ENTOMOLOGY

Comparison of different trapping devices for the capture of *Bactrocera oleae* (Rossi) and other non-target insects in the Mediterranean basin

Andrea Sciarretta,[1] Tania Travaglini,[1] Linda Kfoury,[2] Ines Ksentini,[3] Meelad Yousef-Yousef,[4] Marios-Ioannis Sotiras,[5] Ahmad El Bitar,[6] Mohieddine Ksantini,[3] Enrique Quesada-Moraga,[4] Dionysios Perdikis[5]

[1]Department of Agricultural, Environmental and Food Sciences, University of Molise, Campobasso, Italy; [2]Faculty of Agricultural Sciences, Lebanese University, Beirut, Lebanon; [3]Laboratory of the genetic resources of the olive tree: Characterization, Valorization, and phytosanitary protection, Olive Tree Institute, University of Sfax, Tunisia; [4]Department of Agronomy, María de Maeztu Unit of Excellence DAUCO, Campus de Rabanales, University of Córdoba, Spain; [5]Faculty of Crop Science, Agricultural University of Athens, Greece; [6]Department of Plant Biotechnology, Lebanese Agricultural Research Institute, Tal Amara, Zahle, Lebanon

Correspondence: Andrea Sciarretta, Department of Agricultural, Environmental and Food Sciences, University of Molise, Campobasso, Italy.
E-mail: sciarretta@unimol.it

Key words: olive fruit fly; yellow sticky trap; McPhail; Jackson trap; beneficial insects; olive grove; pest monitoring.

Acknowledgments: the authors wish to thank all members of their teams who were involved in field data collection related to the publication and the owners of the farms who hosted the experiments. The authors are grateful to Zinette Moussa (Lebanese Agricultural Research Institute, Lebanon), who provided help in verifying part of the hymenopteran parasitoid material collected in Italy.

Conflict of interest: the authors declare no potential conflict of interest.

Funding: this work was financed by the EU under the Project "Commercialization of an Automated Monitoring and Control System against the Olive and Med Fruit Flies of the Mediterranean Region, FruitFlyNet-ii, STR_B_A.2.1_0043", as part of the ENI CBC MED Mediterranean Sea Basin Programme 2014-2020.

Availability of data and material: data and materials are available by the authors.

Received: 22 January 2024.
Accepted: 17 March 2024.

Journal of Entomological and Acarological Research 2024; 56:12302
doi:10.4081/jear.2024.12302

Abstract

The present study aimed to compare some commercial traps baited with ammonium carbonate for their efficacy in monitoring *Bactrocera oleae* (Rossi) and their selectivity toward beneficial insects, under the conditions of olive groves located in five Mediterranean countries (Greece, Italy, Lebanon, Spain, Tunisia). The selectivity of the devices was evaluated toward several groups of non-target insects, namely lacewings (Chrysopidae), hoverflies (Syrphidae), ladybirds (Coccinellidae), bees (Apoidea) and hymenopteran parasitoids. The following devices were compared: yellow sticky panel, green sticky panel, Jackson trap with different combinations of yellow and white colours of the device and/or the panel, and McPhail trap. In most cases, the McPhail trap and the yellow panel showed the highest efficacy in monitoring male and female *B. oleae* flies; however, the yellow panel was most attractive for some groups of non-target insects, particularly the hymenopteran parasitoids, whereas the comparative non-target effects were site-specific for the other arthropod groups. In the case of Chrysopidae, McPhail caught more individuals than the other traps in Italy and Spain, whereas in Lebanon and Greece, the highest number of individuals was captured in the two sticky panels. Coccinellidae were found in very low numbers only in Lebanon on yellow panels. Syrphidae were captured mainly on sticky panels in Greece and Tunisia. Apoidea were found only on yellow panels in Lebanon. The choice between the McPhail trap and the yellow panel should be made on the basis of various evaluations carried out at the site, including operational ones.

Introduction

Traps for pest monitoring and control purposes are considered important tools in the context of integrated pest management (IPM). In the case of fruit flies, their use has been a long and well-established practice routinely employed, especially when their attractivity and/or specificity are enhanced by an attractant combined with the specific shape and colour of the device.

Among the numerous traps tested in recent years for fruit flies, most can be traced back to two basic modes of action, wet and dry types, which use an attractant solution inside the device or sticky surfaces to capture the flies, respectively (FAO/IAEA, 2018).

The olive fruit fly (OFF), *Bactrocera oleae* (Rossi) (Diptera: Tephritidae), is the key pest of olive groves in most geographic areas where crops are cultivated (Tzanakakis, 2006). Attractant devices have been extensively used for *B. oleae* monitoring, suppression and control purposes, and various attractive stimuli have been used to make traps more efficient, alone or in combination, that include a yellow color, sexual pheromone (spiroketal) and food attractants, such as hydrolyzed proteins and various ammonium salts, including ammonium carbonate, ammonium sulphate and ammonium phosphate (Ordano *et al.*, 2015; FAO/IAEA, 2018). For monitoring *B. oleae*, various devices have been suggested by the International Atomy Energy Agency (FAO/IAEA, 2018). Among wet traps, McPhail (MP) and Multilure traps baited with protein attractants have been reported. Within the dry trap category, Easy trap, ChamP and yellow panels (YP) baited with spiroketal and ammonium carbonate have been cited. However, other trap models have been tested in recent years, including Jackson traps, a delta-shaped dry model used to monitor various fruit fly pests (Caballero, 2002; Calabrese and Sciarretta, 2019; Manoukis *et al.*, 2023).

The use of attractant devices can also have negative non-target effects, such as the capture of beneficial arthropods, including pollinators, predators and parasitoids (Coelho *et al.*, 2010). This effect becomes particularly problematic for natural enemies attracted to a specific semiochemical, such as pheromones, as observed for bark beetles and San Jose scale insects (McClain *et al.*, 1990; Martin *et al.*, 2013), or when an active stimulus is used for many groups of insects, such as a yellow color (Shimoda and Honda, 2013). In this context, the capture of non-target insects has been recorded for various attractant devices used to monitor, suppress and/or control fruit flies, in particular for *B. oleae*, with several studies focusing on attracting and killing or mass trapping control purposes (Neuenschwander, 1982; Ragoussis, 2005; Porcel *et al.*, 2009; Infusino *et al.*, 2014; Fathkohi *et al.*, 2018; Calabrese and Sciarretta, 2019). Captures of non-target species have also been recorded in trapping devices used to monitor, mass trap, or attract and kill *Ceratitis capitata* Wiedemann and *Anastrepha* sp. and to eradicate invasive *Bactrocera* species (Leblanc *et al.*, 2009; Braham, 2013; Infusino *et al.*, 2014; Galdino and Raga, 2018; Hafsi *et al.*, 2015).

Olive groves are agroecosystems known for their richness in entomofauna (Tzanakakis, 2006). The canopy of olive trees supports a high arthropod diversity that includes parasitic and predatory species acting for the biological control of pests of the olive crop but also provides shelter to many other arthropod species that offer valuable agroecosystem services (Ruano *et al.*, 2004; Rei *et al.*, 2010). For this reason, it is essential to pay more attention to the side effects of traps used for monitoring olive pests, such as *B. oleae*, toward non-target insects.

