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The Influence of Groves on Aboveground Arthropod Diversity and Evolution in a Vineyard in Southern Romania

Diana Elena Vizitiu [1], Ionela-Daniela Sardarescu [1], Elena Cocuta Buciumeanu [1], Ionela-Cătălina Guta [1], Lucian Dincă [2], Flavius Bălăcenoiu [2,*], Dragoș Toma [2,3], Vlad Crișan [2] and Alin Din [1]

1 National Research and Development Institute for Biotechnology in Horticulture, 37 Bucharest-Pitești Road, 117715 Stefanesti, Romania; diana.vizitiu@incdbh-stefanesti.ro (D.E.V.); ionela.sardarescu@incdbh-stefanesti.ro (I.-D.S.); elena.buciumeanu@incdbh-stefanesti.ro (E.C.B.); ionelacatalina.guta@incdbh-stefanesti.ro (I.-C.G.); din.alin96@yahoo.com (A.D.)

2 National Institute for Research and Development in Forestry "Marin Dracea", Eroilor 128, 077190 Voluntari, Romania; lucian.dinca@icas.ro (L.D.); dragos.toma@icas.ro (D.T.); vlad_emil.crisan@icas.ro (V.C.)

3 Faculty of Silviculture and Forest Engineering, Transilvania University of Brașov, Sirul Beethoven 1, 500123 Brașov, Romania

* Correspondence: flavius.balacenoiu@icas.ro

Abstract: This paper investigates the biodiversity of adult arthropods in two grapevine plantations influenced by two adjacent groves over a three-year period (2020–2022) in the viticultural center of Stefănești Argeș, located in southern Romania. The study holds significant implications for introducing parasitoid/predatory insect species into vineyards to control grapevine pests. A total of 164 arthropod species were identified, including 27 beneficial species. Additionally, two moth species, *Lobesia botrana* and *Sparganothis pilleriana*, were identified. *L. botrana* was consistently observed throughout the study, while *S. pilleriana* was only observed in 2022. The research reveals that the location with the highest number of identified species was in a grove near a black field, with 103 species. Other areas with notable species diversity included a vineyard maintained as a black field (89 species), a grove near permanent natural grassland (88 species), and a vineyard with intervals between rows of grapevines maintained as natural permanent grassland (81 species). Introducing beneficial organisms, such as the predator *Crysoperla carnea*, is recommended to control grapevine moths in this ecosystem.

Keywords: *Vitis*; insect; spider; parasitoid; predators

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1. Introduction

Grapevine (*Vitis vinifera* L.) occupies large areas all over the world, as it is a culture of significant economic importance [1]. This species is one of the main fruit crops worldwide. In 2020, the total surface area planted with grapevine globally was estimated at 7.3 million hectares [2]. In Romania, 243,000 ha are cultivated with grapevine (Study of International Trade of Agricultural and Connected Products in Romania); this represents 3.328% of the global vineyard area and 1.8% of Romania's cultivated land. Romania has favorable conditions for the growth and fruiting of grapevines [3] and is internationally recognized for the quality of its wine products [4].

The viticultural biocoenosis consists of populations that include green plants (grapevines, intercrops, and weeds), fungi, bacteria, viruses, insects, and other living things of plant or animal nature. Such territorially linked population groups are functionally independent. Biocoenosis is formed and limited by natural environmental conditions. Viticultural biocoenosis is anthropogenic and simpler than natural forms of biocoenosis (such as meadows and forests) because it consists of only one primary producer (grapevine). The simplicity of grapevine biocoenosis makes it vulnerable both to climatic adversities and those produced by diseases, insects, bacteria, and viruses [5]. Ecosystem functioning results from the sum of the interactions of all organisms (biodiversity) and from factors related to the system, water, soil, and climate [6]. Agricultural systems cannot survive major disruptions due to their lack of diversity and structure [7]. The biodiversity of natural ecosystems can also be the key to sustainable agricultural production and food security. There is evidence that species-rich ecosystems are more stable than species-poor ecosystems [8].

Grapevine pests include several species of insects, mites, and nematodes. The presence of pest insects can result in serious economic damage due to their effects on the quality and quantity of grapes [9]. These pest insects may attack different plant parts such as roots, buds, berries, or leaves [10]. Species diversity in viticultural ecosystems ensures the circulation of material and the energy flow; diversity thus contributes to recycling in these ecosystems. Insects, therefore, play an important role in the functioning of viticultural ecosystems, and grapevine agrotechnology influences biodiversity with regard to both useful and arthropod pest species; this can be measured through the use of diversity indices [11]. Variations in population dynamics are affected by beneficial insects (natural enemies of insect pests), the abundance of which changes over the course of the growing season, with each species contributing more or less to overall pest control [12]. The types and behaviors of herbivorous insects present in vineyards are influenced by environmental temperature [10,13,14]. Monitoring arthropods under current climatic conditions can enhance our understanding of vineyard biodiversity [10].

Harvest losses seem to be lower in traditional agriculture (which uses more ecologically sound and sustainable practices) than in modern industrial agriculture [15,16]. In agriculture and forestry, Lepidoptera is one of the main groups of dangerous insects, and the principal orders of parasitoid insects are Hymenoptera and Diptera [17]. Parasitoids regulate the abundance of phytophagous arthropods [18]. Several parasitoid species can be used for the control of Lepidoptera pests. These include *Trichogramma galloi*, *T. pretiosum*, *T. evanescens*, *T. cacaeciae*, and *T. minutum* [19]. Parasitoids and predators that can control grape pests are very diverse. The arthropod predators of *Lobesia botrana* and *Eupoecilia ambiguella* have been divided into occasional and regular predators. Predators of grapevine moths include a wide range of species such as lacewings (*Chrysopa perla*, *Chrysoperla carnea*, *C. lucasina*, *C. affinis*, *Dichochrysa flavifrons*, and *D. prasina*), true bugs (Miridae, Anthocoridae, Nabidae, and Reduviidae), syrphids (*Xanthandrus comtus*), and spiders [20]. To control the *Sparganothis pilleriana* moth, the following species can be used: *Pimpla rufipes*, *Phytodietus ornatus*, *P. polyzonias*, *Diadegma contractum*, *D. holopygum*, *Colpoclypeus florus*, *Elasmus viridiceps*, *Catolaccus ater*, *Eupelmus vesicularis*, and *Nemorilla maculosa* [21].

