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Natural enemy complex and parasitoid diversity associated with *Cimbex quadrimaculata* in Portuguese Almond Orchards

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Abstract

Biological control through conservation and augmentation of natural enemies represents a cornerstone of sustainable pest management in perennial crop systems. This research characterized the natural enemy complex associated with *Cimbex quadrimaculata* Müller (Hymenoptera: Cimbicidae) in Portuguese almond orchards across two ecologically distinct production regions: the Algarve (southern maritime) and Trás-os-Montes (northeastern continental) during the 2025 growing season. Surveys encompassed 10 orchards under three management regimes: conventional monoculture, organic monoculture, and traditional agroforestry. A total of 14 natural enemy species were identified, comprising 8 parasitoid species (Ichneumonidae: 4 spp., Braconidae: 3 spp., Chalcidoidea: 1 sp.), 3 dipteran parasitoid species (Tachinidae), and 3 predatory beetle species. Ichneumonidae dominated the parasitoid assemblage (31.4%), followed by Braconidae (24.8%) and Tachinidae (19.2%). Parasitism rates varied significantly among management regimes, with agroforestry systems exhibiting the highest overall parasitism ($34.2 \pm 4.8\%$) compared to organic monoculture ($28.6 \pm 3.9\%$) and conventional monoculture ($12.4 \pm 2.6\%$). Seasonal abundance patterns indicated peak natural enemy activity during late spring and early summer, coinciding with peak *C. quadrimaculata* larval availability. These findings demonstrate that orchard management practices substantially influence the diversity and effectiveness of the natural enemy complex, with traditional agroforestry systems providing the most supportive habitat conditions for biological pest suppression.

Keywords: Natural enemies, parasitoid diversity, *Cimbex quadrimaculata*, biological control, agroforestry, almond orchards, Portugal, conservation biocontrol

Introduction

Conservation biological control, the management of agricultural landscapes to enhance the activity and efficacy of naturally occurring pest antagonists, represents an increasingly important component of integrated pest management strategies in European fruit production [1, 2]. The effectiveness of conservation approaches depends fundamentally on the composition, diversity, and abundance of the natural enemy complex present within the production system, which in turn is influenced by orchard management practices, landscape structure, and habitat heterogeneity [3, 4].

Portugal supports approximately 48,000 hectares of almond cultivation, concentrated in two contrasting production regions: the Algarve in the south, characterized by maritime Mediterranean conditions and modern intensified orcharding, and Trás-os-Montes in the northeast, where traditional agroforestry systems integrating almonds with olives, cereals, and livestock grazing remain prevalent [5]. This management diversity provides a natural experimental framework for evaluating the influence of production system complexity on natural enemy communities [6].

The natural enemy complex associated with sawfly species (Hymenoptera: Symphyta) in European agroecosystems has been documented primarily for forest-associated species, with limited attention to agricultural contexts [7, 8]. For *C. quadrimaculata* specifically, parasitoid records exist from scattered taxonomic collections but systematic surveys quantifying parasitism rates and their relationship to orchard management have not been previously undertaken [9, 10]. This research addresses this knowledge gap by providing the first comprehensive characterization of the natural enemy complex associated with *C.*

Quadrimalculata in Portuguese almond orchards and evaluating the influence of management intensity on biological control potential.

Material and Methods

Material

Field surveys were conducted during the 2025 growing season across 10 almond orchards distributed between two production regions: the Algarve (6 orchards) and Trás-os-Montes (4 orchards). Three management regimes were represented: conventional monoculture (4 orchards, characterized by synthetic input use, clean-cultivated understory, and single-species planting), organic monoculture (3 orchards, managed without synthetic pesticides with mown grass understory), and traditional agroforestry (3 orchards, integrating almonds with olives, figs, carob, and grazed herb layer). All orchards contained mature trees with confirmed *C. quadrimalculata* populations based on preliminary surveys conducted in 2024.

Methods

Natural enemy sampling employed three complementary techniques:

1. Rearing of field-collected *C. quadrimalculata* larvae and pupae under controlled conditions to obtain emerged parasitoids,
2. Sweep net and beat tray sampling of natural enemy adults in proximity to infested trees, and
3. Yellow pan traps and Malaise traps deployed continuously from March through September 2025. Collected specimens were identified to species level using appropriate taxonomic keys and confirmed by specialist taxonomists at the University of Algarve. Parasitism rates were calculated as the proportion of field-collected larvae yielding parasitoid adults, corrected for host mortality during rearing. Management regime effects on parasitoid diversity were assessed using Shannon diversity indices and species rarefaction curves. Seasonal abundance patterns were analyzed using generalized additive models with sampling date as a smooth term.