In the present paper, we conducted a comparative study under field conditions on various attractant devices used to monitor OFF. In particular, some dry traps, such as coloured sticky panels and Jackson traps with different combinations of yellow and white, were selected. The MP trap was also included because it has been used for several decades in various Mediterranean countries as a standard monitoring device for *B. oleae* (Katsoyannos and Kouloussis, 2001; Varikou, 2014). Special emphasis was given to comparing the efficacy and selectivity of the trap devices under the different agroecological conditions and arthropod communities in olive groves of five Mediterranean countries, Greece, Lebanon, Italy, Spain and Tunisia, all following the same experimental protocol. The primary objectives of the research were to identify the most effective trapping device for *B. oleae* males and females, as well as to evaluate the selectivity of these different traps towards non-target insects. In particular, our focus was on specific groups of beneficial insects that included lacewings (Neuroptera Chrysopidae), hoverflies (Diptera Syrphidae) and ladybirds (Coleoptera Coccinellidae) as predators; hymenopteran parasitoids (Hymenoptera Ichneumonoidea, Chrysidoidea, Chalcidoidea) as parasitoids; and bees (Apoidea) as pollinators.

Materials and Methods

Experimental sites

The experiments were carried out in five countries: Greece, Italy, Lebanon, Spain and Tunisia (Figure 1).

In Greece, the experimental olive grove was located in Arkadiko village, Argolis region, in eastern Peloponnese, in a hilly area (240 m a.s.l.) at a distance about 6 km from the sea. The surface of the site was 30 ha of the cultivar Manaki (medium- to large-sized drupes). The grove was surrounded mainly by olive groves but also by a citrus orchard, an apricot orchard and small vegetable fields. The trees were about 10-40 years old, 3-4 m high, with a crown size of about 5-6 m; they were spherical trained, with a planting pattern of 4×5 and 5×5. For weed management, the farmer used mechanical control with a rotary mower or rotary cutting of weeds.

In Italy, the experimental site was located in Larino (270 m a.s.l.), Molise region. The olive grove was organic and covered 17.5 ha, with cultivars Gentile di Larino and Peranzana, surrounded by vineyards and cereals. The trees were about 25-30 years old and 5-7

Figure 1. Location of experimental olive groves in each country: A) Greece; B) Italy; C) Lebanon; D) Spain; E) Tunisia.

m high, with a crown size of about 4 m; they were monocone trained, with a planting pattern of 6×6 and 6×5. There was no tillage for rotary cutting of weeds.

In Lebanon, the experimental site was located in the Hassbaya region (600 m a.s.l.), covering 6.25 ha (250×250 m) of non-irrigated olive trees of the cultivar Baladi. The groves were surrounded by pine trees and grapes. The trees were 20-40 years old. The distance between trees ranges from 5 to 6 m, giving a density of 250 to 300 trees per ha. Tree heights ranged from 3 to 5 m, with a canopy diameter of 3×3 m and 5×5.5 m. The planting distance was determined under a linear system. The tree shape showed a spreading growth habit. Weeding was almost absent.

In Spain, the experimental site was located in Alcolea (128 m a.s.l., Cordoba). The farm used IPM and covered 6.25 ha of olive trees (250×250 m) of cultivar Picual under irrigation, surrounded by horticultural and almond crops. The trees were about 3-20 years old and 4-6 me high and had a crown diameter of 5-10 m, with a planting frame of 8×5 m, giving a density of 250 trees per hectare. The trees had an open canopy formation. The farm used a no-tillage system; herbicides were used twice a year, once in spring and once in autumn before harvest.

In Tunisia, the orchard in which the experiment was conducted was part of a conventional domain of 126 hectares belonging to the Olive Tree Institute and composed of a huge collection of olive, almond and pistachio trees. This domain was located 26 km from the coast. The experimental orchard had an area of 68 hectares and contained rain-fed olive trees of the cultivar Chemlali. The distance between trees was 24 m and the orchard was planted under a linear system, giving a density of 17 olive trees per hectare. Trees had a height ranging between 4 and 5 m and a canopy diameter of 8-9 m and were maintained according to goblet pruning. The olive trees were rather aged (around 80 years old) and produced fruit once every 2 years according to the specificity of the cultivated variety and the region. The tillage was mechanical and undertaken 5 times/year.

Trap devices

In Italy, Lebanon, Spain and Tunisia, six trapping devices were compared (Figure 2): yellow sticky panel (YP, Figure 2A); green sticky panel (GP, Figure 2B); white Jackson trap with yellow sticky panel inside (WJYP, Figure 2C); McPhail (MP, Figure 2D); yellow Jackson trap with white sticky panel inside (YJWP, Figure 2E); and yellow Jackson trap with yellow sticky panel inside (YJYP, Figure 2F).

In Greece, the white Jackson trap with the white sticky panel (WJWP) was used instead of the white delta trap with YP and MP was not tested.

All devices were baited with 10 g of solid ammonium carbonate in plastic bags or vials (food attractant to attract both males and females of *B. oleae*), except the MP traps, which were activated with the water-soluble proteins supplied within the trap itself.

In the case of sticky panels (YP or GP), only one side was sticky, and the other side was covered with white paper to make the sticky surfaces of panels and Jackson devices comparable. In all cases, the size of the sticky surface was 21×14 cm.

Experimental design

In Italy and Spain, field trials were carried out following a 6×4 experimental design, with 6 devices and 4 replicates; in Greece, a

