INVENTORY AND DIVERSITY OF BOTANICAL PESTICIDES: A CASE STUDY OF THE BLIDIAN ATLAS, NORTH-CENTRAL ALGERIA

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Abstract. Botanical pesticides are receiving increasing attention from researchers and growers as an alternative to synthetic pesticides. In this study, we identified the pesticidal plants naturally occurring in the Blidian Atlas in North Algeria during the flowering period of the most of plants (mid-March to mid-june). These plants were identified in different habitats: forest, wasteland and maquis across three vegetation zones: Thermo-Mediterranean, Meso-Mediterranean and Supra-Mediterranean. The study recorded notable floristic diversity. Among the 452 total species recorded in the area, 88 species distributed across 39 botanical families were effective against pest insects and fungi. Asteraceae and Lamiaceae were the most dominant families comprising 18.18% and 13.63%, respectively. In terms of biological types, hemicryptophyte and therophyte were the most dominant with 30.68% and 25%, respectively. The highest floristic diversity was recorded in the Meso-Mediterranean stage, particularly in the maquis and forest areas. Insecticidal compounds of most of the identified plants were found primarily in the leaves followed to a lesser extent, by the flowers, while the most targeted insects were storage insects.
Keywords: *plant pesticides, vegetation-zones, pests, fungi, habitats*

Introduction

To meet the growing demand for staple agricultural products from the global population, the use of synthetic chemical pesticides has become a fast and efficient way to protect crops from pest infestations (Lengai et al., 2019), they act directly or indirectly as vectors of plant diseases, contributing to a decline in both the quality and quantity of crops (Zettler et al., 1990).

However, the excessive and indiscriminate use of synthetic pesticides can have detrimental effects on human health (Sayed et al., 2022) and the environment (Sande et al., 2011) including soil and groundwater contamination, ozone layer depletion, and threats to biodiversity. This is primarily due to their non-biodegradable nature (Wimalawansa et al., 2014), toxicity to non-target organisms (Sande et al., 2011) and their ability to promote resistance in insects and pathogens when used over prolonged periods (Lengai et al., 2019).

It is therefore essential to explore safe alternatives to synthetic pesticides such as botanical pesticides, which are believed to be effective against a variety of crop pests (Acheuk et al., 2022). The use of botanical pesticides promotes a healthy environment and supports sustainable agriculture (Shabana et al., 2017). Their importance lies in several factors including their efficacy, biodegradability, and low toxicity. Additionally, they offer a wide range of modes of action and are easily accessible (Neeraj et al., 2017). Furthermore, botanical pesticides are a rich source of bioactive compounds (Qin et al., 2010) that serve as insecticides, repellents, bactericides, fungicides, herbicides, and nematicides (Isman et al., 2006).

In this regard, over 2000 plant species have been identified worldwide for their traditional use as insecticides (Adeniyi et al., 2010). The insecticidal toxicity of these plants has garnered significant attention from researchers in recent years, reflected in the growing number of publications focused on this subject.

Despite the presence of over 3000 spontaneous plant species in Algeria (Quezel and Santa, 1962-1963), studies on the inventory of botanical pesticides in the country remain limited. However, researchers are starting to recognize their significance (Amokrane et al., 2023), especially in mountainous regions. These areas are known for their rich biodiversity, closely associated with the region's topographic and bioclimatic variability (Mekideche et al., 2018).

In this context, the present study aims to create an inventory of pesticidal plants in the Blidian Atlas massif, a significant plant-rich region. It will also synthesize key research on these plants based on existing literature, covering their botanical families, biological types, habitats, phytogeographies, targeted pests and pathogens and the specific plant parts used for biological control. Additionally, the biological trials conducted by researchers on these plants will be reviewed.

This study will serve as a valuable database for future research and the use of bioinsecticides in Algeria and beyond.

Materials and methods

The study region

The Blidean Atlas is located in northern Algeria, within the province of Blida, between 36°15'00" and 36°45'00" North and 2°30'00" and 3°50'00" East, covering an area of 52145 hectares (*Fig. 1*). It belongs to the Mediterranean climate, characterized by wet winters and hot, dry summers.

The analysis of climate data from 1999 to 2013 reveals a subhumid to per-humid bioclimate, with temperate winters. The average annual precipitation ranges from 679 to 1382 mm, while the mean annual temperatures vary between 11°C and 19.2°C (Mekideche et al., 2018).

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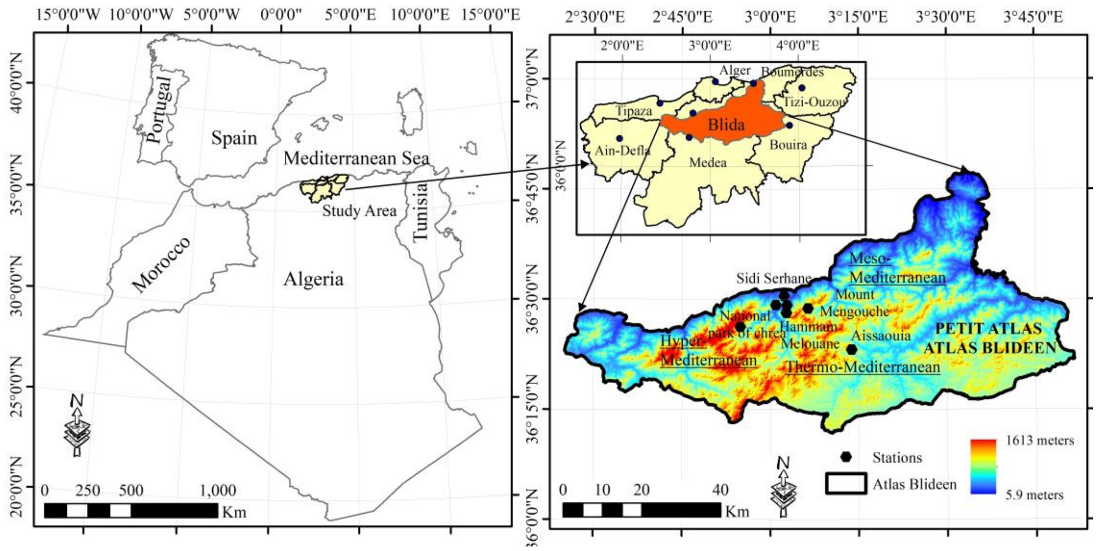

Figure 1. *Location of the study satations (Hammam Melouane, Aissaouia, Chrea) and the main vegetation zones (Thermo-mediterranean, Meso-mediterranean, Supra-mediterranean) in the Blidean Atlas (Algeria)*

Sampling and data analysis

The inventories were conducted over a period of two years (2023 and 2024) and include a total spiecies of 452, involving a total of 48 random surveys in the three bioclimatic zones: Thermo-Mediterranean, Meso-Mediterranean, and Supra-Mediterranean spanning an altitudinal gradient from 250 to 1300 meters. Each bioclimatic zone was further divided into three habitats: wastelands, maquis, and forests.

According to Meddour (1994), the Thermo-Mediterranean zone is located below 600 m in altitude and is characterized by a subhumid bioclimatic stage, the vegetation dominated by *Pinus halepensis, Olea europaea, and Pistacia lentiscus*. The Meso-Mediterranean zone, situated between 600 and 1300 m, features humid bioclimatic stage dominated by *Quercus suber and Quercus ilex.* The Supra-Mediterranean zone, found above 1300 m, is characterized by perhumid bioclimatic stage, dominated by *Cedrus atlantica*.

