All respondents identified as either herbalists (37.6%) or farmers (62.4%). Notably, more than half of the respondents (57.6%) indicated that their heritage, despite their illiteracy, facilitated their access to careers as herbalists or farmers. This finding contrasts with results reported by other researchers (Chaachouay *et al*. 2022, Nath & Puzari 2022) who have found that most of their respondents were uneducated, on the other hand, they were somewhat consistent with other ethnobotanical studies (Ammor *et al*. 2020, Amrati *et al*. 2021, El-Ghazouani *et al*. 2021, Kabbaj *et al*. 2012).

Regarding the recorded plants, the results revealed a total of 23 species distributed across 14 families: (*Lamiaceae* (FUV = 27.8), *Asteraceae* (FUV = 4.33), *Myrtaceae* (FUV = 13.5), *Amaryllidaceae* (FUV = 8.5), *Rutaceae* (FUV = 1), *Urticaceae* (FUV = 6), *Solonaceae* (FUV = 2), *Rhamnaceae* (FUV = 3), *Rosaceae* (FUV = 2), and *Zingiberaceae*, *Vitaceae*, *Oleaceae*, *Anacardiaceae*, *Chenopodiaceae* FUV = 1 for each). Rosemary, thyme, and lavender were the most frequently mentioned plants, with frequencies of 27.52%, 19.26%, and 14.68%, respectively. This prevalence may be attributed to their membership in the Lamiaceae family and their significant role in essential oil production. These plants are notable for their high content of phenolic compounds, like shown in table 5, which possess medicinal properties, including potential antibacterial and antioxidant effects (Harley *et al*. 2004, Hussain *et al*. 2011, Mascoloti *et al*. 2022, Nezhadali *et al*. 2014, Stagos *et al*. 2012.

Table 5. Plant Species Frequently Reported by Informants with Dominant Chemical Constituents

Plant species	Major chemical molecules	References
Rosmarinus officinalis **L.**	Volatile compounds: 1,8-cineole (eucalyptol), α-pinene, camphor, borneol, limonene	(Bekhechi *et al*. 2024, Hashemi Gholamhosseinpour *et al*. 2023, Oualdi *et al*. 2023, Rafya *et al*. 2024)
	Non-volatile compounds: rosmarinic acid, carnosic acid, carnosol	
Thymus vulgaris **L.**	Volatile compounds: thymol, carvacrol, p-cymene, γ-terpinene, α-terpinene, terpinen-4-ol, linalool	(Ali and O 2023, Govedarov *et al*. 2023, Waheed *et al*. 2024)
	Non-volatile compounds: rosmarinic acid, vanillic acid, caffeic acid, flavonoids (apigenin, luteolin derivatives)	
Lavandula angustifolia **Medik.**	linalool, linalyl acetate, camphor, 1,8-cineole, β-ocimene.	(Batiha *et al*. 2023, Hadj Moussa *et al*. 2023, Khatri *et al*. 2023)
Eucalyptus torquata **Luehm.**	Torquatone, 1,8-cineole, α-pinene, p-cymene, limonene, terpinen-4-ol	(Bulama Modu *et al*. 2025, Čmiková *et al*. 2023, Nasir Shah *et al*. 2023)
Allium sativum **L.**	allicin, diallyl disulfide (DADS), diallyl sulfide (DAS), ajoene, S-allyl cysteine, also contains flavonoids and other minor volatiles	(El-Saadony *el al*. 2024)
Artemisia absinthium **L.**	sabinene, myrcene, α- and β-thujone, camphor, cymene, chamazulene, trans-sabinyl acetate, terpinen-4-ol, camphene	(Polito *et al*. 2024, Raal *et al*. 2024)

Eucalyptus, wormwood, and garlic were mentioned with a percentage of 9.6%, 6.4%, and 3.2%, respectively, likely due to the presence of a variety of chemical components (Table 5) that have notable antimicrobial properties, as reported in various studies (Aati *et al*. 2020, Akullo *et al*. 2022, Aleksic & Knezevic 2021, Fratianni *et al*. 2016, Jiang *et al*. 2021, Meriga *et al*. 2012). Other plants, such as Sumac, Spinach, and Ginger, were mentioned only once. This may be attributed to either inadequate transmission of ethnobotanical knowledge or the gradual extinction of these plant species from their natural habitats. Additionally, these plants may have limited value as pesticidal agents (Nath & Puzari 2022).

The groupings in figure 10 reveal choices based on experience, local availability, and perceived or demonstrated bioactive properties. Leaves, which are easy to collect and often rich in active principles, making them the most widely used (39.63%), as they offer promising potential for preserving fresh produce, both in terms of accessibility and efficacy (Alkufeidy *et al*. 2022, Jamir *et al*. 2022, Nath & Puzari 2022). Roots and bulbs, on the other hand, although less accessible, are renowned for their concentration of powerful antimicrobial compounds (Mascolo *et al*. 1989, Oyawoye *et al*. 2022, Rabah *et al*. 2020). They are often reserved for targeted applications requiring enhanced efficacy. Seeds, less frequently mentioned, often contain oils and lipophilic compounds with antimicrobial potential (Joujou *et al*. 2024, Kitsiou *et al*. 2023), but their use remains more specialized, the results of the analyses reinforce the idea that empirical knowledge, although derived from oral traditions or local experience, is the fruit of a long-term process of experimentation and selection. This knowledge, often ignored by conventional scientific research, nevertheless provides a valuable basis for the development of sustainable biological solutions, particularly in the context of food security and the valorisation of local plant resources. The spatial structure shown in Figure 10 provides more than just a descriptive overview; it provides a framework for identifying priority plant species that merit more in-depth phytochemical and biological study. This approach allows traditional ethnobotanical knowledge to be leveraged in scientific research on natural preservatives derived from local plants. Integrating this knowledge into modern research strategies enhances the cultural and environmental value of traditional practices, supports the sustainable use of plant diversity, and promotes a comprehensive understanding of the relationship between humans, plants, and their environment.