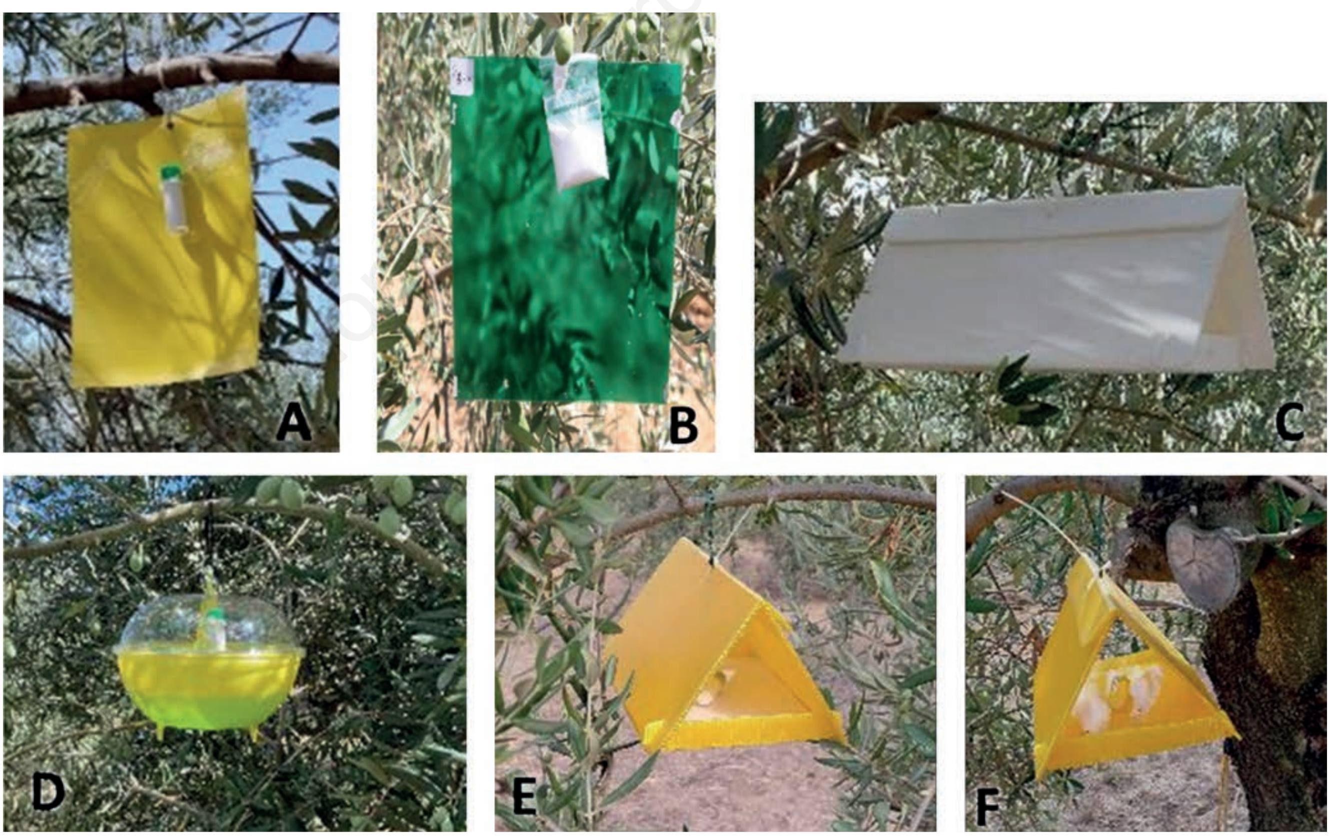

Figure 2. The different types of devices used in the field trials: A) yellow panel; B) green panel; C) white Jackson with yellow panel; D) McPhail; E) yellow Jackson with white panel; F) yellow Jackson with yellow panel.

5×4 scheme was applied, with 5 devices and 4 replicates; in Lebanon and Tunisia, a 6×6 scheme was applied, with 6 devices and 6 replicates. The distance between traps in the same block was around 50 m. Within each block, the traps were rotated every four days in Greece, Italy, Spain and Tunisia and every six days in Lebanon.

In all countries, the trials were carried out at the end of the summer or in the autumn months, *i.e.*, during the period when the monitoring system with attractant devices is implemented in most Mediterranean countries. In each country, the start time was decided when an increase in the *B. oleae* population was observed to have a sufficient number of catches in the traps. Specifically, they started on August 29th, 2021 in Lebanon, on September 14th and 27th in Spain and Italy, respectively, on October 24th in Greece, and on November 8th in Tunisia.

A complete rotation of the traps was carried out once in all countries, except Tunisia, where it was carried out twice. The total duration of the experiment was 24 days in Greece, Italy and Spain, 42 days in Lebanon, and 48 days in Tunisia.

During each monitoring period, all sticky panels and the content of MP traps were brought to the laboratory to identify trapped insects.

In addition to the male and female olive flies, the following non-target insect groups were recorded: lacewings (Chrysopidae), hoverflies (Syrphidae), ladybirds (Coccinellidae), bees (Apoidea) and hymenopteran parasitoids. For this last category, in Greece and Spain, insects belonging to Ichneumonoidea, Chrysidoidea and Chalcidoidea were considered together, without stricter identification, whereas in Italy, Lebanon and Tunisia, identification was performed at the family level. The identification of the different insects found in the traps was realised under a magnifying stereoscope based on several identification keys (Ashmead, 1900; Achterberg, 1993; Sarthou *et al.*, 2001; Tschorsnig and Herting, 2001; Noyes, 2007; Giacomino, 2007; Broad, 2011).

Data analysis

For each experimental site, *B. oleae* males and females and non-target insect categories expressed as individuals/trap/day were submitted to a one-way analysis of variance (ANOVA), with the trap device as the main effect. All analyses were conducted using Statistical Package for the Social Sciences Statistics version 26. Before analysis, counts (x+1) were natural log-transformed to normalize the variances and standardize the averages. The averages were separated using the *post-hoc* Tukey-Kramer test at $P<0.05$.

Results

Bactrocera oleae trap captures

Considering all traps together, the OFF catches in various countries ranged from the highest level of 9.9 flies/trap/day (FTD) in Spain to a minimum of 0.1 FTD in Greece, Italy and Lebanon; in the case of Tunisia, only sporadic catches were made, which did not allow for statistical analysis.

Regarding *B. oleae* male catches, YP was the most effective in all countries (Figure 3). In Italy and Spain, GP and MP were statistically

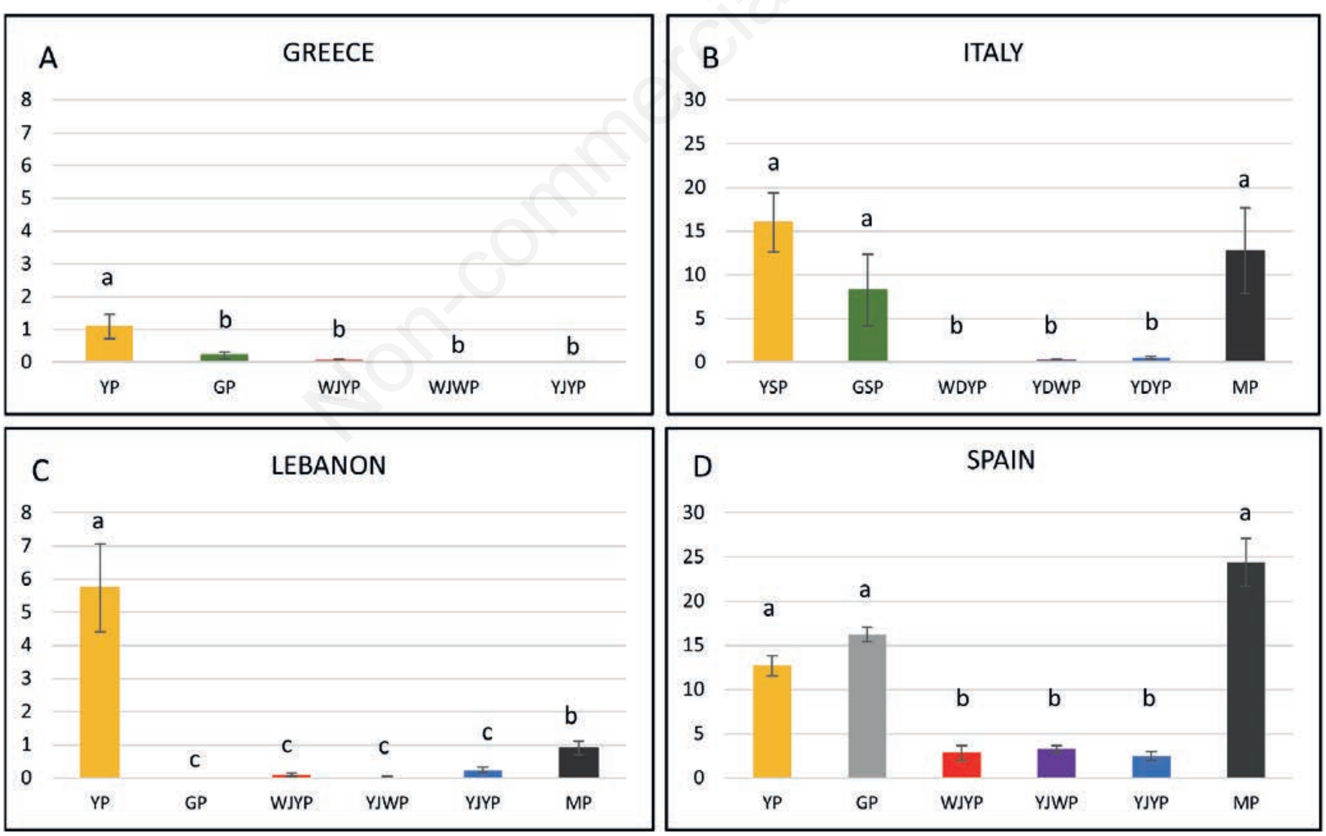

Figure 3. Mean daily capture of *Bactrocea oleae* males in the attractant devices in Greece (A), Italy (B), Lebanon (C), and Spain (D). YP, yellow panel; GP, green panel; WJYP, white Jackson with yellow panel; YJWP, yellow Jackson with white panel; YJYP, yellow Jackson with yellow panel; MP, McPhail; WJWP, white Jackson with white panel (only for Greece). Different letters refer to significant differences between devices (ANOVA, P<0.05).

as effective as YP, although GP captured fewer flies. However, in Lebanon, MP was significantly less effective than YP, and in Greece and Lebanon, GP caught fewer flies than YP. Jackson traps, in any tested combination (white or yellow Jackson traps with white or yellow sticky panels), showed the lowest number of catches in all countries. The ANOVA results are reported in *Supplementary Table 1*.