Botanical identification was based on specimens from the herbarium of Chrea National Park. The family of each species was determined according to the APG IV (2016) classification, the biological types were distinguished according to Raunkiaer (1934), and the phytogeographical distribution according to Quézel and Santa (1962-1963).

The species diversity associated with each bioclimatic zone and habitat was calculated using Shannon diversity index (H′), which combines species richness and evenness (Shannon and Weaver, 1949). It is calculated as follows:

$$H' = \sum_{i=1}^{s} pi \, log_2 \, pi \qquad \text{(Eq.1)}$$

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where: H′ = The Shannon index value, pi= the proportion of individuals belonging to the ith species, $\log 2$= the natural logarithme and S = the number of species in the community.

To study the relationship between the different species and their habitats, we used Correspondence Analysis (CA), a multivariate technique that examines associations and oppositions within the data, using the R software.

Results

Among 452 species recorded in the study area, 88 were effective against pests and phytopathogenic agents (*Table 1*), distributed among 39 distinct botanical families. The Asteraceae family contained the largest number of species, with 16 species (18%), followed by the Lamiaceae with 12 species (14%), the Apiaceae with 8 species (9%), and the Euphorbiaceae with 4 species (5%). The Myrtaceae, Cistaceae, and Fabaceae families each had 3 species (3%). The Hypericaceae, Brassicaceae, Pinaceae, Plantaginaceae, Malvaceae, and Caprifoliaceae families with 2 species (2%), while the Oleaceae, Asphodelaceae, Urticaceae, Lauraceae, Anacardiaceae, Convolvulaceae, Orobanchaceae, Dennstaedtaceae, Scrophulariaceae, Thymelaeaceae, Rosaceae, Resedaceae, Violaceae, Capparaceae, Caryophyllaceae, Linaceae, Verbenaceae, Taxaceae, Polygonaceae, Papaveraceae, Aristolochiaceae, Boraginaceae, Apocynaceae, and Oxalidaceae each with only one species (1%) (*Fig. 2*). The aerial parts, particularly the leaves, were the most commonly used for extracting bioinsecticidal molecules. Most of these biopesticides were applied against storage pests, such as *Tribolium castaneum*, *Sitophilus granarius*, *Tribolium confusum*, *Callosobruchus maculatus*, and *Rhyzopertha dominica* (*Table 1*).

In terms of biological types, hemicryptophytes (Hem) were the most represented, with 27 species (31%), followed by therophytes (The) and phanerophytes (Pha), with 22 species (25%) and 21 species (24%), respectively. chamaephytes (Cha) accounted for 14 species (16%), while geophytes (Geo) comprised only 4 species (4%) (*Fig. 3*).

Most of the inventoried species were of Mediterranean origin, with 43 species (49%), followed by cosmopolitan species with 9 species (10%), Euro-Asiatic species with 8 species (9%) and European species with 5 species (6%). 4 species (5%) were from Euro-Mediterranean origin, while Atlantico-Mediterranean and endemic plants each accounted for 3 species (3%). Australian, Mediterranean-Saharo-Sindian and Paleo-temperate species each represented by 2 species (2%). Finally, Oro-Mediterranean, Ibero-Mauritian, subtropical and South African species acconounted for 1 species each (1%) (*Fig. 4*).

The highest diversity was recorded in the Maottorals (ranging from 4.2 to 4.5), followed by wastelands (4.2 to 4.3), while forests were the least diverse habitats (3.2 to 3.7). In terms of vegetation zones, the meso-Mediterranean and supra-Mediterranean zones exhibited the highest diversity, with Shannon indices (*Eq.1*) of 4.17 and 4.14, respectively, while the thermo-Mediterranean zone was less diverse, with a Shannon index of 3.87 (*Table 2*). Overall, the results indicate that the study area displays very high diversity.

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Table 1. *Inventoried pesticide plants, used parts and target pests*

Species	Pest	Plant part	References
Anacyclus clavatus (Desf.) Pers.	*Tribolium castaneum (H) Herbst*	LE	Pascual-Villalobos et al. (1998)
Atractylis gummifera (L)	*Bactrocera oleae (Rossi.)*	NM	Mejdoub et al. (2020)
	Sitophilus granarius (L)	RO	Chelef et al. (2021)
Atractylis cancellata (L)	*Tribolium castaneum (H).Herbst*	WP	Pascual-Villalobos et al. (1998)
Calendula arvensis Boiss.	*Tribolium castaneum (H) Herbst*	WP	Pascual-Villalobos et al. (1998)
Carthamus lanatus (L)	*Spodoptera littoralis (Bois.)*	ST	Pavela (2011)
Coleostephus myconis (L)	*Tribolium confusum (J. Du Val)*	FL/LE	Haouas et al. (2014)
Dittrichia viscosa (L)	*Callosobruchus aculatus (Fab.)*	AP	Gueribis et al. (2019)
	Spodoptera littoralis (Bois.) / Myzus persicae (Sulzer) / Rhopalosiphum padi (Linnaeus)	AP	Mamoci et al. (2012)
	Verticillium dahliae Kleb	NM	Varo et al. (2017)
Echinops spinosissimus Turra	*Bactrocera oleae (Rossi.)*	NM	Belabbes et al. (2020)
Erigeron canadensis (L).	*Tribolium castaneum(H) Herbst /Aspergillus flavus (L)*	AP	Azeem et al. (2022)
Glebionis coronaria (L.) Cass. ex Spach	*Alternaria brassicicola (Schwein.) / Aspergillus flavus (L)/ Botrytis cinerea Pers. / Fusarium verticillioides (Sacc.) / Fusarium solani (Mart.) Sacc. / Mycocentrospora acerina (R. Hartig) / Pythium ultimum Trow / Rhizoctonia solani Kühn /Sclerotinia sclerotiorum (Lib.) / Serpula lacrymans (Wulfen)*	NM	Alvarez-Castellanos et al. (2001)
	Tribolium castaneum (H).Herbst. / Rhyzopertha dominica (Fab.)	NM	Hazafa et al. (2022)
Helichrysum stoechas (L.)	*Tribolium castaneum (H).Herbst*	NM	Pascual-Villalobos et al. (1998)
Mauranthemum paludosum (Poir.) Vogt & Oberpr.	*Tribolium confusum (J. Du Val)*	FL/LE	Haouas et al. (2014)
Pallenis spinosa (L.) Cass	*Tribolium castaneum (H).Herbst.*	WP	Pascual-Villalobos et al. (1998)
Sonchus asper (L.) Hill	*Tribolium castaneum (H).Herbst.*	RO/LE	Samreen et al. (2014)
	Helicoverpa armigera Hübner/ Spodoptera litura (Fab.)	NM	Shehzad et al. (2021)
Sonchus oleraceus (L.)	*Sitophilus oryzae (L.)*	LE	Shawer et al. (2020)
Senecio vulgaris (L.)	*Tribolium castaneum (H).Herbst.*	WP	Pascual-Villalobos et al. (1998)