Pesticides are used to control the *L. botrana* moth; however, an alternative is provided by beneficial organisms like the native natural enemies of this moth that exist in the ecosystem. For this biological control to be successful, it is essential to know the identity of these natural enemies and whether they are present in the ecosystem [22].

The purpose of this work is to survey adult arthropod diversity in two grapevine plantations with two adjacent groves over a period of three consecutive years in the Stefanesti Arges vineyard, located in southern Romania. This is important to know in order to introduce parasitic and predatory insects used in grapevine moths' control into the ecosystem.

2. Materials and Methods

2.1. Study Site and Data Collection

Adult arthropod monitoring was performed in 2020–2022 in grapevine plantations belonging to the National Research and Development Institute for Biotechnology in Horticulture at Stefanesti–Arges, southern Romania (Figure 1). The vineyard plantations were 25 years old, with 2.4 m between rows and a 15 m distance between plants within each row. The Guyot cutting system was in use at the plantations.

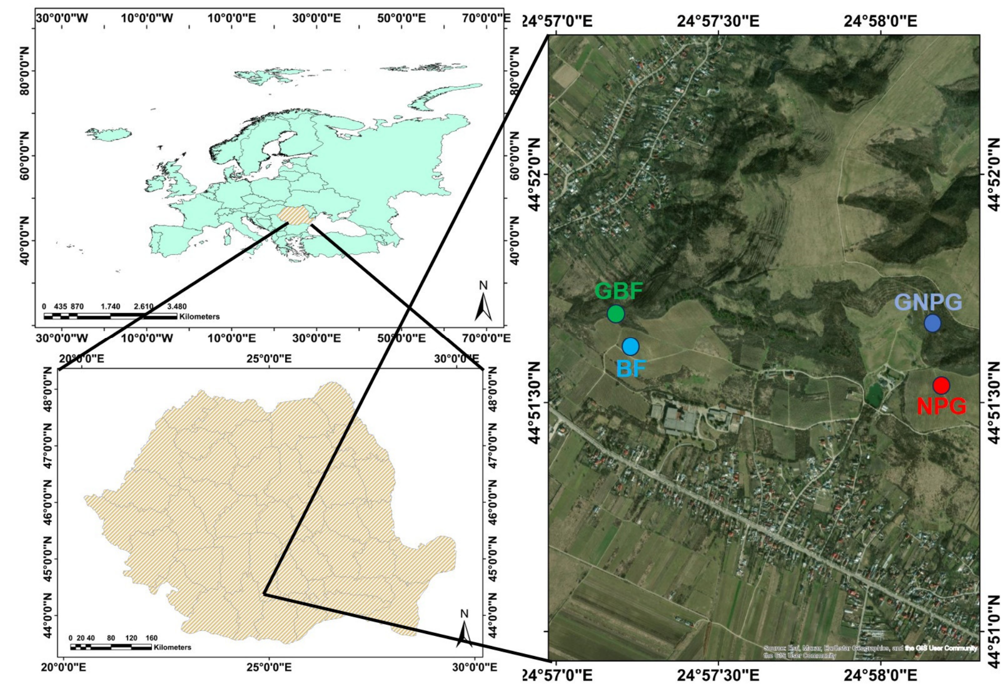

Figure 1. Location of the study area (Esri, Maxar, Earthstar Geographics, and the GIS User Community).

Yellow sticky traps were placed on a weekly basis from 1 July to 30 September (BBCH scales: 73–89) for three years, allowing arthropods to be monitored in four lots: a vineyard maintained as a black field (maintained with periodic plowing of the row intervals, BF), a grove near the black field (GBF), a vineyard where the row intervals were maintained as natural permanent grassland (NPG), and a grove near natural permanent grassland (GNPG).

The following weed species were identified by us in the NPG vineyard: *Equisetum arvense*, *Convolvulus arvensis*, *Polygonum convolvulus*, *Alopecurus myosuroides*, *Amaranthus retroflexus*, *Setaria glauca*, *S. viridis*, *Galium aparine*, *Chenopodium album*, *Apera spica-venti*, *Sonchus arvensis*, *Stenactis annua*, *Polygonum aviculare*, *Agrostis alba*, *Erigeron canadensis*, *Echinochloa crus-galli*, *Rumex obtusifolius*, *Agropyron repens*, *Calamagrostis epigejos*, *Cirsium arvense*, *Matricaria inodora*, *Lamium album*, *L. purpureum*, *Xanthium strumarium*, *Sorghum halepense*, *Taraxacum officinale*, *Veronica hederifolia*, *Avena fatua*, *Poa pratensis*, *Cardaria draba*, *Agropyron repens*, *Digitaria sanguinalis*, *Senecio vulgaris*, *Stachys annua*, *Matricaria chamomilla*, *Daucus carota*, and *Dactylis glomerata*.

The GBF and GNPG groves mainly contained *Crataegus monogyna*, *Robinia pseudoacacia*, *Rosa canina*, *Prunus spinosa*, *Quercus robur*, *Prunus padus*, *Fagus sylvatica*, *Carpinus betulus*, and *Alnus glutinosa*.

Tetratrap pheromone traps were also placed in the vineyards during the same period to monitor specific grapevine pests. These were the atraBOT (for *L. botrana)*, atraAMBIG (for *E. ambiguella*), and atraPILL (for *Sparganothis pilleriana*) traps produced by the Pheromone Production Center at the Raluca Ripan Institute for Research in Chemistry, Babes Bolyai University, Romania. These traps are based on the attraction exerted by the sex pheromone capsules emitted by female *L. botrana*, *E. ambiguella,* and *S. pilleriana;* males are captured via fixation to an adhesive surface. The traps were inspected once a week, and the captured adults were counted, noted, and removed from the adhesive valve. At the same time, any plant that remained stuck to the adhesive valve was also removed. In the period 2020–2022, no insecticides were applied.

An IPM-scope digital microscope (Spectrum Technologies, Aurora, IL, USA) and an Optika SZM-2 trinocular stereomicroscope equipped with an Optika CP-8 photo camera (Optika, Ponteranica, Italy) were used for arthropod identification.

2.2. Data Analysis

As an initial step, we examined the data distribution for normality using Shapiro-Wilk tests and evaluated variance homogeneity with Levene's test. Once these assessments confirmed the data's adherence to the assumptions of a normal distribution and homogeneity of variance, the conditions for conducting parametric tests were met. In order to ascertain whether crop types exert an influence on species richness and individual abundance, we conducted a variance analysis using the One-Way ANOVA test. Significance levels were established using Tukey's multiple test.