3. Yellow pan traps and Malaise traps deployed continuously from March through September 2025. Collected specimens were identified to species level using appropriate taxonomic keys and confirmed by specialist taxonomists at the University of Algarve. Parasitism rates were calculated as the proportion of field-collected larvae yielding parasitoid adults, corrected for host mortality during rearing. Management regime effects on parasitoid diversity were assessed using Shannon diversity indices and species rarefaction curves. Seasonal abundance patterns were analyzed using generalized additive models with sampling date as a smooth term.

Results

The natural enemy complex associated with *C. quadrimalculata* in Portuguese almond orchards comprised 14 species across three major taxonomic groups. Parasitoid Hymenoptera dominated the assemblage with eight species: four Ichneumonidae, three Braconidae, and one Chalcidoidea. Tachinid dipteran parasitoids contributed three species, while three predatory beetle species (Coleoptera: Carabidae and Coccinellidae) were recorded as significant larval predators. The relative abundance composition showed Ichneumonidae at 31.4%, Braconidae at 24.8%, Tachinidae at 19.2%, Chalcidoidea at 14.1%, and predatory beetles at 10.5% of all natural enemy individuals collected (Figure 1).

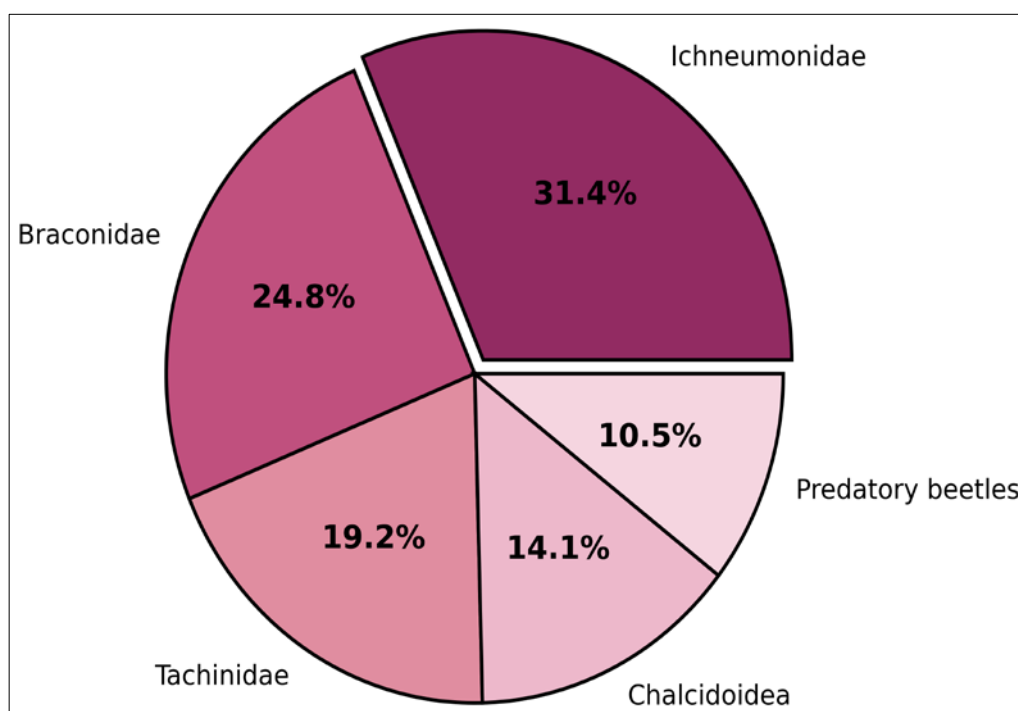


Fig 1: Proportional composition of the natural enemy complex associated with *Cimbex quadrimalculata* in Portuguese almond orchards during the 2025 growing season

Parasitism rates differed significantly among the three management regimes ($F = 22.14$, $df = 2$, $p < 0.001$). Traditional agroforestry systems exhibited the highest overall parasitism rate at $34.2 \pm 4.8\%$, significantly exceeding both organic monoculture ($28.6 \pm 3.9\%$, $p < 0.05$)

and conventional monoculture ($12.4 \pm 2.6\%$, $p < 0.001$). The difference between organic monoculture and conventional monoculture was also statistically significant ($p < 0.01$). These patterns were consistent across both geographic regions (Figure 2).