For females, YP was the most effective in all countries (Figure 4). In Spain, GP and MP were also as effective as YP. In Italy, the same effectiveness was shown for YP and MP, whereas GP was statistically less effective. As for males in Greece and Lebanon, GP caught fewer flies than YP. Jackson traps, in any tested combination (white or yellow Jackson trap with a white or yellow sticky panel), showed the lowest number of catches in all countries. The statistical results are summarised in *Supplementary Table 1*.

The average proportion of females and males varied from country to country (see *Supplementary Table 2*). In Greece, there was a prevalence of females over males in all trapping devices. In Italy, in the case of YP, there was a marked prevalence of males over females but a 1:1 proportion in GP and MP. In Lebanon, there was a prevalence of males in all tested devices. In Spain, there was, in general, a proportion close to 1:1, with a slight prevalence of females in sticky panels and yellow Jackson traps.

Natural enemies' capture

Chrysopidae

Lacewings were found in all trials, being more abundant in Italy and Spain and less abundant in Greece and Lebanon. In Tunisia, only one specimen was caught during the trial period in MP. In Italy and Spain, MP was the most attractive trap, whereas in Greece and Lebanon, it was YP (Figure 5). In Spain, although to a lesser extent, all other traps caught Chrysopidae, while in Italy, the other traps caught very few specimens. In Greece, GP was comparable to YP (Figure 5). The statistical results are reported in *Supplementary Table 1*.

Coccinellidae

In Lebanon, only a few ladybirds were caught in YP, JYWP and MP (Figure 6), with no statistical differences among trap types (see *Supplementary Table 1*).

Syrphidae

No hoverflies were caught in Italy or Spain. In Lebanon, due to the low number of individuals captured, statistical tests were not conducted. In Greece, trapping was more abundant; in this case, YJYP was the most attractive device, followed by YJWP and WJWP (Figure 7). The captures of syrphids on either YP or GP were kept at almost zero levels. In Tunisia, GP and YP were the only traps to attract a few specimens (Figure 7). The statistical results are shown in *Supplementary Table 1*.

Hymenopteran parasitoids

The number of parasitoids caught during the trials was very variable in different countries, being higher in Italy and Lebanon and much lower in Spain. In Italy and Tunisia, both YP and GP

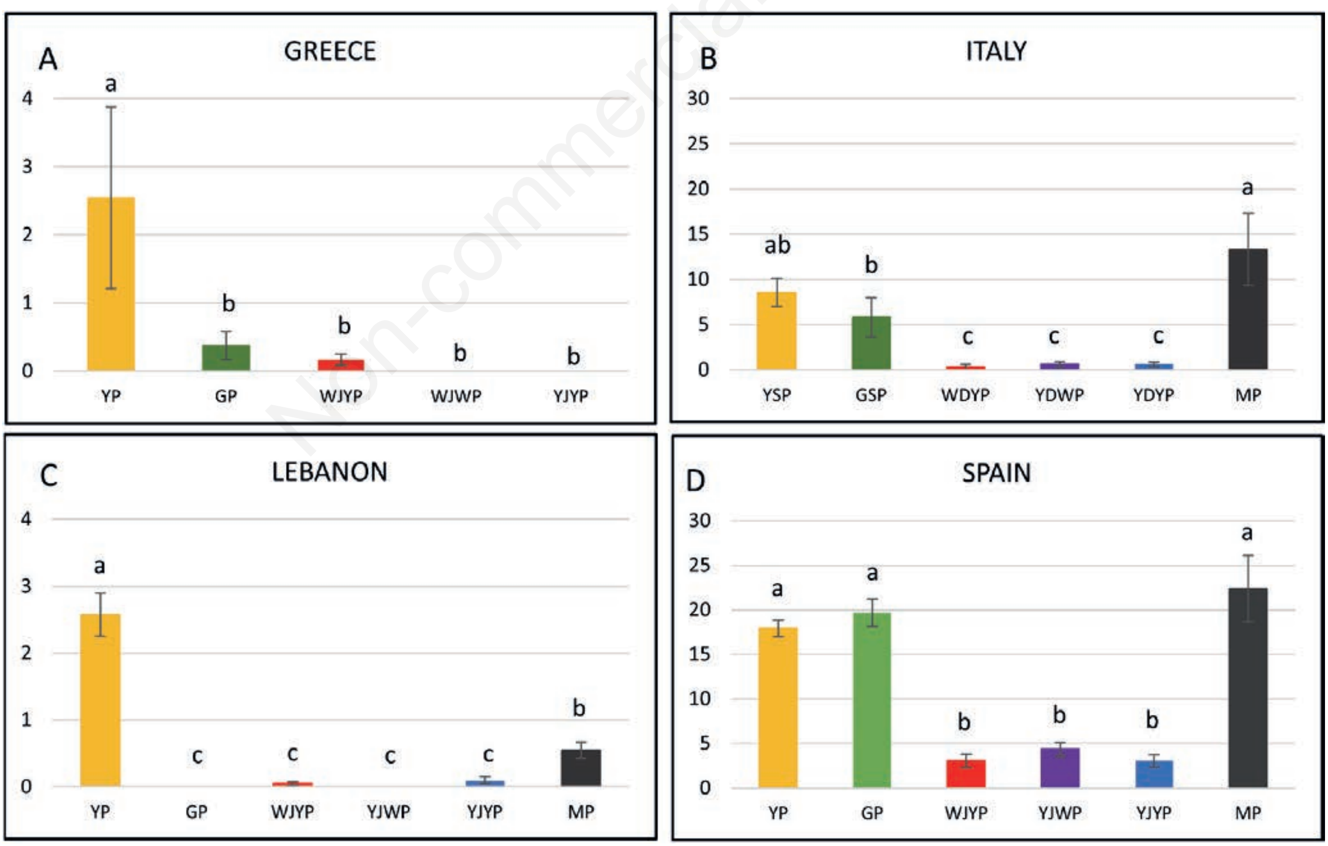

Figure 4. Mean daily captures of *Bactrocea oleae* females in the attractant devices in Greece (A), Italy (B), Lebanon (C), and Spain (D). YP, yellow panel; GP, green panel; WJYP, white Jackson with yellow panel; YJWP, yellow Jackson with white panel; YJYP, yellow Jackson with yellow panel; MP, McPhail; WJWP, white Jackson with white panel (only for Greece). Different letters refer to significant differences between devices (ANOVA, P<0.05).

were the most attractive devices. In Lebanon, however, YP was by far the most attractive compared to all other devices tested (Figure 8). In Spain, GP caught about one-third as many specimens as YP, similar to both yellow Jackson traps (Figure 8). In all countries, MP captured a very low number of parasitoids. The statistical results are shown in *Supplementary Table 1*.