We conducted a Rarefaction Curve Analysis to assess the sufficiency of sampling intensity in identifying arthropod species and to compare the expected species richness among the four crops studied over three years. This analysis utilized the total number of individuals captured in traps as a basis for comparison.

To highlight significant differences in the ecological structure of arthropods, revealing distinct groups based on arthropod orders and crop types, we conducted a Two-Way Cluster Analysis, along with the use of the Bray–Curtis dissimilarity.

The data analysis was carried out using STATISTICA 8.0 (StatSoft, Inc., Tulsa, OK, USA) and PAST 4.03 [23]. The presence of the detected species in one or more of the four crops was illustrated using Venn diagrams (VIB/UGent).

3. Results

In the three years of the study, 164 species of arthropods were identified. Most of them were common to the four lots (Figure 2). The highest number of species was recorded in GBF (103 species), followed by GNPG (89 species), BF (88 species), and NPG (82 species) (Table A1). However, some insect species were present only in one lot: the largest number of unique species was identified in GBF (30 species), followed by BF (16), NPG (14), and GNPG (10).

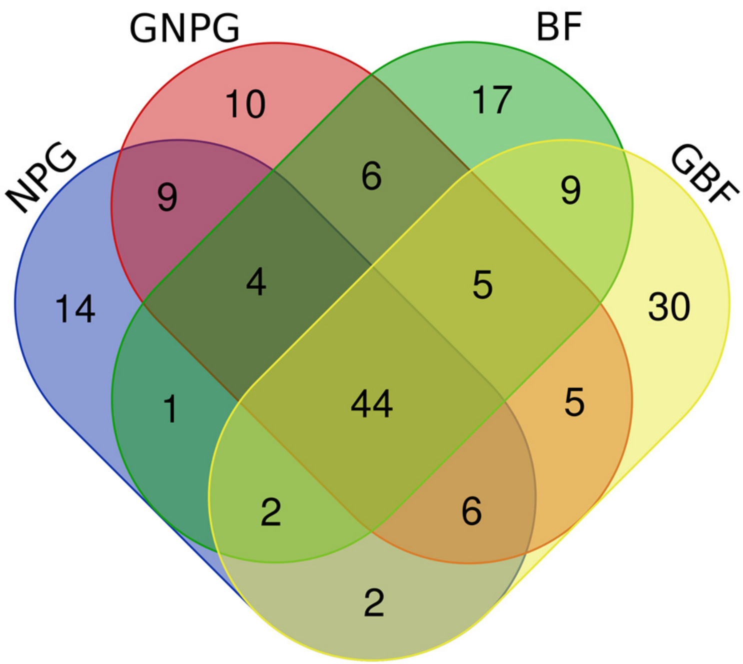

Figure 2. Occurrence of 164 species of arthropods detected in the four crops.

However, when analyzing the number of species based on the type of crop, we observe that there are no significant differences between them (Figure 3).

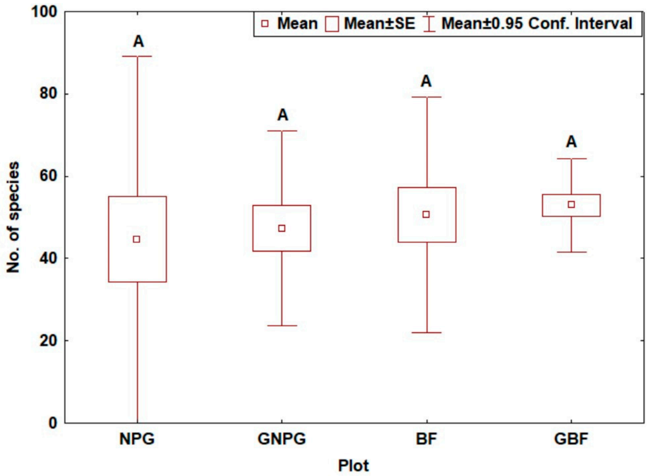

Figure 3. Variation in the number of species across different types of crops: a black field (BF), a grove near the black field (GBF), a natural permanent grassland (NPG), and a grove near the natural permanent grassland (GNPG). The differences between means labeled with the same letters (A) are not statistically significant ($p > 0.05$).

The arthropods identified in the four ecosystems belonged to 13 orders. Only four major orders are presented in Figure 4, while the remaining ones, which were underrepresented, have been grouped into a larger category labeled "other orders." The number of orders was almost the same in each of the four ecosystems: 12 orders were found in NPG, 11 in GBF, and the same number of orders was recorded for BF and GNPG (10 orders). The orders Coleoptera, Diptera, Hymenoptera, Araneae, Mecoptera, Hemiptera, Orthoptera, Neuroptera, Dermaptera, and Lepidoptera were present in all four ecosystems.

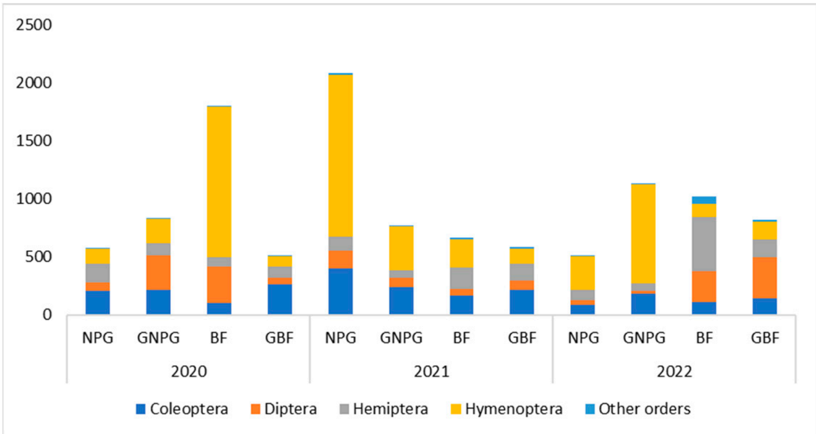

Figure 4. Distribution of arthropod orders in four different ecosystems: a black field (BF), a grove near the black field (GBF), a natural permanent grassland (NPG), and a grove near the natural permanent grassland (GNPG).

Of the 164 species identified in the four lots, 27 are considered beneficial (Table A2). Of the 27 beneficial species, 15 were found in all lots.