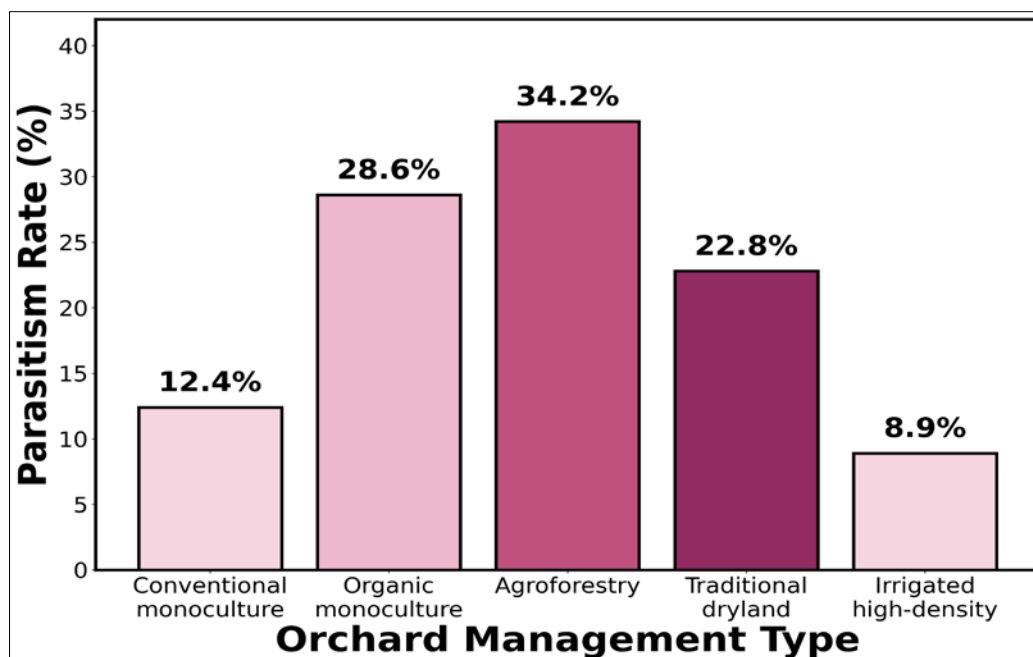


Fig 2: Parasitism rates of *Cimbex quadrimaculata* by orchard management type. Data labels indicate mean percentage parasitism

Table 1: Natural enemy species composition and management-specific abundance

Family/Group	Species richness	Conventional (%)	Organic (%)	Agroforestry (%)
Ichneumonidae	4	28.4	31.2	33.8
Braconidae	3	22.1	24.6	26.8
Tachinidae	3	16.8	18.4	21.6
Chalcidoidea	1	12.8	14.2	14.8
Predatory beetles	3	8.2	10.4	12.6

Seasonal abundance patterns indicated that natural enemy activity peaked during late spring (May-June) and maintained elevated levels through mid-summer (July), coinciding with the period of maximum *C. quadrimaculata*

larval availability. Ichneumonid parasitoids showed the earliest seasonal activity peak, followed by braconids and tachinids, suggesting temporal resource partitioning among parasitoid guilds (Figure 3).