In Italy, Lebanon and Tunisia, hymenopteran parasitoids have been identified at the family level. In Italy, 16 families were found. The most common were Mymaridae and Platygastridae, followed by Eurytomidae, Pteromalidae and Encyrtidae (Figure 9A). In Lebanon, almost all parasitoids belonged to the superfamily Chrysidoidea; the remainder belonged to the families Encyrtidae, Pteromalidae and Eupelmidae (Figure 9B). In Tunisia, the Ichneumonidae family was dominant over Braconidae, whereas families in the Chalcidoidea group were less abundant (Figure 9C).

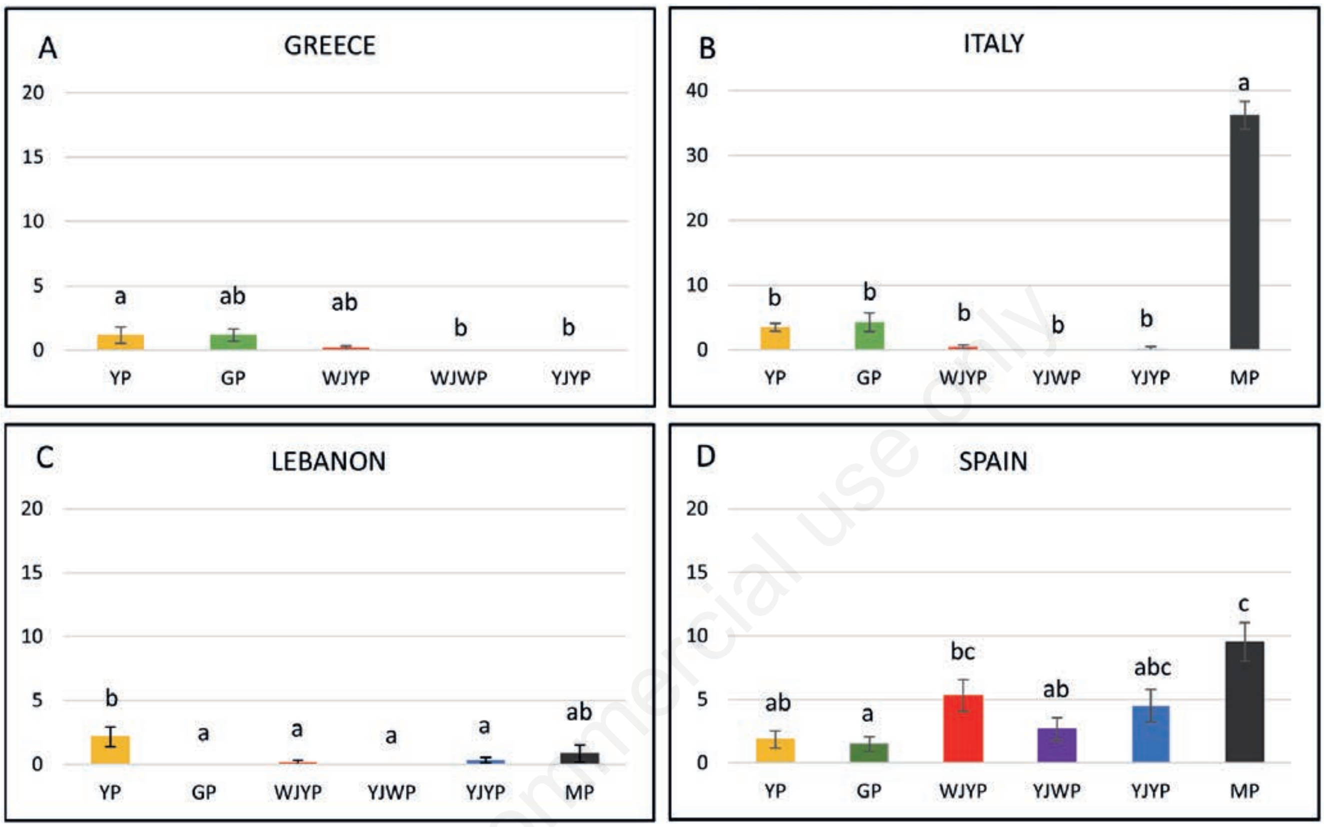

Figure 5. Mean captures of Chrysopidae in the attractant devices in Greece (A), Italy (B), Lebanon (C), and Spain (D). YP, yellow panel; GP, green panel; WJYP, white Jackson with yellow panel; YJWP, yellow Jackson with white panel; YJYP, yellow Jackson with yellow panel; MP, McPhail; WJWP, white Jackson with white panel (only for Greece). Different letters refer to significant differences between devices (ANOVA, P<0.05).

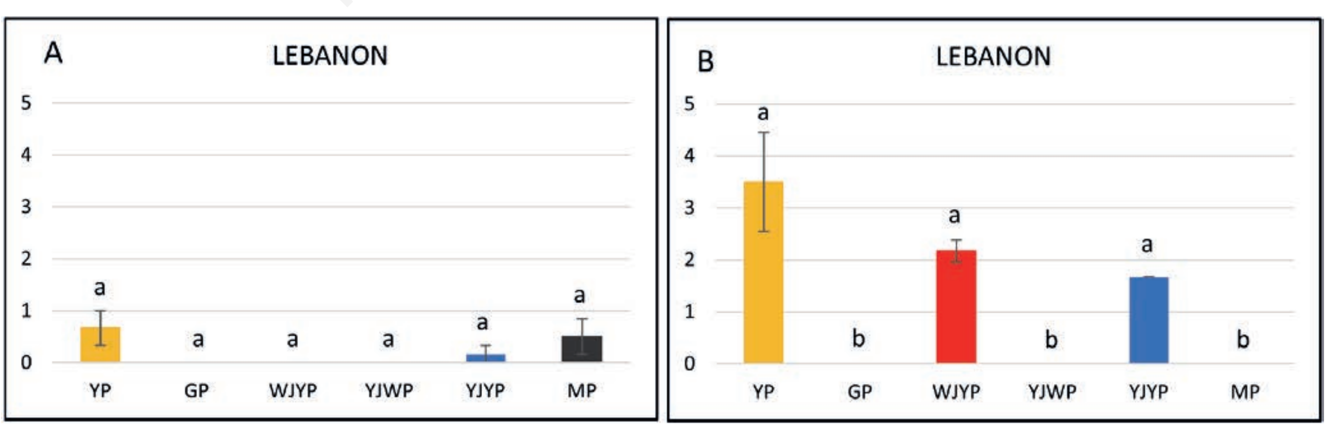

Figure 6. Mean capture of Coccinellidae (A) and Apoidea (B) in attractant devices in Lebanon. YP, yellow panel; GP, green panel; WJYP, white Jackson with yellow panel; YJWP, yellow Jackson with white panel; YJYP, yellow Jackson with yellow panel; MP, McPhail. Different letters refer to significant differences between devices (ANOVA, P<0.05).

Apoidea

Bees were captured only in Lebanon in YP and in Jackson traps with YP (Figure 6). The specimens identified belonged to five families, the most abundant of which was Colletidae, with 43% of bee captures, whereas 21% of the captures were honeybees (Figure 10). The statistical results are reported in *Supplementary Table 1*.