Regarding species richness across different crop types (Figure 5), in 2020, GBF exhibited the highest species diversity. In 2021, cultures GNPG, BF, and GBF displayed similar levels of species richness, while NPG recorded the highest species diversity. In 2022, the rarefaction curves of BF and GBF showed similarities, indicating higher species richness compared to cultures NPG and GNPG.

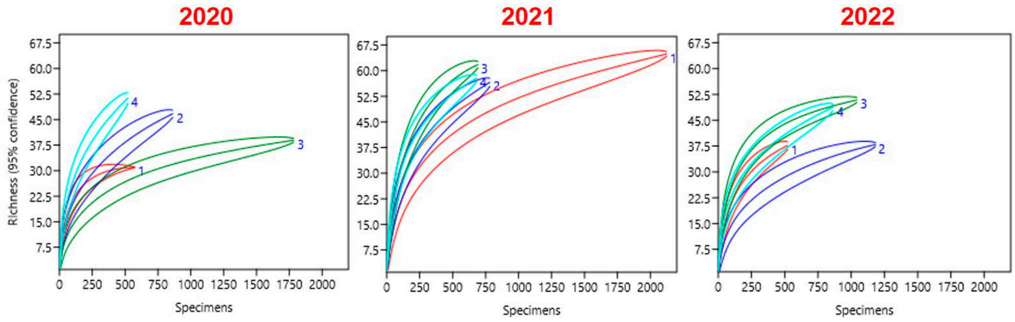

Figure 5. Crop-specific changes in species richness over a three-year period (2020–2022). With 1 = NPG; 2 = GNPG; 3 = BF; 4 = GBF.

When it comes to species richness over time, the rarefaction curves suggest an adequate sampling effort to characterize the arthropod populations, with all three curves approaching or reaching asymptotes in all three years (Figure 6). The years 2020 and 2021 exhibited similar arthropod richness compared to 2022, which displayed higher species diversity.

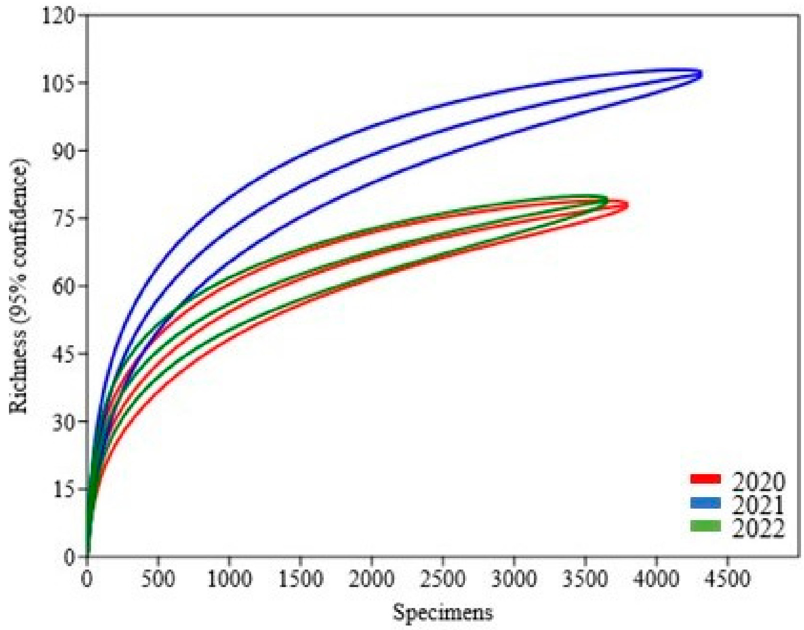

Figure 6. Temporal dynamics of species richness across three years (2020–2022).

Notable variations and differences were observed in their ecological structure over time and among crop types when the biodiversity indices of arthropods were analyzed (Table 1). According to the Shannon index, the highest diversity was recorded in GBF in all three years, while the lowest diversity varied between the years 2020 (BF), 2021 (NPG), and 2022 (GNPG). However, the Simpson index and evenness indicate that, although GBF exhibited high diversity, the evenness of species distribution was relatively low in all three study years. In contrast, the highest evenness of species distribution was observed in 2020 (BF), 2021 (NPG), and 2022 (GNPG).

Table 1. Temporal variation in biodiversity indices for different crop types.

Year	Crop	No. of Species	Individuals	Biodiversity Index				
				Shannon–Wiener	Simpson	Evenness	Margalef	Berger-Parker
2020	NPG	31	588	2.636	0.8831	0.4501	4.705	0.2517
	GNPG	47	878	2.533	0.86	0.2678	6.787	0.3007
	BF	39	1796	1.566	0.5652	0.1227	5.071	0.6487
	GBF	52	539	3.032	0.9267	0.3986	8.108	0.141
2021	NPG	65	2134	1.935	0.6085	0.1066	8.349	0.6195
	GNPG	57	798	2.603	0.8044	0.2368	8.381	0.4211
	BF	62	705	2.939	0.8758	0.3047	9.301	0.3007
	GBF	58	690	3.182	0.933	0.4152	8.72	0.1348
2022	NPG	38	539	2.258	0.7531	0.2517	5.883	0.4768
	GNPG	38	1190	1.467	0.5109	0.1141	5.225	0.6924
	BF	51	1057	2.793	0.8625	0.3201	7.181	0.3359
	GBF	49	876	2.823	0.9048	0.3434	7.084	0.2158

In terms of species richness within the four crops over the three years, according to the Margalef index, all areas recorded a relatively high level; however, the highest species diversity was recorded in the year 2021 across all sample areas. Similarly to the Evenness and Simpson indices, the highest values recorded using the Berger-Parker index are in the areas where the Shannon index value is the lowest. This indicates that the communities of aboveground insects were moderately dominated in those respective areas by the common species.

The data analysis highlights that the orders Diptera and Hemiptera exhibit similar group structures, while Hymenoptera significantly differentiates from the other orders (Figure 7). Regarding the types of crops, GBF forms a distinct cluster, while GNPG and NPG are more similar to each other. These differences can be primarily attributed to the high number of individuals from the Hymenoptera order observed in NPG and BF, where over a thousand specimens were captured. For the orders Diptera, Hemiptera, Coleoptera, and the remaining orders, the capture rate is generally in the hundreds of individuals, regardless of the crop type.