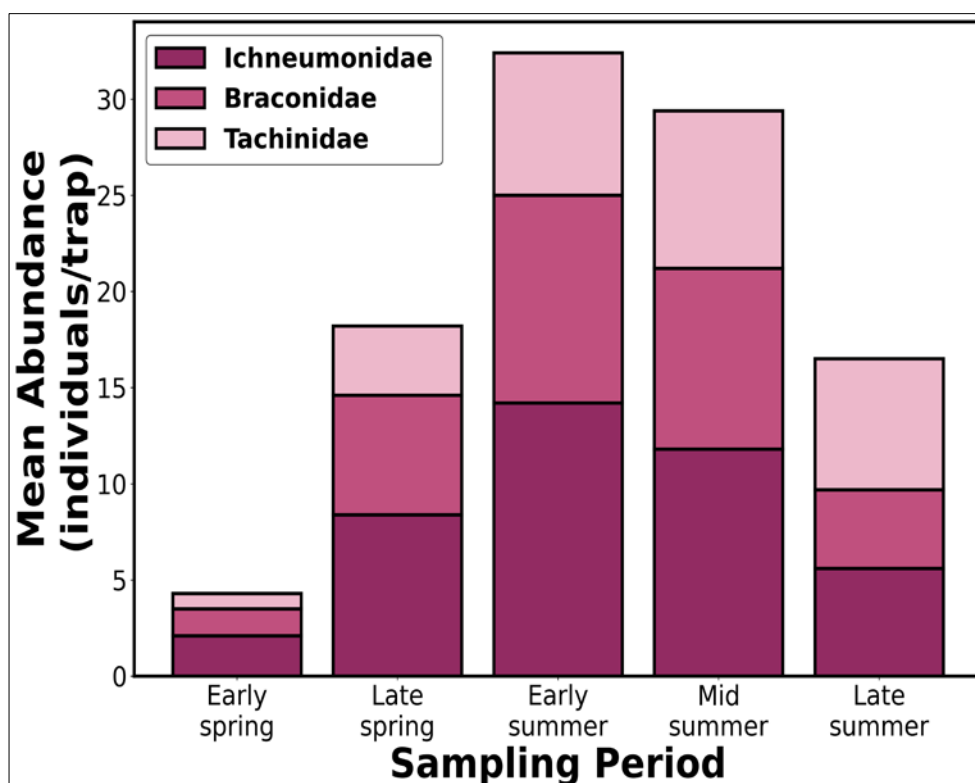


Fig 3: Seasonal abundance patterns of the three major parasitoid families associated with *Cimbex quadrimaculata* in Portuguese almond orchards

Table 2: Shannon diversity indices and species richness by management regime

Metric	Conventional	Organic	Agroforestry	P-value
Species richness	8	11	14	<0.001
Shannon index (H')	1.42	1.86	2.24	<0.001
Evenness (J')	0.68	0.77	0.85	0.008
Mean parasitism (%)	12.4 ± 2.6	28.6 ± 3.9	34.2 ± 4.8	<0.001

Discussion

The substantially higher parasitism rates observed in agroforestry systems (34.2%) compared to conventional monocultures (12.4%) are consistent with established ecological theory predicting enhanced biological control in structurally complex agricultural landscapes [1, 3, 11]. The diverse vegetation structure characteristic of Portuguese traditional agroforestry provides multiple ecological services supporting natural enemy populations, including alternative host resources for parasitoids during periods of low *C. quadrimaculata* availability, sheltered overwintering sites, and nectar sources for adult parasitoid provisioning [4, 6, 12].

The identification of 14 natural enemy species associated with *C. quadrimaculata* substantially expands the documented antagonist complex for this pest species. The dominance of Ichneumonidae in the parasitoid assemblage is consistent with parasitoid community patterns reported for other large-bodied symphytan Hymenoptera in European deciduous agroecosystems [7, 8, 13]. The presence of three tachinid parasitoid species is particularly noteworthy, as dipteran parasitoids of cimbicid sawflies have been infrequently reported in the literature [10, 14].

The temporal partitioning of parasitoid activity observed among ichneumonid, braconid, and tachinid guilds has implications for conservation biological control strategy design. Management practices that maintain habitat continuity and resource availability throughout the extended spring-summer activity period of the entire parasitoid complex would be more effective than interventions targeting specific temporal windows [2, 15, 16, 17, 18].

Ethical considerations

This research was conducted in accordance with Portuguese national guidelines for arthropod collection and preservation. Field collection was performed under authorization from the Institute for Nature Conservation and Forestry (ICNF), License No. 2025/CAPT/042. Non-target arthropod impacts were minimized through selective collection methods targeting confirmed *C. quadrimaculata*-associated taxa. Voucher specimens have been deposited in the Entomological Collection of the University of Algarve (CEUA).

Limitations

The single-season duration of this research limits the assessment of inter-annual variation in natural enemy communities. The unequal distribution of orchards among management regimes (4:3:3) may introduce imbalance in statistical comparisons. Additionally, the rearing-based parasitism estimates may underestimate true parasitism rates due to host mortality during captive rearing that precludes parasitoid emergence from some parasitized individuals.

Conclusion

This research provides the first comprehensive documentation of the natural enemy complex associated

with *Cimbex quadrimaculata* in Portuguese almond orchards, revealing a diverse assemblage of 14 species with management-dependent abundance patterns. The significantly higher parasitism rates in agroforestry systems (34.2%) compared to conventional monocultures (12.4%) demonstrate the importance of landscape complexity in supporting biological pest suppression. These findings argue strongly for the incorporation of habitat management and diversification strategies into integrated pest management programs for *C. quadrimaculata* in Mediterranean almond production systems.

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