Discussion and Conclusions

The comparative results of the OFF captures among the trap devices showed that MP and YP had the best trapping performance for both males and females and that it was fairly evenly across the various countries where the experiments were conducted. In Lebanon, however, MP performed quite poorly. In any case, for

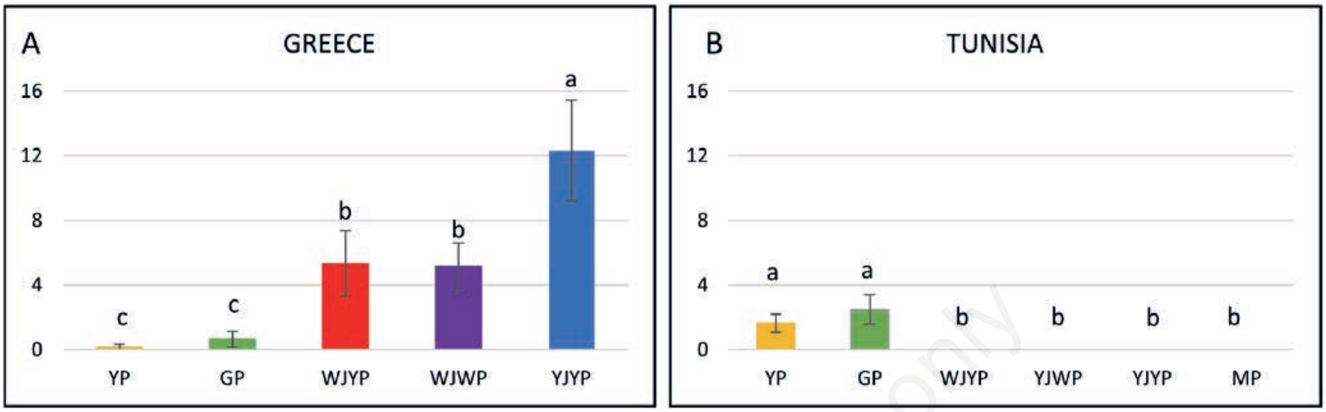

Figure 7. Mean capture of Syrphidae in the attractant devices in Greece (A), and Tunisia (B). YP, yellow panel; GP, green panel; WJYP, white Jackson with yellow panel; YJWP, yellow Jackson with white panel; YJYP, yellow Jackson with yellow panel; MP, McPhail; WJWP: white Jackson with white panel (only for Greece). Different letters refer to significant differences between devices (ANOVA, P<0.05).

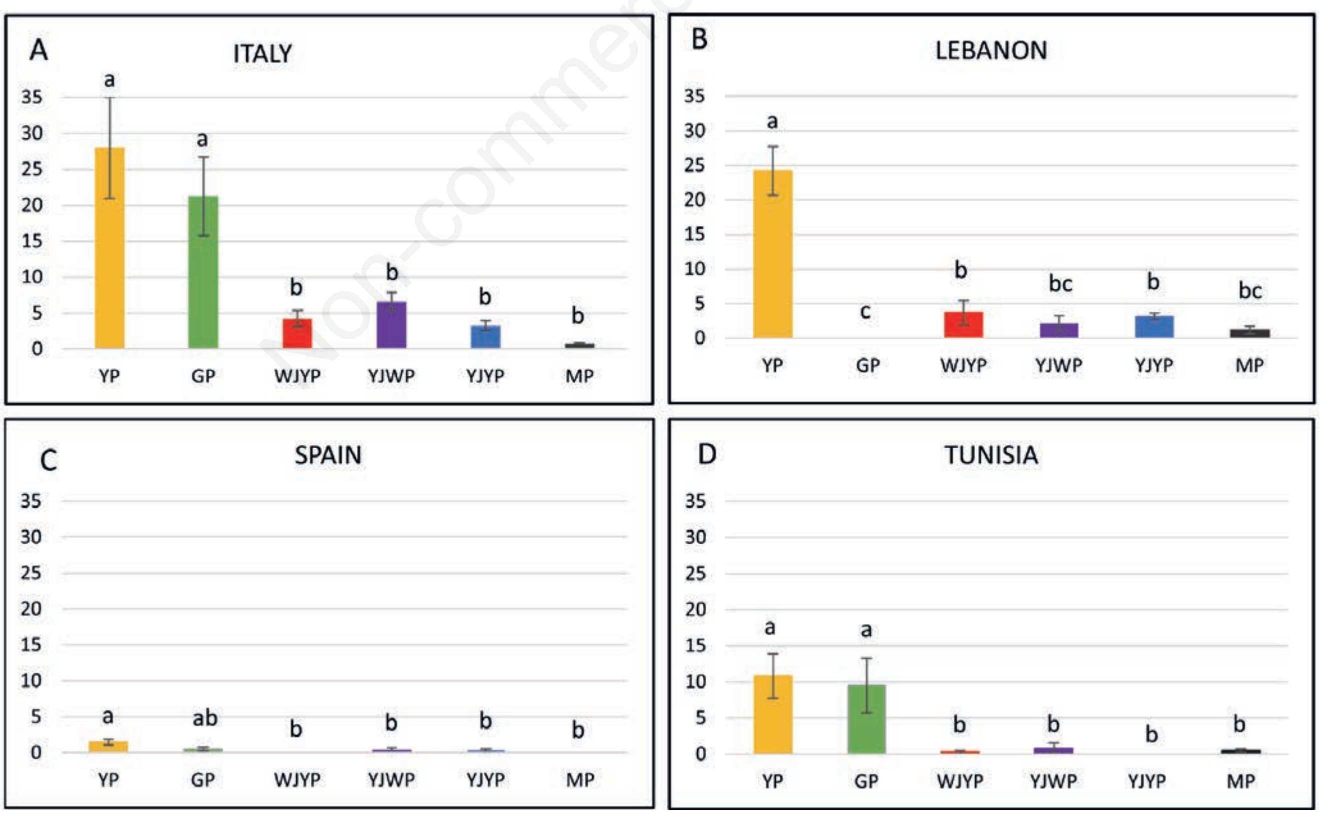

Figure 8. Mean captures of hymenopteran parasitoids in the attractant devices in Italy (A), Lebanon (B), Spain (C), and Tunisia (D). YP, yellow panel; GP, green panel; WJYP, white Jackson with yellow panel; YJWP, yellow Jackson with white panel; YJYP, yellow Jackson with yellow panel; MP, McPhail. Different letters refer to significant differences between devices (ANOVA, P<0.05).

comparison reasons, we tested only one-sided sticky panels, while the standard practice is to have both sticky surfaces exposed. Studies carried out in Crete (Greece) in September reported that YP captures were significantly lower than those using MP (Varikou *et al.*, 2013), whereas other studies in the Balearic Islands (Spain) highlighted a better performance of YP than MP (Miranda *et al.*, 2019). Katsoyannos *et al*. (2007) suggested that, under dry and hot conditions, wet traps perform better for OFF than dry ones. Environmental conditions can thus influence the performance of traps and could explain the differences observed among the different cases. More generally, the information provided by monitoring traps in the field is always limited because it is subject to ecological or biological factors that may interfere with the performance of the trap; thus, a good practice is to supplement the capture of adults with sampling of the drupes (Varikou, 2014).

GP had a comparable result with YP in Italy and Spain but a significantly lower result in Greece and Lebanon. The color yellow has a reflectance between 500 and 520 nm and has the highest attractivity toward *B. oleae* (Girolami and Cavalloro, 1973). In previous experiments, Katsoyannos and Kouloussis (2001) highlighted that yellow was comparatively more attractive for *B. oleae* than green. However, odor attractants are usually more effective than visual cues (Prokopy *et al.*, 1975); this could explain why GP and YP performed equally in Italy and Spain.

Jackson traps with different combinations of colours always had significantly lower levels of catches. Calabrese and Sciarretta (2019) tested various traps, including YP and Jackson traps of different sizes, baited with ammonium carbonate, and in contrast to our results, they found that making traps equivalent in relation to the size of the sticky surface resulted in no differences in the capture of both sexes. However, the observed lower catches could be explained by the reduced propensity of *B. oleae* individuals to enter the inner part of the trap. For example, using MP, Prokopy *et al.* (1975) observed that flies first land on the trap exterior, mostly on the outer wall, and many of these arrivals eventually fly away and escape.