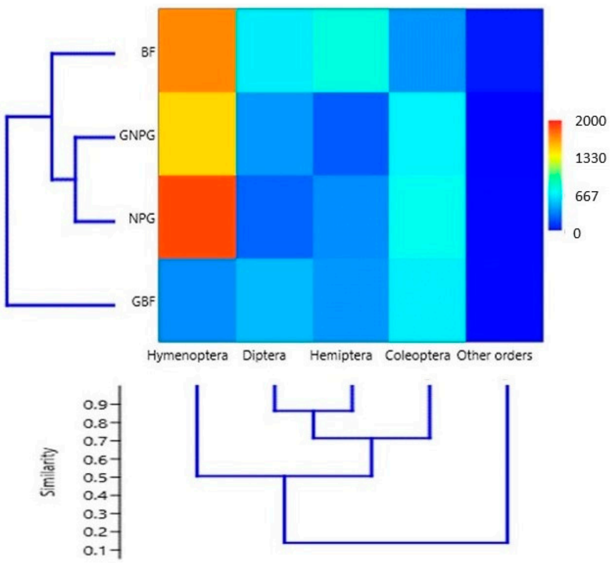

Figure 7. Exploring crop-arthropod relationships: a Two-Way Cluster Analysis.

Although the data analysis reveals that in most cases, the order Hymenoptera had the highest number of individuals, a more detailed description of these differences is provided via the Analysis of Variance (Figure 8):

- In the case of NPG, the insects captured from the order Hymenoptera were significantly more numerous than those in the "other orders" group ($p < 0.05$) but not significantly different from Coleoptera, Diptera, and Hemiptera ($p > 0.05$).
- For GNPG, the insects captured from the Hymenoptera group were significantly more numerous than those in Diptera, Hemiptera, and other orders ($p < 0.05$) but not significantly different from those in Coleoptera ($p > 0.05$).
- Regarding BF, there were no significant differences ($p > 0.05$) in the number of individuals captured among the five orders.
- In GBF, the insects captured from the Diptera and Coleoptera groups were significantly more numerous ($p < 0.05$) than those in the "other orders" group but not significantly more numerous ($p > 0.05$) than those in Hemiptera and Hymenoptera.

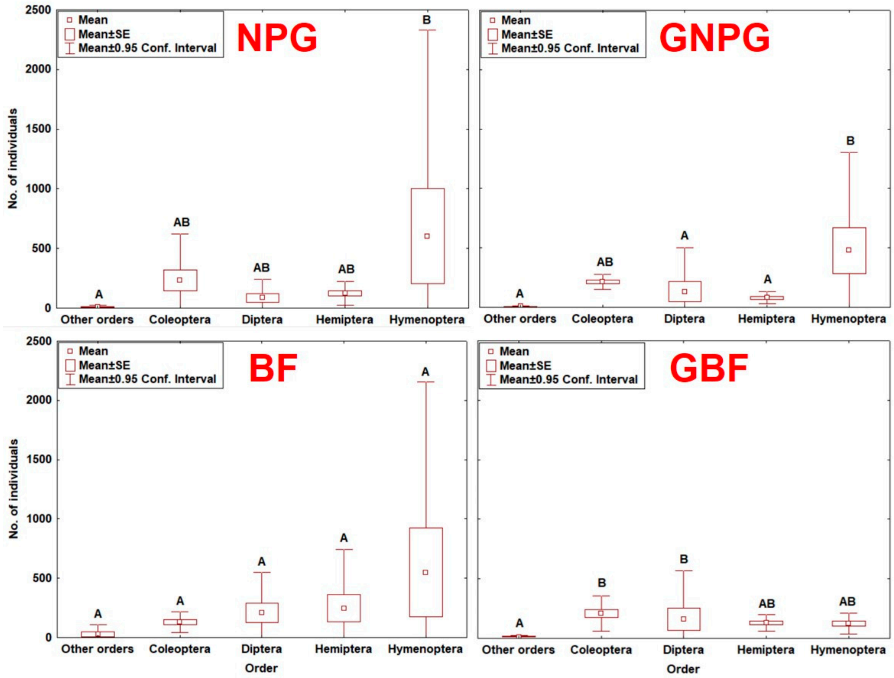

Figure 8. Crop type influence on arthropod order abundance. The differences between means labeled with the distinct letter are statistically significant ($p < 0.05$).

4. Discussion

This research aimed to assess the impact of groves on arthropod diversity and evolution in a vineyard located in southern Romania. Our objective was to examine how the presence and types of groves influence the composition, abundance, and diversity of arthropods in this specific viticultural environment.

Over the course of three years of study, we meticulously identified and documented 164 species of arthropods that played a significant role in the vineyard ecosystem. This research involved the collection and analysis of field data in four distinct lots: Black Field (BF), Grove near Black Field (GBF), Natural Permanent Grassland (NPG), and Grove near Natural Permanent Grassland (GNPG).

Despite the presence of common species across all four research lots, the surrounding environment significantly impacts arthropod diversity within this vineyard ecosystem. The fact that the Grove near Black Field (GBF) recorded the highest number of species suggests that the specific type of grove in this lot may provide additional habitat or resources for the respective arthropods.

The identification of unique species in each lot represents an intriguing discovery, highlighting that these unique species can be considered indicators of adaptation and preferences among arthropods for the different conditions offered in various types of groves.

The orders Hymenoptera, Coleoptera, Diptera, and Hemiptera consistently dominated in abundance throughout the study, but significant variations were observed between the research years. The absence of the Mecoptera and Dermaptera orders in 2020 suggests seasonal influences or natural fluctuations in biodiversity. These findings provide a complex understanding of the interaction between groves and vineyard arthropods and can serve as a foundation for conservation and biodiversity management strategies in similar vineyard environments.

The results of the present study indicate significant differences in terms of insect species diversity within the same ecosystem, with the highest number of species identified in the Grove near Black Field (GBF) and the fewest in the Natural Permanent Grassland (NPG). The order Coleoptera predominated in all four ecosystems, while fewer species were found in the orders Scutigeromorpha, Odonata, and Mantodea.

However, in terms of abundance, the order Hymenoptera exhibited the highest predominance across all four ecosystems. This order included species such as *Vespula vulgaris*, *Figitidae* sp., and *Vespula germanica*, which recorded the highest number of individuals.