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Species	Pest	Plant part	References
Ajuga iva (L.) Schreb.	*Tribolium castaneum (H) Herbst*	NM	Jbilou et al. (2008)
	Plodia interpunctella (Hübner)	AP	Bouayad et al. (2013)
Clinopodium nepeta (L.) Kuntze	*Aspergillus flavus (L)/ Tribolium confusum (J. Du Val)/ Sitophilus zeamais (L).*	NM	Debbabi et al. (2020)
Clinopodium vulgare (L.)	*Spodoptera littoralis (Bois.)*	ST	Pavela (2011)
Lavandula stoechas (L.)	*Tetranychus cinnabarinus (Bois.)*	AP	Sertkaya et al. (2010)
	Ceratitis capitata (Wiedemann)	NM	Ghalbane et al. (2021)
	Spodoptera littoralis (Bois.)/ Leptinotarsa decemlineata (Say.)/ Myzus persicae (Sulzer)	FL/LE	Gonzalez-Coloma et al. (2006)
Lavandula dentata (L.)	*Sitophilus zeamais /Tribolium castaneum(L)/Epicauta atomaria (Germar)*	ST/LE	Wagner et al. (2021)
	Ceratitis capitata (Wiedemann)	NM	Ghalbane et al. (2021)
Mentha rotundifolia (L.) Huds.	*Fusarium culmorum/ Sitophilus granarius (Linnaeus) /Tribolium confusum (J)*	ST/LE	Yakhlef et al. (2020)
Salvia verbenaca (L.)	*Callosobruchus chinensis (Linnaeus)*	LE	Righi et al. (2014)
Origanum floribundum Munby	*Sitobion avenae (F)*	LE	Mouas et al (2021)
Satureja montana (L)	*Spodoptera littoralis (Bois.)/ Myzus persicae (Sulzer) / Leptinotarsa decemlineata (Say.)*	LE / FL	Navarro-Rocha et al. (2020)
	Acyrthosiphon pisum (Harris)	AP	Lacotte et al. (2023)
Teucrium polium (L.)	*Callosobruchus maculatus (Fab.)*	LE	Arab et al. (2008)
Thymus hirtus subsp. algeriensis (Boiss. & Reut.) Murb.	*Tribolium castaneum (H) Herbst*	AP	Amari et al. (2022)
Thymus algeriensis Boiss. & Reut.	*Aphis fabae Scopoli*	LE / FL	Kouache et al. (2024)
Bupleurum fruticosum (L)	*Spodoptera littoralis (Bois.)*	LE/ RO/ ST	Ben El Hadj Ali et al. (2015)
	Sitophylus oryzae (L)	NM	Koutsaviti et al. (2018)
Daucus carota (L.)	*Spodoptera littoralis (Bois.)*	SE	Ben-Khalifa et al. (2018)
Ferula communis (L.)	*Spodoptera littoralis (Bois.)/ Myzus persicae (Sulzer)*	NM	Mamoci et al. (2012)
Eryngium tricuspidatum (L.)	*Tribolium confusum (J. Du Val)*	NM	Majdoub et al. (2024)
Visnaga daucoides Gaertn.	*Culex quinquefasciatus Say*	NM	Pavela (2008)
Foeniculum vulgare Mill.	*Sitophilus granarius (Linnaeus) / Tribolium castaneum(L)*	NM	Teke et al. (2021)
	Rhopalosiphum padi (Linnaeus)	LE	Benddine et al. (2023)
	Spodoptera littoralis (Bois.)	SE	Ben-Khalifa et al. (2018)

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	Acyrthosiphon pisum (Harris)	SE	Lacotte et al. (2023)
	Aphis gossypii Glover	NM	Atanasova et al. (2018)
Thapsia garganica (L.)	*Tribolium Castaneum(H) Herbst*	SE	Khemis et al. (2023)
	Sitophilus granarius(L)	ST/LE	Chelef et al. (2021)
Smyrnium olusatrum (L.)	*Tetranychus urticae Koch*	FL	Benelli et al. (2017)
Olea europaea subsp. Europaea	*Ephestia kuehniella Zeller*	ST	Lahcene et al. (2018)
Asphodelus microcarpus Rchb.	*Tribolium castaneum (H) Herbst*	AP	Saada et al. (2010)
Urtica dioica(L)	*Culex pipiens (Linnaeus)*	NM	Toubal et al. (2019)
Myrtus communis (L.)	*Callosobruchus maculatus (Fab.), Tribolium confusum (J. Du Val)*	LE	Khani et al. (2012)
	Acyrthosiphon pisum (Harris)	AP	Lacotte et al. (2023)
Eucalyptus globulus Labill.	*Myzus persicae (Sulzer)*	AP	Oulebsir-Mohandkaci et al. (2015)
	Acyrthosiphon pisum (Harris)	LE	Lacotte et al. (2023)
Eucalyptus camaldulensis Dehnh.	*Oryzaephilus surinamensis (Linnaeus) /Sitophilus oryzae (L)*	LE	Ebadollahi et al. (2020)
	Ectomyelois ceratoniae	LE	Haouel et al. (2010)
	Aphis gossypii Glover	LE	Koorki et al. (2018)
Juniperus oxycedrus (L.)	*Sitophylus oryzae/tribolium confusum (J)*	NM	Athanassiou et al. (2013)
	Rhopalosiphum padi (Linnaeus) / Sitobion avenae (Fab.) / Fusarium spp/ Botrytis cinerea Pers. /, Colletotrichum spp. / Rhizoctonia solani Kühn/ Cylindrocarpon pauciseptatum Wollenw.	NM	Semerdjieva et al. (2021)
	Aphis spiraecola Patch	LE	Amokrane et al. (2024)
Tetraclinis articulata (Vahl) Mast.	*Sitophilus granarius/ Tribolium confusum (J. Du Val)*	FR	Sadiki et al. (2022)
Laurus nobilis (L.)	*Tribolium confusum (J. Du Val)*	NM	Isikber et al. (2006)
	Acyrthosiphon pisum	LE	Lacotte et al. (2023)
Pistacia lentiscus (L.)	*Lobesia botrana(Denis)*	FR/LE	Dasenaki et al. (2022)
	Anopheles maculatus Theobald	FR /LE	Pourya et al. (2018)
	Aphis spiraecola Patch / Aphis gossypii Glover	NM	Behi et al. (2019)
Convolvulus lineatus (L)	*Chaitophorus leucomelas Koch*	LE	Zaid et al. (2021)
	Sitophilus oryzae(L)	AP	Allali et al.