The ammonium carbonate used in dry traps was demonstrated to attract both sexes, although with a variable ratio of females to total catches among the different countries. For YP, the ratio was above 50% in Greece and Spain but 33-35% in Italy and Lebanon. In previous studies where ammonia attractants were used, a prevalence of males was usually found (Longo *et al.*, 1982; Rice *et al.*, 2003; Katsoyannos *et al.*, 2007). However, Mazomenos *et al*. (2002) found no differences in male and female captures when using MP baited with 3% ammonium carbonate. The result was similar for GP, except in Lebanon, where this device caught very few flies and no females. In the case of MP activated with water-soluble proteins, the ratio was close to 50% in Italy and Spain, lower than that in Lebanon.

With regard to the capture of non-target insects, Crysopidae is an important group of beneficial insects, and its presence is well-known in olive agroecosystems (Herrera *et al.*, 2019). Their larval stages are key predators of main olive pests, such as *Prays oleae* (Bernard), *Saissetia oleae* (Olivier) and *Euphyllura olivina* (Costa) (Ramos *et*

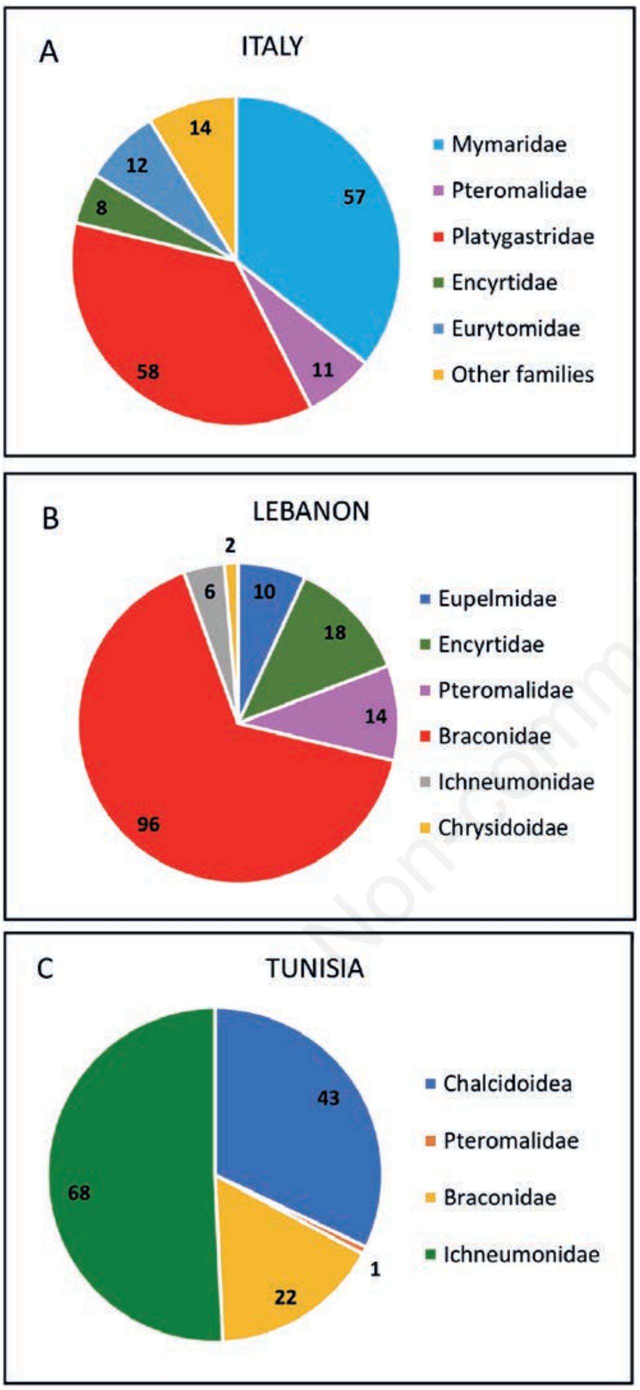

Figure 9. Families of hymenopteran parasitoids recorded in all trapping devices during the field trials carried out in Italy (A), Lebanon (B), and Tunisia (C).

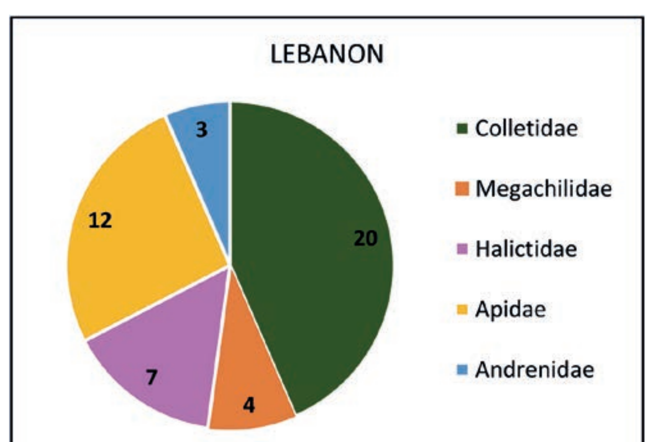

Figure 10. Numbers of specimens belonging to different families of Apoidea recorded in all trapping devices during the field trials carried out in Lebanon.

al., 1984; Campos, 1989; Szentkirályi, 2001). In our trials, lacewings were well represented at all sites. MP caught more individuals than the other traps in Italy and Spain, whereas, in Lebanon and Greece, the highest catches were found using the two sticky panels. The high presence in MP-type traps has also been reported by Katsoyannos *et al*. (2007), who observed an increase in catches when baiting with ammonium bicarbonate. The use of ammonium carbonate in sticky traps may explain the high number caught in the sticky traps in our experiments.

Captures related to hymenopteran parasitoids, for which sensitivity to certain colors, such as yellow, is known (Vargas *et al.*, 1991), were relatively homogenous between countries, with a general prevalence of catches in sticky panels. The family composition in traps was diverse in the three countries where identification was carried out, showing different dominant families. Olive groves are home to a rich fauna of hymenopteran parasitoids, linked to the numerous phytophagous insects present in the olive grove, including *B. oleae*, as well as to the many species linked to other plants existing in this rich agroecosystem (Neuenschwander, 1982; Pascual *et al.*, 2022). Among the most commonly reported families are Scelionidae, Encyrtidae, Pteromalidae, Eulophidae, Mymaridae, Braconidae, Aphelinidae and Trichogrammatidae (Pascual *et al.*, 2022). Their faunal composition is strongly influenced by environmental factors, such as the presence of cover crops (Rodríguez *et al.*, 2012) and the heterogeneity of the landscape (Pascual *et al.*, 2022).

Coccinellidae is a family of predatory beetles considered to be well-represented in olive groves, with numerous species present from spring to autumn (Gonçalves *et al.*, 2007; Franin *et al.*, 2019). Neuenschwander (1982) reported the presence of hundreds of coccinellids in YP, with a decline during the summer months. However, in our experiments, they were found only in Lebanon in very low numbers. This result could be related to the type of management of the herbaceous cover of the olive grove; in fact, Lebanon was the only case where there was no weed management, not even mowing.