It is noteworthy that species from the genus *Vespula* play diverse roles within the ecosystem, ranging from limiting the spread of other invasive species by capturing pestiferous insects to potentially contributing to the transmission of plant diseases after feeding on crops such as grapevines. These findings highlight the complexity of interactions between arthropods and the vineyard environment, emphasizing the need for careful management of these species to protect vineyard crops. *Vespula* spp. are known as predators of pestiferous flies and may play a role in limiting the spread of other invasive species. *Vespula* spp. can also promote plant diseases after feeding on crops such as grapevine. Members of *V. germanica* attack beehives and contribute to fruit deterioration [24]. The members of another species of the genus *Vespula*, *V. vulgaris*, sting grapes, eat the contents, and leave only the peel; the affected grapevine is later attacked by fungi or bacteria [25]. In spite of that, some wasps are a crucial vector of the yeast species used in the winemaking process [26]. For instance, *Polistes*, *Vespa*, and *Vespula* play an essential role in the *Saccharomyces cerevisiae* yeast ecology, responsible for must fermentation in the winemaking process [27]. In the ecosystems where there was other vegetation adjacent to the grapevines, the largest number of individuals belonged to the Figitidae family. This is a parasitoid family [28] that parasitizes aphids and fruit flies [29]. Other Hymenoptera species found in the studied ecosystems included *T. femorata*, a beetle-killing wasp [30] which parasitizes *Phyllopertha horticola* larvae at the same time supplementing this food with pollen [31], and *A. subopaca*, which feeds on the pollen of different plant species [32].

Biodiversity is essential for crop defense: the more diverse the plants, animals, and soil organisms in a farming system are, the more diverse the community of beneficial organisms that fight pests is [33].

The Simpson and Shannon indices determine species diversity based on species richness and evenness of abundance. The Simpson index tends to be more sensitive to the predominant species from the community than the Shannon index [34,35]. The Shannon diversity index represents species abundance and evenness, with values ranging from 0 to 4. The Margalef index is a biodiversity index that indicates the species richness within a community and is sensitive to sample size [36]. Index values increase as community richness and evenness increase, and higher values indicate that richness is evenly distributed among species [37]. The Berger-Parker index, considered one of the best diversity indices [38], expresses the proportional importance of the most abundant species within a community [39]. It can also be used as an indicator of biodiversity under human influence [40]. Although the use of a soil maintenance system, which includes plants from spontaneous flora, is beneficial for attracting beneficial species [41], it seems that, in the studied vineyard area, it creates favorable conditions for the development of grapevine moths.

L. botrana, the European grapevine moth, perturbs grapevine and other economically important species [42]; it is one of the main grape pests [43,44] and causes extensive economic losses [22]. Specific insects that are found in agricultural land are essential indicators of the health of agroecosystems and are vital for agricultural production and food security (The 2030 EU Biodiversity Strategy). The urgent need to reduce reliance on pesticides and reverse biodiversity decline ('Farm to Fork' Strategy) compels us to find alternative ways to combat horticultural crop pests. For instance, parasitoid species can be used to control the *L. botrana* moth, such as: *Actia pilipennis*, *Bessa parallela*, *Clemelis massilia*, *Elodia morio*, *Eurysthaea scutellaris*, *Nemorilla maculosa*, *Neoplectops pomonellae*, *Phytomyptera nigrina*, *Pseudoperichaeta nigrolineata* [17]; *Trichogramma cacoeciae*, and *T. daumalae*, *Campoplex capitator*, Ichneumonidae, *Elachertus affinis*, Chalcidoidea, *Brachymeria* sp., Elasmidae, *Ascogaster quadridentada*, Bethylidae, Tachinidae [45,46]. At the same time, microbial insecticides can also be used, and the interruption of mating can be achieved using volatile attractants [47]. Biological control based on parasitoids and predators could be developed as a valuable alternative to chemical pest control in viticulture [20].

5. Conclusions

In the three years of this study, 164 species of arthropods were identified. Most of them were common to the four lots. The location with the highest number of species was found in a grove near a grapevine plantation maintained as a black field (103 species), followed by a vineyard maintained as a black field (89 species), a grove near natural permanent grassland (88 species), and a vineyard maintained with natural permanent grassland (82 species).

Of the one hundred and sixty species identified in the four lots, twenty-nine are considered beneficial; these belong to eight orders and seventeen families.

Lobesia botrana was identified in all three years of the study, and *Sparganothis pilleriana* only in 2022. To control these moths, parasitic and predatory species can be introduced into the ecosystem since only one species (*Chrysoperla carnea*) is beneficial in controlling the *L. botrana* moth.

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Appendix A

Table A1. Species identified in the four lots (BF—a vineyard maintained as a black field; GBF—a grove near the black field; NPG—a vineyard where the intervals were kept as natural permanent grassland; and GNPG—a grove near the natural permanent grassland). With 0 = unrecorded; 1 = recorded in 1/3 years; 2 = recorded in 2/3 year, 3 = recorded in 3/3 year.

No.	Species	NPG	GNPG	BF	GBF
1	*Acanthoscelides* sp.	0	0	0	1
2	*Adonia variegata*	0	1	3	1
3	*Aelia acuminata*	0	1	0	1
4	*Agrilus* sp.	2	2	1	3
5	*Agriotes lineatus*	0	0	1	1
6	*Agriotes ustulatus*	1	2	2	1
7	*Ampedus nigerrimus*	1	0	0	0
8	*Andrena cineraria*	0	0	1	0
9	*Andrena subopaca*	3	3	1	2
10	*Andrena wilkella*	0	1	1	0
11	*Anisosticta novemdecimpunctata*	0	0	0	2
12	*Anthaxia cichorii*	1	1	1	1
13	*Anthaxia nitidula signaticollis*	1	1	1	0
14	*Anthocomus rufus*	1	0	0	0
15	*Anthomyia procellaris*	3	3	3	3
16	*Apis mellifera*	3	3	3	1
17	*Araneus diadematus*	1	0	0	0
18	*Arge ochropus*	2	1	0	0
19	*Athalia rosae*	1	2	1	1
20	*Bombus terrestris*	2	1	0	0
21	*Bruchidius villosus*	0	0	1	0
22	*Calliptamus barbarus*	0	0	0	1
23	*Cantharis rubra*	0	0	0	1
24	*Cantharis rustica*	0	1	0	0
25	*Carpomya incompleta*	0	0	2	1
26	*Carpomya schineri*	1	1	1	2
27	*Centrotus cornutus*	1	1	1	0
28	*Ceresa bubalus*	1	2	2	3
29	*Cheiracanthium mildei*	2	1	1	2
30	*Chlorophorus sartor*	1	1	0	0
31	*Chlorophorus varius*	3	3	3	2
32	*Chorthippus brunneus*	0	1	1	0
33	*Chorthippus vagans*	1	0	0	0
34	*Chrysis ignita*	1	0	0	1
35	*Chrysoperla carnea*	2	1	2	1
36	*Chrysura refulgens*	1	0	0	0
37	*Cicadetta hannekeae* sp.	1	2	2	2
38	*Clytra laeviuscula*	2	2	1	0
39	*Clytus lama*	2	2	2	2
40	*Coccinella septempunctata*	1	2	2	1
41	*Colias croceus*	1	0	0	0
42	*Conocephalus strictus*	0	1	0	1
43	*Coreus marginatus*	1	1	0	1
44	*Corythucha ciliata*	3	3	3	3
45	*Cryptocephalus* sp.	2	1	2	1
46	*Danacea pallipes*	3	3	3	3
47	*Deraeocoris ruber*	0	1	2	1
48	*Dolycoris baccarum*	0	0	0	1
49	*Drosophila melanogaster*	1	1	1	1
50	*Ellychnia corrusca*	1	0	0	0
51	*Episyrphus balteatus*	0	0	0	1