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Species	Pest	Plant part	References
			(2010)
Bellardia trixago (L.) All	*Tribolium castaneum (H) Herbst*	AP	Pascual-Villalobos et al. (1998)
Pteridium aquilinum (L.) Kuhn	*Chaitophorus populialbae*	LE	Zaid et al. (2022)
Cistus creticus (L.)	*Fusarium moniliforme/ Fusarium culmorum Schltdl / Alternaria alternata (Fr.) Keissl / Botrytis cinerea Pers.*	AP	Çaşkurlu et al. (2020)
Cistus salviifolius (L.)	*G.citri-aurantii*	NM	Karim et al. (2017)
	Plodia interpunctella (Hübner)	AP	Bouayad et al. (2013)
Cistus monpeliensis (L.)	*G.citri-aurantii*	NM	Karim et al. (2017)
	Plodia interpunctella (Hübner)	AP	Bouayad et al. (2013)
Hypericum perforatum (L)	*Leptinotarsa decemlineata*	WP	Daraban et al. (2021)
Hypericum humifusum (L.)	*Culex pipiens (Linnaeus)*	AP	Rouis et al. (2013)
Raphanus raphanistrum (L.)	*Tribolium castaneum (H) Herbst*	NM	Jbilou et al. (2008)
Hirschfeldia incana (L.) Lagr.-Foss.	*Verticillium dahliae Kleb*	LE/ST	Varo et al. (2017)
Verbascum sinuatum (L.)	*Aphis gossypii Glov.*	WP	Soliman et al. (2005)
Daphne gnidium (L.)	*Sitophilus granarius(L)*	ST/LE	Chelef et al. (2021)
Rubus ulmifolius Schott	*Ceratitis capitata (Wiedemann)*	LE	Ghabbari et al. (2018)
Reseda alba (L.)	*Phthorimaea operculella (Zeller)*	AP	Mazrou et al. (2021)
Viola odorata (L.)	*Acalyptris pistaciae van Nieukerken & Hull*	ST/LE/FL	Razavi et al. (2015)
	Ceratitis capitata (Wiedemann)	LE	Ibrahim et al.2023
Capparis spinosa (L.)	*Tribolium confusum (J. Du Val)*	FR	Manesh et al. (2022)
	Bemisia tabaci (Gennadius)	SE	Shahrour et al. (2024)
Cytisus villosus Pourr.	*Culex pipiens (Linnaeus)*	LE	Djidel et al. (2018)
Ceratonia siliqua (L.)	*Fusarium oxysproum f.sp.c / Monilinia fructigena Honey*	LE	Yavuz et al. (2018)
Melilotus officinalis (L.) Lam.	*Diaphorina citri Kuwayama / Aphis gossypii Glover*	NM	Tayyab et al. (2022)
Silene vulgaris (Moench) Garcke	*Spodoptera littoralis (Bois.)*	ST	Pavela (2011)
Linum bienne (L.)	*Rhyzopertha dominica (Fab.)*	SE	Moon et al. (2021)
	Myzus persicae (Sulzer)	SE	Haidar et al, (2023)
Verbena officinalis (L.)	*Culex pipiens (Linnaeus)*	LE	Zoubiri et al.

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			(2011)(b)
Taxus baccata (L)	*Sitophilus oryzae(L)*	LE	Riffi et al. (2019)
Polygonum aviculare (L.)	*Tetranychus cinnabarinus (Bois.)*	NM	Jin and al. (2012)
Cedrus atlantica (Endl.) Manetti ex Carrière	*Dactylopius opuntiae (Cockerell)*	LE	El Finti et al. (2022)
Pinus halepensis Mill.	*Aphis spiraecola Patch / Fusarium verticillioides (Sacc.) / Fusarium oxysporum Schltdl. /Fusarium poae /Fusarium nygamai/ Fusarium solani (Mart.) Sacc. / Fusarium redolens Wollenw. / Bipolaris sorokiniana (Sacc.) Shoemaker, / Phoma sp/ Monographella nivalis (Schaffnit) , Stemphylium,*	LE	Derbali et al. (2024)
Papaver rhoeas (L.)	*Hylobius abietis (Linnaeus)*	LE	Korczyński et al. (2007)
Euphorbia peplus (L.)	*Gonipterus platensis (Marelli)*	NM	Huerta et al. (2022)
Euphorbia bupleuroides Desf.	*Tribolium castaneum (H) Herbst / Trogoderma granarium (Everts)*	ST	Brik et al. (2021)
Ricinus communis (L.)	*Macrosiphum rosae (Linnaeus)*	LE	El Haddad et al. (2021)
	Plutella xylostella (Linnaeus)	LE/RO/SE	Kodjo et al. (2011)
	Tuta absoluta (Meyrick)	NM	Ait Taadaouit et al. (2012)
Mercurialis annua (L.)	*Tribolium confusum (J. Du Val)*	LE	Ben Nasr et al. (2021)
Aristolochia fontanesii Boiss. & Reut.	*Oryzaephilus surinamensis (Linnaeus)*	NM	Tail et al. (2017)
Plantago lanceolata (L.)	*Spodoptera littoralis (Bois.)*	ST	Pavela (2011)
Plantago lagopus (L.)	*Rhizoctonia napaeae Westend.*	NM	Behiry et al. (2022)
Scrophularia canina (L.)	*Culex pipiens (Linnaeus)*	AP	Giacinto et al. (2011)
Malva sylvestris (L.)	*Colletotrichum lindemuthianum (Sacc. & Magnus)*	LE	Pinto et al. (2010)
Althaea officinalis (L.)	*Alternaria spp*	LE	Maghsoodi et al. (2021)
Sambucus ebulus (L.)	*Tribolium confusum (J. Du Val)*	LE	Haghighian et al. (2005)
Scabiosa arenaria Forssk.	*Culex pipiens (Linnaeus)*	WP/FR	Hlila et al. (2017)
Borago officinalis (L.)	*Spodoptera littoralis (Bois.)*	LE	Hazaa et al. (2020)
	Myzus persicae (Sulzer)	LE	Fawaz et al. (2020)
Nerium oleander (L.)	*Chaitophorus leucomelas Koch*	LE	Zaid et al. (2021)
Oxalis pes-caprae (L.)	*Macrosiphum rosae (L) / Gynaikothrips ficorum (Marchal)*	LE/FL	Lachguer et al. (2021)

LE: Leaves, RO: Roots, WP: whole plant, ST: stem, FL: Flowers, AP: Arial partt, SE: Seeds, FR: Fruits, NM: not mentioned

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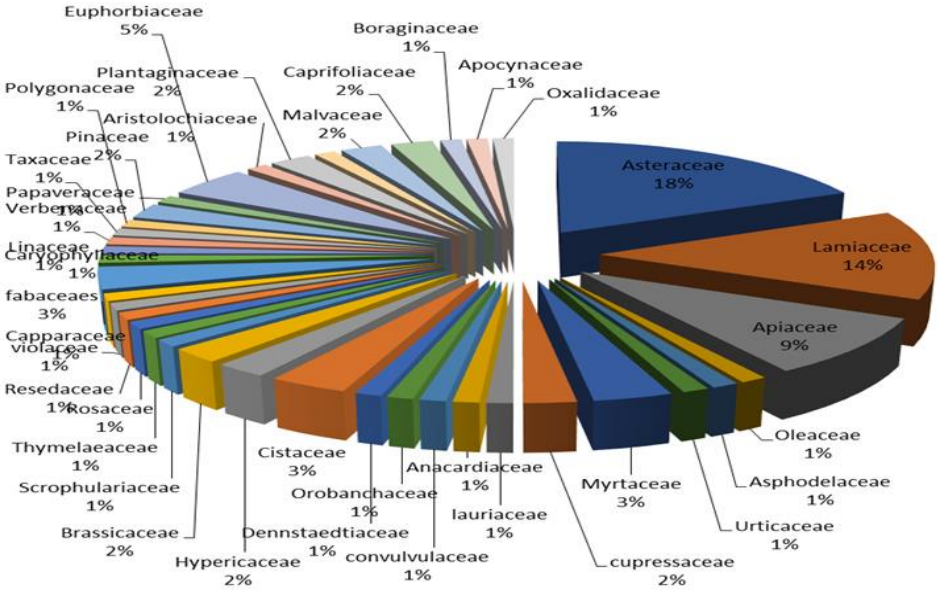

Figure 2. *Diagram of the distribution of botanical pesticides by families in the Blidian Atlas*