The distillation method was the most used (38.07%), followed by the infusion method (32.49%). This preference may be due to both methods' effectiveness in extracting secondary metabolites with potential antimicrobial activity, which aligns with the study's objectives. Additionally, the frequent use of these methods may be attributed to their cost-effectiveness (Harouak *et al*. 2021, Mailaram & Maity 2022). The extracts form was mentioned with a frequency of 31.94%. This form is a concentrated preparation obtained by extracting bioactive compounds from medicinal and aromatic plants materials, using solvents such as water, ethanol, or other organic solvents, this form includes various groups of secondary metabolites, among which polyphenols are one of the most common and widespread subgroups in plants, with more than 8 000 phenolic structures identified to date (Santiago *et al*. 2021). Indeed, this form can be effective against many pathogenic microbes (Bessi *et al*. 2025).

Since medieval times, essential oils have been widely utilized for their antimicrobial properties, including their antibacterial, antiviral, antifungal, and insecticidal effects (Risaliti *et al*. 2019), results of our study align with this fact, as essential oils were the second most used form, representing 31.02% of the total. This preference may be attributed to the high concentration of effective bioactive phytochemicals in essential oils, particularly terpenoid compounds. (Ahsaei *et al*. 2020, Ainane *et al*. 2019, Iseppi *et al*. 2019, Risaliti *et al*. 2019, Soulaimani *et al*. 2021). Spraying was the most frequently employed method, utilized by 62.4% of respondents. This finding is consistent with the results reported by Nath and Puzari (2022) suggesting that spraying is likely the most practical and effective method for application.

The usage of chemical pesticides is on the rise (WHO 2022), this may account for the high percentage of farmers employing them in our study (61.45%). Results of the statistical analysis shown in figure 8a and 8b highlight a dichotomy between traditional and conventional approaches, closely tied to professional background. Herbalists tend to rely on empirically transmitted knowledge, favoring local and natural resources such as medicinal plants, sulfur, or honey. Farmers, by contrast, appear more embedded in mechanized and standardized production systems, often based on chemical inputs (Li *et al*. 2021, Li *et al*. 2021, Zhao *et al*. 2022).

The spatial patterns revealed by the analysis not only confirm the observed preferences but also suggest the emergence of hybrid strategies in food preservation. Some members of the community combine traditional herbal methods with modern techniques, reflecting the dynamic adaptation of ethnobotanical knowledge. This division of practices may also reflect broader sociocultural differences, as herbalists are often more closely linked to local traditions, while farmers combine traditional and contemporary methods. From an ethnobotanical perspective, these findings underscore the complementarity between traditional knowledge and innovative approaches to food preservation. Long-practiced natural methods form a valuable basis for preserving food quality while also complying with ecological and health principles. Promoting the use of organic preservatives from medicinal and aromatic plants encourages biodiversity, enhances the value of available local resources, and strengthens sustainable cultural approaches to food management.

Among the farmers surveyed, 46.55% prioritize price when selecting pesticides, while 27.59% focus on efficiency and 25.86% consider safety. More than half of the farmers (51.97%) apply chemical pesticides at a moderate frequency, and 25.98% use them more frequently, contributing to soil pollution (Huang *et al*. 2017, Huang & Lu 2021). Additionally, 50.39% of farmers sometimes take precautions, whereas 30.71% do not use any precautions. This lack of precautionary measures is likely a major factor contributing to pesticide poisoning among farmers globally (Bondori *et al*. 2021, Pathak *et al*. 2022). Approximately one-third of the farmers perceive eco-friendly crop protection methods as costly, another third finds them less efficient compared to chemical pesticides, and the remaining third consider them time-consuming, noting that biopesticides often require more time to be effective than chemical alternatives.

Conclusion

This study identified a total of 23 plant species with biological potential for the conservation of tomato and strawberry plants, distributed across 14 families, with *Lamiaceae* family being the most prominent (FUV = 27.8). Chi-square test results indicate a strong preference for the use of medicinal and aromatic plants among respondents. The most frequently cited plant species were rosemary (UR = 60), thyme (UR = 42), and lavender (UR = 32). Leaves were the most utilized plant part, with a citation frequency of 39.63%. Extracts and essential oils were the predominant forms of application, representing 31.94% and 31.02% of the total, respectively.

The results confirm the richness and continuity of ethnobotanical knowledge in the regions of Fez-Meknes, Rabat-Salé-Kenitra and Tangier-Tetouan-Al Hoceima. They demonstrate a deep understanding of the conservation potential of local plants and their integration into local food traditions. These records provide valuable information on Morocco's cultural heritage and offer a scientific basis for future research on the phytochemical and bioactive properties of traditionally used species. Preserving and promoting this knowledge is essential to maintaining the link between biodiversity and traditional practices that promote the well-being and cultural identity of the community.

Declarations

List of abbreviations: Not applicable

Ethics approval and consent to participate: The research was carried out in strict adherence to established ethical standards and fully aligned with the principles of the Nagoya Protocol, ensuring responsible access to genetic resources and the fair and equitable sharing of benefits derived from their use. Before collecting any data, informed consent was obtained from all participants. Each participant was provided with a detailed explanation of the study’s purpose and methods. Confidentiality and anonymity were ensured throughout the study, and participation was entirely voluntary. Any data collected will be used solely for research purposes.

Consent for publication: Not applicable

Availability of data and materials: No datasets have been deposited in public repositories

Competing interests: The authors declare no conflicts of interest.

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