Table A1. *Cont.*

No.	Species	NPG	GNPG	BF	GBF
52	*Eristalis tenax*	2	3	3	3
53	*Eupteryx atropunctata*	0	0	0	1
54	*Eurydema (Eurydema) oleracea*	0	0	1	0
55	*Eysarcoris inconspicuous*	0	1	0	1
56	*Eysarcoris ventralis*	0	0	0	1
57	*Figitidae* sp.	2	2	2	2
58	*Forficula auricularia*	2	1	1	2
59	*Geocoris erythrocephalus*	1	1	3	2
60	*Gonioctena fornicate*	0	1	0	0
61	*Graphosoma italicum*	0	1	0	0
62	*Graphosoma lineatum*	2	1	0	1
63	*Gymnocheta viridis*	0	0	2	0
64	*Halictus scabiosae*	0	0	1	1
65	*Halictus sexcinctus*	0	0	1	0
66	*Halyzia sedecimguttata*	0	0	0	1
67	*Harmonia axyridis*	3	3	3	3
68	*Harrisina metallica*	0	0	1	0
69	*Hedychrum nobile*	0	0	1	0
70	*Heliophanus kochii*	0	1	0	1
71	*Hippodamia variegata*	1	1	0	0
72	*Holcostethus albipes*	0	0	0	1
73	*Holcostethus limbolarius*	1	0	0	2
74	*Ichneumon gracilentus*	0	0	0	2
75	*Iphiclides podalirius*	0	2	0	1
76	*Lagria hirta*	0	0	0	1
77	*Lampyris noctiluca*	1	2	0	1
78	*Larinus centaurii*	0	0	0	1
79	*Lasiommata maera*	0	0	1	0
80	*Lasius niger*	2	2	0	1
81	*Libellula depressa*	1	0	0	0
82	*Lucilia sericata*	0	0	1	1
83	*Lygaeus kalmii*	0	1	0	0
84	*Lygus pabulinus*	0	1	0	0
85	*Machimus atricapillus*	1	0	0	0
86	*Malachius bipustulatus*	2	2	1	2
87	*Maniola jurtina*	0	0	0	1
88	*Mantis religiosa*	1	0	0	0
89	*Meiosimyza* sp.	0	1	1	0
90	*Melanargia galathea*	0	0	1	2
91	*Melitaea deione*	0	0	1	1
92	*Micrommata virescens*	0	0	1	0
93	*Mordella* sp.	1	1	1	1
94	*Musca autumnalis*	1	2	2	2
95	*Musca domestica*	3	3	3	3
96	*Myathropa florea*	0	0	0	1
97	*Neomyia cornicina*	0	0	1	0
98	*Neoscona crucifera*	0	0	0	1
99	*Nysius graminicola*	0	0	1	0
100	*Ochlodes sylvanoides*	0	1	0	0
101	*Ochlodes sylvanus*	1	0	0	0
102	*Ochlodes venatus*	1	0	1	1
103	*Oecanthus californicus*	0	0	0	1
104	*Oecanthus pellucens*	0	0	0	1
105	*Oedemera flavipes*	3	3	3	1
106	*Oedemera podagrariae*	0	0	1	0
107	*Onthophagus* sp.	1	1	0	0
108	*Oodes helopioides*	3	2	2	2
109	*Orius insidiosus*	1	1	1	1

Table A1. *Cont.*

No.	Species	NPG	GNPG	BF	GBF
110	*Oulema obscura*	0	0	1	1
111	*Oxycarenus lavaterae*	1	1	0	0
112	*Pachybrachis tessellatus*	0	0	0	2
113	*Panorpa communis*	2	1	2	2
114	*Penthimia nigra*	1	0	0	0
115	*Penthimia* sp.	0	1	1	0
116	*Peponapis pruinosa*	0	0	1	0
117	*Phaenicia sericata*	0	0	0	1
118	*Phaneroptera nana*	0	0	1	0
119	*Philaenus spumarius*	3	3	3	3
120	*Phlogotettix cyclops*	0	1	1	1
121	*Phyllotreta undulata*	3	3	3	2
122	*Pieris rapae*	0	0	1	0
123	*Polistes dominulus*	3	2	3	2
124	*Pollenia rudis*	0	0	0	1
125	*Priocnemis perturbator*	0	1	0	0
126	*Propylea quatuordecimpunctata*	2	1	2	2
127	*Protapion fulvipes*	0	0	0	1
128	*Psyllobora vigintiduopunctata*	0	2	3	2
129	*Raglius alboacuminatus*	0	1	1	0
130	*Rhagoletis completa*	0	0	0	2
131	*Rhynchomitra microrhina*	1	0	1	1
132	*Sarcophaga bercaea*	1	1	0	1
133	*Sarcophaga carnaria*	1	0	0	0
134	*Sarcophaga* sp.	1	3	3	3
135	*Scaphidium quadrimaculatum*	0	0	1	0
136	*Scaphoideus titanus*	2	2	3	3
137	*Sceliphron caementarium*	1	1	0	0
138	*Scutigera coleoptrata*	0	0	0	1
139	*Scymnus frontalis*	3	3	3	2
140	*Scymnus rubromaculatus*	0	0	3	3
141	*Scythris sinensis*	0	0	1	0
142	*Sitochroa verticalis*	0	1	0	0
143	*Sphecodes hyalinatus*	0	0	0	1
144	*Stenocorus* sp.	0	0	0	1
145	*Stenocorus vestitus*	0	1	0	0
146	*Stevenia deceptoria*	0	0	0	1
147	*Stictocephala bisonia*	1	1	0	1
148	*Stomoxys calcitrans*	1	0	0	0
149	*Strongylocoris leucocephalus*	0	1	1	0
150	*Synema globosum*	0	0	0	1
151	*Tachycixius pilosus*	0	0	0	1
152	*Tachysphex pompiliformis*	0	1	0	0
153	*Tettigonia viridissima*	1	0	2	0
154	*Tiphia femorata*	1	1	2	3
155	*Tomoplagia obliqua*	1	1	0	0
156	*Tomoxia bucephala*	2	2	2	2
157	*Trichaetipyga juniperina*	0	1	1	1
158	*Trichodes apiarius*	1	1	1	0
159	*Tritomegas sexmaculatus*	0	0	0	1
160	*Vespa crabro*	3	3	2	1
161	*Vespula germanica*	3	3	3	2
162	*Vespula vulgaris*	2	3	3	3
163	*Voria ruralis*	0	0	3	3
164	*Zygaena ephialtes*	2	1	0	0