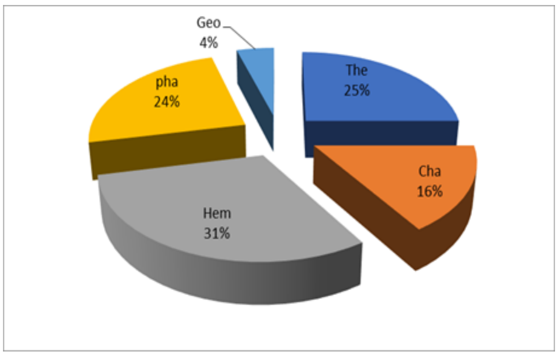

Figure 3. *Biological types of the species Inventoried*

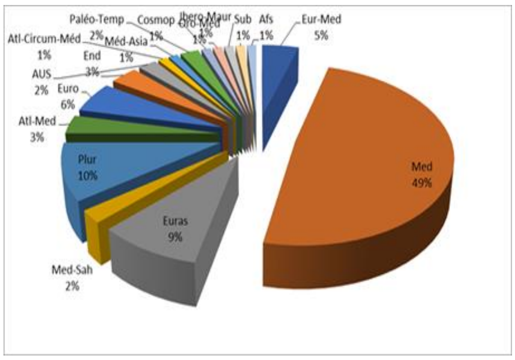

Figure 4*. Spectrum of phytogeological repartition of plants inventoried*

Table 2. *Shannon diversity indices in the different habitats*

	F.T	**M.T**	**W.T**	**F.ME**	**M.ME**	**W.ME**	**F.S**	**M.S**	**W.S**
Taxa_S	16	40	41	24	55	47	25	55	42
Shannon_H	3.24	4.18	4.20	3.66	4.5	4.34	3.7	4.5	4.23
Veg-zone		3.87			4.17			4.141	

F.T = forests thermo-Mediterranean, M.T = maquis thermo-Mediterranean, W.T = wastlands Thermo-Mediterranean, F.ME = forests meso-Mediterranean, M.ME = maquis meso-Mediterranean, W.ME = wastlands meso-Mediterranean, F.S = forests supra-Mediterranean, M.S = maquis supra-Mediterranean, W.S = wastlands supra-Mediterranean

Classification

The Ascending Hierarchical Classification (AHC) using the presence-absence Jaccard index identified six groups of species (*Fig. 5*). The group 1: comprised 52 species, including: *Ajuga iva*, *Althaea officinalis*, *Anacyclus clavatus*, *Aristolochia*

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paucinervis, Atractylis cancellata, Atractylis gummifera, Bellardia trixago, Carthamus lanatus, Ceratonia siliqua, Clinopodium nepeta, Clinopodium vulgare, Convolvulus lineatus, Coleostephus myconis, Daucus carota, Daphne gnidium, Dittrichia viscosa, Echinops spinosissimus, Erigeron canadensis, Eryngium tricuspidatum, Euphorbia bupleuroides, Eucalyptus camaldulensis, Eucalyptus globulus, Euphorbia peplus, Ferula communis, Hypericum humifusum, Hypericum perforatum, Juniperus oxycedrus, Lavandula stoechas, Linum bienne, Malva sylvestris, Mercurialis annua, Melilotus officinalis, Olea europaea, Oxalis pes-caprae, Papaver rhoeas, Pallenis spinosa, Pinus halepensis, Pistacia lentiscus, Plantago lagopus, Plantago lanceolata, Reseda alba, Rubus ulmifolius, Sambucus ebulus, Salvia verbenaca, Senecio vulgaris, Silene vulgaris, Sonchus asper, Sonchus oleraceus, Urtica dioica, Verbena officinalis, Verbascum sinuatum, and Viola odorata.

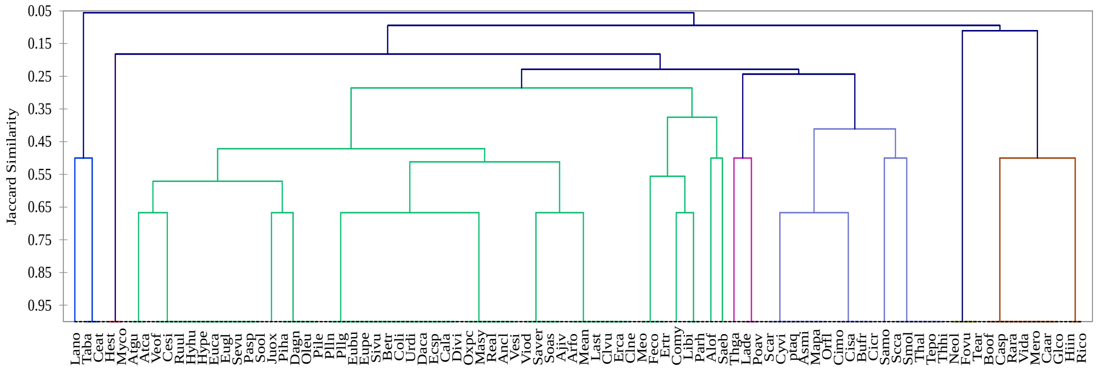

Figure 5. *Classification of the 88 species using the presence absence data and Jaccard similarity index*

Group 2 consisted of 9 species: *Borago officinalis, Calendula arvensis, Capparis spinosa, Glebionis coronaria, Hirschfeldia incana, Mentha rotundifolia, Raphanus raphanistrum, Ricinus communis,* and *Visnaga daucoides.*

Group 3, the least diverse, contained only two species: *Helichrysum stoechas* and *Myrtus communis.*

Group 4, the second largest, included the following species: *Asphodelus microcarpus, Bupleurum fruticosum, Cistus creticus, Cistus monspeliensis, Cistus salviifolius, Cytisus villosus, Mauranthemum paludosum, Origanum floribundum, Polygonum aviculare, Pteridium aquilinum, Satureja montana, Scabiosa arenaria, Scrophularia canina, Smyrnium olusatrum, Teucrium polium, Thymus algeriensis, Thapsia garganica,* and *Thymus hirtus.*

The fifth and sixth groups each contained three species: *Foeniculum vulgare, Nerium oleander, Tetraclinis articulata, and Cedrus atlantica, Laurus nobilis, and Taxus baccata.*

Correspondence analysis (CA)

To explore the relationship between species, habitats, and vegetation zones, we conducted a Correspondence Analysis (CA). Species were coded using the first two letters of the genus and the first two letters of the species. The results revealed that the first two axes (F1 and F2) explained 50.71% of the variance (*Fig. 6*), facilitating the identification of four distinct groups, each represented by a set of species sharing

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similar habitat. The first axis (F1) explained 27.94% of the variance, allowing for the differentiation of group 1 and group 2. Group 1 which was positively correlated with Axis F1, primarily consists of species from the forest habitat. The species in this group include: *Sonchus asper (Soas), Viola odorata (Viod), Ajuga iva (Ajiv), Salvia verbenaca (Save), Ceratonia siliqua (Cesi), Eucalyptus globulus (Eugl), Rubus ulmifolius (Ruul), Sonchus oleraceus (Sool), Eucalyptus camaldulensis (Euca), Senecio vulgaris (Sevu), Hypericum perforatum (Hype), Hypericum humifusum (Hyhu), Pallenis spinosa (Pasp), Verbena officinalis (Veof), Atractylis gummifera (Atgu), Atractylis cancellata (Atca), Satureja montana (Samo), Taxus baccata (Taba), Cedrus atlantica (Ceat), Laurus nobilis (Lano), Helichrysum stoechas (Hest), Myrtus communis (Myco), Juniperus oxycedrus (Juox), Pinus halepensis (Piha), Olea europaea (Oleu), Daphne gnidium (Dagn), and Pistacia lentiscus (Pile).*Group 2, which was negatively correlated with axis 1 (F1), was primarily composed of species found in the wasteland and maquis habitats across the three vegetation zones: Thermo-Mediterranean, Meso-Mediterranean, and Supra-Mediterranean. This group includes the following species: *Reseda alba (Real), Linum bienne (Libi), Papaver rhoeas (Parh), Nerium oleander (Neol), Foeniculum vulgare (Fovu), Tetraclinis articulata (Tear), Anacyclus clavatus (Ancl), Oxalis pes-caprae (Oxpc), Malva sylvestris (Masy), Verbascum sinuatum (Vesi), Silene vulgaris (Sivu), Convolvulus lineatus (Coli), Euphorbia peplus (Eupe), Euphorbia bupleuroides (Eubu), Bellardia trixago (Betr), Plantago lanceolata (Plln), Plantago lagopus (Pllg), Urtica dioica (Urdi), Daucus carota (Daca), Carthamus lanatus (Cala), Dittrichia viscosa (Divi), Echinops spinosissimus (Ecsp), Sambucus ebulus (Saeb), Melilotus officinalis (Meo), Ferula communis (Feco),* and *Eryngium tricuspidatum (Ertr).*

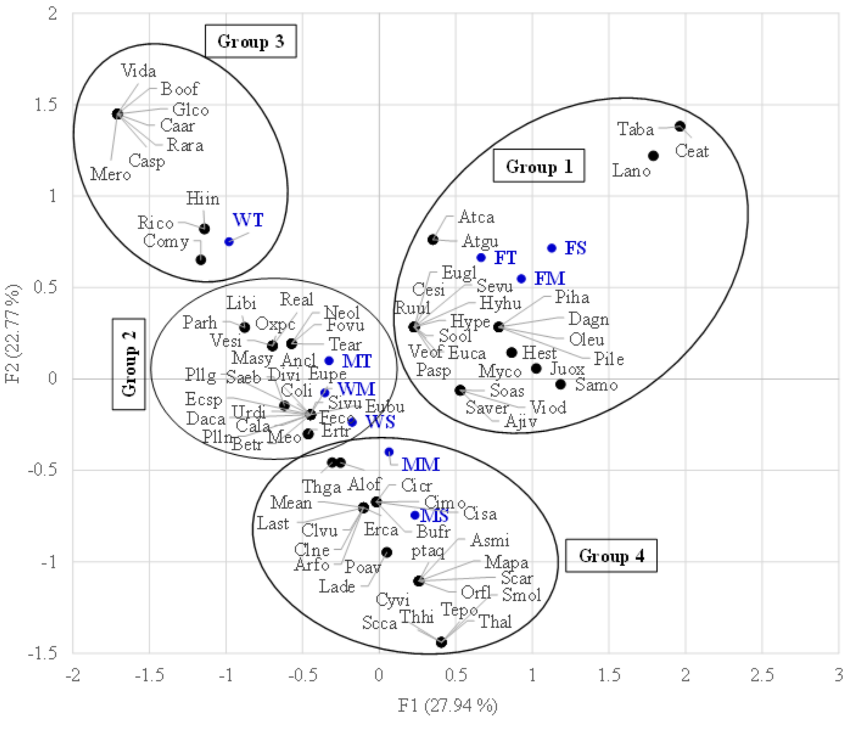

***Figure 6.** Plot (F1-F2) of the correspondence analysis (CA) conducted on a contingency table of 88 species, three habitats (Forest, Maquis, and Wasteland), and three vegetation zones (Thermo-Mediterranean, Meso-Mediterranean, and Supra-Mediterranean)*

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The second axis (F2) explained 22.7% of the variance and was positively correlated with Group 3, which consists of the following species: *Visnaga daucoides (Vida), Borago officinalis (Boof), Glebionis coronaria (Glco), Calendula arvensis (Caar), Raphanus raphanistrum (Rara), Capparis spinosa (Casp), Mentha rotundifolia (Mero), Hirschfeldia incana (Hiin), Ricinus communis (Rico),* and *Coleostephus myconis (Comy).* The species in this group were primarily found in the wastelands of the Thermo-Mediterranean zone. This axis was negatively correlated with Group 4, which was primarily found in the maquis of the Meso-Mediterranean and Supra-Mediterranean zones. The species in this group include: *Thapsia garganica (Thga), Althaea officinalis (Alof), Cistus creticus (Cicr), Cistus monspeliensis (Cimo), Cistus salviifolius (Cisa), Bupleurum fruticosum (Bufr), Mercurialis annua (Mean), Lavandula stoechas (Last), Clinopodium vulgare (Clvu), Clinopodium nepeta (Clne), Aristolochia paucinervis Pomel (Arfo), Erigeron canadensis (Erca), Pteridium aquilinum (Ptaq), Asphodelus microcarpus (Asmi), Mauranthemum paludosum (Mapa), Scabiosa arenaria (Scar), Origanum floribundum (Orfl), Smyrnium olusatrum (Smol), Cytisus villosus (Cyvi), Scrophularia canina (Scca), Thymus hirtus (Thhi), Teucrium polium (Tepo),* and *Thymus algeriensis (Thal).*

Discussion

The Blidian Atlas region, like many Mediterranean areas, is renowned for its rich biodiversity, which arises from a combination of complex ecological factors, including vegetation zones: thermo-Mediterranean, meso-Mediterranean, and supra-Mediterranean, as well as topographical and bioclimatic influences. Despite extensive studies on the chemical composition, medicinal properties, and antibacterial effects of essential oils from plants in Algeria and the Blidian Atlas (Mehalaine et al., 2017), research on botanical pesticides in the region remains limited. This study identified a total of 452 plant species from 74 botanical families. In comparison, a recent study by Ouelmouhoub and Benrima (2021) recorded only 104 taxa from 50 botanical families. Additionally, Aouadj et al. (2020) documented the presence of 25 endemic, 31 rare, and 9 protected taxa in the area.

Across Algeria, Zoubiri and Aoumeur (2011) identified 230 plants with pesticide properties and discussed the methodologies for evaluating their practical use. Among the inventoried species, 88 have been identified as botanical pesticides effective against pests and phytopathogens. The most common families included Asteraceae, Lamiaceae, and Apiaceae. Notable species in the study were *Pistacia lentiscus (L.), Daucus carota (L.), Eryngium tricuspidatum (L.), Ferula communis (L.), Smyrnium olusatrum (L.), Thapsia garganica (L.), Dittrichia viscosa (Greuter), Helichrysum stoechas (L.), Sonchus oleraceus (L.), Cistus salviifolius (L.), Cytisus villosus (Pourr.), Clinopodium vulgare (L.), Lavandula stoechas (L.), Eucalyptus camaldulensis (Dehnh.), Olea europaea var. sylvestris (Mill.), Cedrus atlantica (Manetti ex Endl.), Pinus halepensis (Mill.), Rubus ulmifolius (Schott), Scrophularia auriculata (L.), and Daphne gnidium (L.).*

The same botanical families were highlighted by Amokrane et al. (2023) and Fragkouli et al. (2023) as having significant pesticide potential. Acheuk et al. (2022) emphasized the active compounds in these families, such as alkaloids, phenols, essential oils, fatty acids, limonoids, and polyketides, and their mechanisms of action, which include toxicity, anti-feeding effects, and growth regulation. According to Fusar et al.

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(2024), the biopesticidal properties of these plants play a crucial role in the Euro-Mediterranean region, especially in countries like Tunisia, Spain, and Turkey.