unique species in NPG; unique species in GNPG; unique species in BF; unique species in GBF.

Table A2. Beneficial insect species identified in the 2020–2022 study period.

Order	Family	Species	Feeding, Benefits	References	Lots
Araneae	Araneidae	*Neoscona crucifera*	Insects, Lepidoptera, mostly prefer soft-bodied, immature stages with more internal body fluid, especially the homopterans.	[48–50]	GBF.
	Eutichuridae	*Cheiracanthium mildei*	Various insect pests, especially *Spodoptera littoralis* and *Phyllonorycter blancardella*.	[51]	BF, GBF, NPG, GNPG.
Coleoptera yanbnb	Coccinelidae	*Adonia variegata*	*Aphis gossypii*	[52]	BF, GBF, NPG, GNPG.
		Psyllobora vigintiduopunctata	Powdery mildew spores, such as Oidium-infected *Euonymus japonica*, *Erysiphe holosericea*, *Podosphaera xanthii*, pomegranate tree aphids; powdery mildew of trees, shrubs, and herbaceous plants (prefer powdery mildew on Trifolium, Melilotus, and Medicago (Fabaceae)	[53–60]	BF, GBF, GNPG.
		Scymnus rubromaculatus	Mites, aphids, and crustaceans.	[61–63]	BF, GBF.
		Anisosticta novemdecimpunctata	Aphids and other soft insects.	[64,65]	GBF.
		Halyzia sedecimguttata	Powdery mildew (Ascomycotina: Erysiphales) of trees, shrubs, and herbaceous plants; prefers powdery mildew on Trifolium, Melilotus, and Medicago (Fabaceae).	[58]	GBF.
		Coccinella septempunctata	Fungal spores, aphids (e.g., *Rhopalosiphum padi*).	[66]	BF, GBF, NPG, GNPG.
		Propylea quatuordecimpunctata	Aphids (e.g., the Aphidoidea superfamily).	[67,68]	BF, GBF, NPG, GNPG.
	Melyridae	*Danacea pallipes*	Larvae feed on fungal mycelia.	[69]	BF, GBF, NPG, GNPG.
		Malachius bipustulatus	*Lymantria dispar*; small insects found on flowers; nymphae of some xilophagous insects; pollen; *Oulema melanopus* L.	[70–74]	BF, GBF, NPG, GNPG.
	Mordellidae	*Mordella* sp.	Native pollinators.	[75]	BF, GBF, NPG, GNPG.
Diptera	Tachinidae	*Gymnocheta viridis*	Noctuidae species.	[76]	BF.
		Voria ruralis	Various caterpillars, but used mainly to control the cabbage looper (*Trichoplusia ni*) caterpillar; feeds on aphid honeydew;lepidopteran species, particularly *Trichoplusia ni*.	[77–79]	BF, GBF.
Hemiptera	Geocoridae	*Geocoris erythrocephalus*	Aphids, whiteflies, thrips, mites, caterpillars, eggs, and larvae (tobacco budworm, soybean loopers).	[80,81]	BF, GBF, NPG, GNPG.
	Miridae	*Deraeocoris ruber*	*Cacopsylla pyrisuga*, younger caterpillar instars of some butterflies, mites, and various other small insects in apple orchards, aphids, *Acizzia jamatonica*, and *Cacopsylla pyrisuga*.	[82–84]	BF, GBF, GNPG
Heteroptera	Anthocoridae	*Orius insidiosus*	Thrips larvae and adults (e.g., *Flankliniella occidentalis*, *Bemisia tabaci* and *Frankliniella occidentalis*, *Thrips palmi*) and other soft-bodied insects.	[85–89]	BF, GBF, NPG, GNPG.
Hymenoptera	Andrenidae	*Andrena subopaca*	Insect pollinators.	[90]	BF, GBF, NPG, GNPG.
		Andrena wilkella	Pollen, especially from Fabaceae.	[91]	BF, GNPG.
		Andrena cineraria	Pollinator.	[92,93]	BF.
	Apidae	*Apis mellifera*	Pollen.	[94–96]	BF, GBF, NPG, GNPG
		Bombus terrestris	Pollinators.	[97]	NPG, GNPG.
		Peponapis pruinosa	Pollen grains from Cucurbita flowers.	[94,98]	BF.
	Halictidae	*Halictus scabiosae*	Nectar and pollen.	[99]	GBF.
	Tiphiidae	*Tiphia femorata*	Flowers, nectar, and pollen (especially from *Apiaceae* species); *Rhizotrogus solstitialis*, *Anisoplia austriaca*, and several *Aphodius* species (Aphodiidae).	[30,100]	BF, GBF, NPG, GNPG.

Table A2. *Cont.*

Order	Family	Species	Feeding, Benefits	References	Lots
Mecoptera	Panorpidae	*Panorpa communis*	Dead arthropods, pollen, and fruit, also scavengers of dead insects and rotting fruit	[101,102]	BF, GBF, NPG, GNPG.
Neuroptera	Chrysopidae	*Chrysoperla carnea*	Grapevine moths, *Helicoverpa armigera* (Hubner), *Bemisia tabaci*, aphids (e.g., *Aphis pomi*), mites and mealy bugs, coccids, small homopterous pests; *Jacobiasca lybica*, *Compsus viridivittatus* eggs.	[103–107]	BF, GBF, NPG, GNPG.

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