The Lamiaceae family, which accounts for 14% of the inventory, was particularly notable for its essential oils, which possess antimicrobial and insecticidal properties, as highlighted by Salhi et al. (2010), and Adjou and Aoumanou (2013). Despite the large number of species within this family, its insecticidal potential remains largely underutilized.

Most of the species identified as botanical pesticides were hemicryptophytes (31%). According to Houessou et al. (2012) and Poveda et al. (2020), these species are known for their ability to withstand harsh climatic conditions. They are among the first to emerge in early spring and possess bioactive properties that help protect against certain parasites and infections. In contrast, in the semi-arid region of Chlef (Algeria), Amokrane et al. (2023) identified 47 plant species from 21 botanical families, with Lamiaceae, Asteraceae, Apiaceae, and Cupressaceae being the most prevalent. However, therophytes were the most common in this region, with 21 species predominating.

The species recorded in this area reflect a wide range of biogeographical origins, but the Mediterranean component predominates, making up 49% of the floral heritage. This is consistent with the study area's location within the Mediterranean basin and the findings of Ouelmouhoub and Benrima (2021).

Finally, most of the biopesticides recorded in this study were primarily effective against storage pests, such as *Tribolium castaneum*, *Sitophilus granarius*, *Tribolium confusum*, *Callosobruchus maculatus*, and *Sitophilus oryzae*. These pests pose significant challenges to grain preservation and result in substantial economic losses (Pascual-Villalobos et al., 1999; Haouas et al., 2014; Polatoğlu et al., 2017; Rotundo et al., 2019).

Conclusion

The Blidian Atlas region boasts a rich and diverse plant life, shaped by its unique ecological features, including a variety of bioclimatic and topographical conditions that foster the growth of many rare and endemic species. These wild plants are vital to the local ecosystem and possess significant therapeutic, aromatic, biopesticidal, and commercial potential. Our study identified 88 pesticidal plants from 38 botanical families, highlighting their importance for sustainable agriculture. The ongoing research into isolating and synthesizing the active components of these plants offers promising prospects for developing commercial biopesticides, which can be utilized to combat harmful pests, contributing to more robust and eco-friendly agricultural practices.

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APPENDIX

Appendix of some plant species recorded and their botanical families, some photos showing the sampled areas

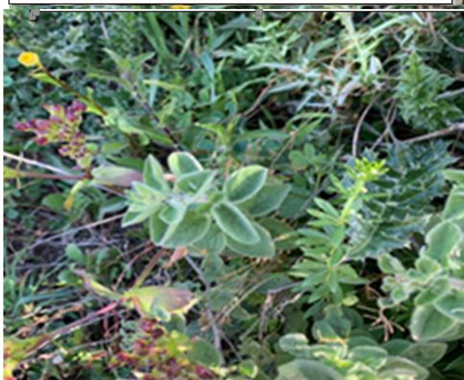
Lamiaceae

Mentha rotundifolia (L.) Huds.

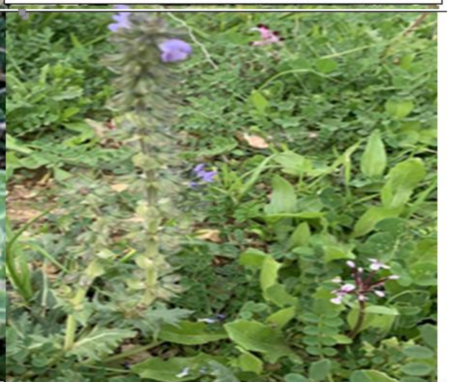
Clinopodium nepeta (L.) Kuntze

Teucrium polium L.

Lavandula stoechas L.



Origanum floribundum Munby



Salvia verbenaca L.

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Asteraceae

***Echinops spinosissimus* Turra**

***Atractylis gummifera* L.**

***Glebionis coronaria* (L.) Cass. ex Spach**

***Calendula arvensis* Boiss.**

Anacyclus clavatus

***Sonchus asper* (L.) Hill**

***Pallenis spinosa* (L.) Cass**

***Senecio vulgaris* L.**

***Carthamus lanatus* L**

***Atractylis cancellata* L.**

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Mauranthemum paludosum (Poir.)

Coleostephus myconis (L.) Rchb.f.

Helichrysum stoechas (L.) Moench

Dittrichia viscosa (L.) Greuter

Apiaceae

Daucus carota L.

Ferula communis L.

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Foeniculum vulgare Mill.

Eryngium tricuspidatum L.

Bupleurum fruticosum L

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Brassicaceae

Hirschfeldia incana (L.) Lagr.-Foss.

Raphanus raphanistrum L.

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Hypericaceae

Hypericum humifusum L.

Hypericum perforatum L

Asphodelaceae

Asphodelus microcarpus Rchb.

Capparaceae

Capparis spinosa L.

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Cistaceae

Cistus salviifolius L.

Cistus monspeliensis L.

Cistus creticus L.

Plantaginaceae

Plantago lagopus L.

Plantago lanceolata L.

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Myrtaceae

Eucalyptus camaldulensis Dehnh.

Oxalidaceae

Oxalis pes-caprae L.

Orobanchaceae

Bellardia trixago (L.) All

Fabaceaes

Cytisus villosus Pourr.

Convulvulaceae

Convolvulus lineatus L

Dennstaedtiaceae

Pteridium aquilinum (L.) Kuhn

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Verbenaceae

Verbena officinalis L

Polygonaceae

Polygonum aviculare L.

Cupressaceae

Tetraclinis articulata (Vahl) Mast.

Taxaceae

Taxus baccata L

Thymelaeaceae

Daphne gnidium L

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Pinaceae

Cedrus atlantica (Endl.) Manetti ex Carrière

Pinus halepensis Mill.

Malvaceae

Althaea officinalis L.

Malva sylvestris L.

Resedaceae

Reseda alba L

Euphorbiaceae

Mercurialis annua L.

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Caprifoliaceae

Sambucus ebulus L.

Papaveraceae

Papaver rhoeas L.

Lauriaceae

Laurus nobilis L.

Violaceae

Viola odorata L.

Aristolochiaceae

Aristolochia fontanesii Boiss.

Apocynaceae

Nerium oleander L.

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Scrophulariaceae

Scrophularia canina L.

Photos showing some sampled areas

Meso- mediterranean Maquis ***Supra- mediterranean Forest***

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Thermo-mediterranean Wasteland

APPENDIX 2

Bibliographic references in Table 1: Inventoried pesticide plants, used parts and target pests

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APPENDIX 3

Table of existence absence of plant species in the three habitats and the three vegetation stages

Species	T	M	S	FT	FM	FS	MT	MM	MS	WT	WM	WS
Ancl	1	1	0	0	0	0	1	1	0	1	1	0
Atgu	1	1	1	1	1	1	0	0	0	1	1	1
Atca	1	1	1	1	1	1	0	0	0	1	1	1
Caar	1	0	0	0	0	0	0	0	0	1	0	0
Cala	1	1	1	0	0	0	1	1	1	1	1	1
Comy	1	1	0	0	0	0	0	0	0	1	1	0
Divi	1	1	1	0	0	0	1	1	1	1	1	1
Ecsp	1	1	1	0	0	0	1	1	1	1	1	1
Erca	0	1	1	0	0	0	0	1	1	0	1	1
Glco	1	0	0	0	0	0	0	0	0	1	0	0
Hest	0	1	0	0	1	0	0	1	0	0	0	0
Mapa	0	1	1	0	0	0	0	1	1	0	0	0
Pasp	1	1	1	1	1	1	1	1	1	1	1	1
Soas	0	1	1	0	1	1	0	1	1	0	1	1
Sool	1	1	1	1	1	1	1	1	1	1	1	1
Sevu	1	1	1	1	1	1	1	1	1	1	1	1
Ajiv	0	1	1	0	1	1	0	1	1	0	1	1
Clne	0	1	1	0	0	0	0	1	1	0	1	1
Clvu	0	1	1	0	0	0	0	1	1	0	1	1
Last	0	1	1	0	0	0	0	1	1	0	1	1
Lade	0	0	1	0	0	0	0	0	1	0	0	1
Mero	1	0	0	0	0	0	0	0	0	1	0	0
Saver	0	1	1	0	1	1	0	1	1	0	1	1
Orfl	0	1	1	0	0	0	0	1	1	0	0	0
Samo	0	0	1	0	0	1	0	0	1	0	0	0
Tepo	0	0	1	0	0	0	0	0	1	0	0	0
Thhi	0	0	1	0	0	0	0	0	1	0	0	0
Thal	0	0	1	0	0	0	0	0	1	0	0	0
Bufr	1	1	1	0	0	0	1	1	1	0	0	0
Daca	1	1	1	0	0	0	1	1	1	1	1	1
Feco	0	1	1	0	0	0	0	0	0	0	1	1
Ertr	0	1	1	0	0	0	0	0	0	0	1	1
Vida	1	0	0	0	0	0	0	0	0	1	0	0
Fovu	1	0	0	0	0	0	1	0	0	0	0	0
Thga	0	0	1	0	0	0	0	0	0	0	0	1
Smol	0	0	1	0	0	0	0	0	1	0	0	0
Oleu	1	1	1	1	1	1	1	1	1	0	0	0
Asmi	0	1	1	0	0	0	0	1	1	0	0	0
Urdi	1	1	1	0	0	0	1	1	1	1	1	1
Myco	0	1	0	0	1	0	0	1	0	0	0	0

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Species	T	M	S	FT	FM	FS	MT	MM	MS	WT	WM	WS
Eugl	1	1	1	1	1	1	1	1	1	1	1	1
Euca	1	1	1	1	1	1	1	1	1	1	1	1
Juox	0	1	1	0	1	1	0	1	1	0	0	0
Tear	1	0	0	0	0	0	1	0	0	0	0	0
Lano	0	1	1	0	1	1	0	0	0	0	0	0
Pile	1	1	1	1	1	1	1	1	1	0	0	0
Coli	1	1	1	0	0	0	1	1	1	1	1	1
Betr	1	1	1	0	0	0	1	1	1	1	1	1
ptaq	0	1	1	0	0	0	0	1	1	0	0	0
Cicr	1	1	1	0	0	0	1	1	1	0	0	0
Cisa	1	1	1	0	0	0	1	1	1	0	0	0
Cimo	1	1	1	0	0	0	1	1	1	0	0	0
Hype	1	1	1	1	1	1	1	1	1	1	1	1
Hyhu	1	1	1	1	1	1	1	1	1	1	1	1
Rara	1	0	0	0	0	0	0	0	0	1	0	0
Hiin	1	0	0	0	0	0	1	0	0	1	0	0
Vesi	1	1	0	0	0	0	1	1	0	1	1	0
Dagn	1	1	1	1	1	1	1	1	1	0	0	0
Ruul	1	1	1	1	1	1	1	1	1	1	1	1
Real	1	1	0	0	0	0	1	1	0	1	1	0
Viod	0	1	1	0	1	1	0	1	1	0	1	1
Casp	1	0	0	0	0	0	0	0	0	1	0	0
Cyvi	0	1	1	0	0	0	0	1	1	0	0	0
Cesi	1	1	1	1	1	1	1	1	1	1	1	1
Meo	0	1	1	0	0	0	0	0	0	0	1	1
Sivu	1	1	1	0	0	0	1	1	1	1	1	1
Libi	1	1	1	0	0	0	0	0	0	1	1	1
Veof	1	1	1	1	1	1	1	1	1	1	1	1
Taba	0	0	1	0	0	1	0	0	0	0	0	0
Poav	0	0	1	0	0	0	0	0	1	0	0	1
Ceat	0	0	1	0	0	1	0	0	0	0	0	0
Piha	1	1	1	1	1	1	1	1	1	0	0	0
Parh	1	1	1	0	0	0	0	0	0	1	1	1
Eupe	1	1	1	0	0	0	1	1	1	1	1	1
Eubu	1	1	1	0	0	0	1	1	1	1	1	1
Rico	1	0	0	0	0	0	1	0	0	1	0	0
Mean	0	1	1	0	0	0	0	1	1	0	1	1
Arfo	0	1	1	0	0	0	0	1	1	0	1	1
Pllg	1	1	1	0	0	0	1	1	1	1	1	1
Plln	1	1	1	0	0	0	1	1	1	1	1	1
Scca	0	0	1	0	0	0	0	0	1	0	0	0
Masy	1	1	0	0	0	0	1	1	0	1	1	0
Alof	0	1	0	0	0	0	0	1	0	0	1	0
Saeb	0	1	0	0	0	0	0	0	0	0	1	0

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Species	T	M	S	FT	FM	FS	MT	MM	MS	WT	WM	WS
Scar	0	1	1	0	0	0	0	1	1	0	0	0
Boof	1	0	0	0	0	0	0	0	0	1	0	0
Neol	1	0	0	0	0	0	1	0	0	0	0	0
Oxpc	1	1	0	0	0	0	1	1	0	1	1	0

T: Thermo-medeterranean
M:Meso-medeterranean
S:Supra-medeterranean

Forest Thermo-medeterranean
Forest Meso-medeterranean
Forest supra-medeterranean

Maquis Thermo-medeterranean
Maquis Meso-medeterranean
Maquis supra-medeterranean

wasteland Thermo-medeterranean
wasteland Meso-medeterranean
wasteland supra-medeterranean

Taxa_S	16	40	41	24	55	47	25	55	42
Individuals	16	40	41	24	55	47	25	55	42
Dominance_D	0	0	0	0	0	0	0	0	0
Simpson_1-D	1	1	1	1	1	1	1	1	1
Shannon_H	3.241	4.176	4.201	3.657	4.498	4.34	3.699	4.498	4.226
Evenness_e^H/S	1.598	1.628	1.629	1.615	1.634	1.631	1.616	1.634	1.629
Brillouin	1.917	2.758	2.781	2.283	3.06	2.911	2.32	3.06	2.804
Menhinick	4	6.325	6.403	4.899	7.416	6.856	5	7.416	6.481
Margalef	5.41	10.57	10.77	7.237	13.48	11.95	7.456	13.48	10.97
Equitability_J	1.169	1.132	1.131	1.151	1.123	1.127	1.149	1.123	1.131
Fisher_alpha	0	0	0	0	0	0	0	0	0
Berger-Parker	0.0625	0.025	0.02439	0.04167	0.01818	0.02128	0.04	0.01818	0.02381
Chao-1	128.5	800.5	841	288.5	1513	1105	313	1513	882.5
iChao-1	128.5	800.5	841	288.5	1513	1105	313	1513	882.5
ACE	128.5	800.5	841	288.5	1513	1105	313	1513	882.5

This paper has also an electronic APPENDIX 4.

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