The presence of Syrphidae in olive groves has been reported to be well-represented and favored by complex landscape structures in the presence of flowers (Ortega *et al.*, 2023). Syrphid larvae are predators of various olive pests, such as *Euphyllura straminea* Loginova, *E. olivina*, *Palpita vitrealis* (Rossi) and *P. oleae* (Rojo *et al.*, 2003), whereas adults are pollinators of many types of plants, including olives (Canale and Loni, 2010). In our case, hoverflies were found only in tests conducted at the end of the season (Greece and Tunisia), when some fall blooms probably occurred. In Tunisia, most of the catches occurred in sticky panels, whereas in Greece, catches in sticky panels were extremely low but highest in yellow Jackson traps.

A large number of bees are usually found in the olive grove agroecosystem throughout the year, although the olive tree does not require entomophilous pollination (Pascual, 2022). However, it has been reported that even if olive trees produce small and inconspicuous flowers that are less attractive to many pollinators, bees are highly attracted to the scent and nectar of olive flowers (Giovanetti, 2018). In our trials, we observed bee catches only in Lebanon in YP with one-quarter of them being honeybees.

According to the captured data of male and female *B. oleae* flies, both MP and YP showed the best performance in terms of the flies captured. Therefore, as far as their efficacy is concerned, both trap types can be used in automated traps for monitoring OFF, particularly the sticky panel, which can be easily adapted (Shaked *et al.*, 2018). From an operational point of view, counting the trapped individuals in the MP trap and their sexing is a more time-consuming and complex operation than the adhesive panel. Furthermore, in the case of low temperatures, the reduced evaporation of the liquid may reduce the attractiveness of MP. However, the sticky panel, in the case of high populations, can quickly become saturated within a few days, *i.e.*, it is covered with dead flies and loses its adhesive capacity.

Overall, YP and GP showed more catches of hymenopteran parasitoids in all countries, whereas for other groups of non-target insects, such as Chrysopidae, a more differentiated situation was observed. According to Neuenschwander (1982), who assessed the effect on beneficial insects when using YP for *B. oleae* mass trapping, a density of 3-5 YP/tree can virtually eliminate beneficial fauna from the olive grove. However, if YPs are used for monitoring purposes with a density of around 2 YP/ha, the negative effect on the populations of any non-target insect groups is deeply reduced.

These data, combined with the efficacy data of the different trap types tested in this study, are also useful in choosing the trap type to be used in the development of electronic traps. In fact, the selection of the trap type should be made based on various evaluations carried out on-site, including operational ones such as those implemented here in 5 Mediterranean countries. Based on the evidence gained, both MP and YP could be used in automated traps to monitor OFFs, particularly sticky panels, which can be easily adapted (Shaked *et al.*, 2018).

References

ASHMEAD W.H., 1900 – Classification of the Bees, or the Superfamily Apoidea. – T. Am. Entomol. Soc. 26: 49-100.

ACHTERBERG C. VAN, 1993 – Illustrated key to the subfamilies of the Braconidae (Hymenoptera: Ichneumonoidea). – Zool. Verh. Leiden 283, 30.X: 1-189.

BRAHAM M., 2013 – Trapping adults of the Medfly *Ceratitis capitata* and non target insects: Comparison of low-cost traps and lures. – Tunisian J. Plant Prot. 8: 107-118.

BROAD G., 2011 – Identification key to the subfamilies of Ichneumonidae (Hymenoptera). – The Natural History Museum, London: 40 pp.

CABALLERO J.A., 2002 – Sistema de control de la mosca del olivo (*Bactrocera oleae*) en olivar ecológico. Experiencias en “Los Pedroches”. – Actas de la I Conferencia Mundial de IFOAM sobre olivar ecológico: Producciones y culturas. [In Spanish] Puente de Génave (Jaén), Spain, May 22-25: 421-424.

CALABRESE P., SCIARRETTA A., 2019 – Evaluation of attractant devices for the monitoring of olive fruit fly with particular reference to colour, size and selectivity toward natural enemies. – IOBC-WPRS Bull. 141: 138-146.

CAMPOS M., 1989 – Observaciones sobre la bioecologia de *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) en el sur de España. – Neuroptera Int. 5: 159-164.

CANALE A., LONI A., 2010 – Insects visiting olive flowers (*Olea europaea* L.) in a Tuscan olive grove. – Redia XCIII: 95-98.

COELHO V.P., BENTO A., MEXIA A., PEREIRA J.A., 2010 – Olive fruit fly, *Bactrocera oleae* (Gmelin), mass-trapping with olipe traps: effect of hole size in the olive fruit fly and non-target arthropod captures. – Proceedings 8th International Symposium on Fruit Flies of Economic Importance, Valencia, 26 Sept-1 Oct 2010. Proceeding Book: 309-315.

FAO/IAEA., 2018 – Trapping guidelines for area-wide fruit fly programmes – 2nd ed., Enkerlin W.R. and Reyes-Flores J. (eds). Rome, Italy. 65 pp.

FATHKOHI S.A., SAHRAGARD A., MOJDEHI M.R.A., 2018 – The efficacy of some traps in attracting and capturing olive fruit fly, *Bacterocera oleae* (Diptera: Tephritidae) and non-target insects in Roudbar region of Iran. [in Iranian] – J. Entomol. Soc. Iran. 38: 307-318.

FRANIN K., KUŠTERA G., MARCELIĆ Š., MARIČIĆ B., LONČAR J., KOS T., 2019 – The ladybeetle fauna (Coleoptera: Coccinellidae) in olive orchards on the island of Pašman (Croatia). – Integrated Protection of Olive Crops IOBC-WPRS Bull 141: 188-192.

GALDINO L.T., RAGA A., 2018 – Non-target insects captured in McPhail traps baited with proteinaceous and salts in citrus crop. – J. Adv. Biol. Biotechnol. 17: 1-9.

GIACOMINO M., 2007 – Clé de détermination des Myrmeleontidae de France. – Invertébrés Armoricains, 1: 29-34.

GIOVANETTI M., 2018 – Do bees like olive? A preliminary analysis of honey bee behaviour on flowers of the wind-pollinated species *Olea europaea*. – Acta Hortic. 1199: 121-126.

GIROLAMI V., CAVALLORO R., 1973 – Metodi cromotropici per indagine di popolazione degli adulti di *Dacus oleae* Gmel. – Note e appunti Sper. Entomol. Agr. Perugia 14: 13-29.

GONÇALVES M.F., SANTOS S.A.P., RAIMUNDO A., PEREIRA J.A., TORRES L.M., 2007 – Coccinellids associated with olive groves in north-eastern Portugal. – Integrated Protection of Olive Crops, IOBC/wprs Bull. 30: 211.

INFUSINO M., IANNOTTA N., SCALERCIO S., 2014 – Field selectivity of a spinosad-poisoned bait toward target tephritids and non-target insects. – Boll. Soc. Entomol. Ital. 146: 11-15.

HAFSI A., ABBES K., HARBI A., DUYCK P.-F., CHERMITI B., 2015 – Attract-and-kill systems efficiency against *Ceratitis capitata* (Diptera: Tephritidae) and effects on non-target insects in peach orchards. – J. Appl. Entomol. 140: 28-36.

HERRERA R.A., CAMPOS M., GONZÁLEZ-SALVADÓ M., RUANO F., 2019 – Abundance and population decline factors of Chrysopid juveniles in olive groves and adjacent trees. – Insects 10: 134.

KATSOYANNOS B.I., KOULOUSSIS N.A., 2001 – Captures of the olive fruit fly *Bactrocera oleae* on spheres of different colours. – Entomol. Exp. Appl. 100: 165-172.

KATSOYANNOS B.I., PAPADOPOULOS N.T., HEATH R.R., 2007 – Field evaluation of trap types and lures for *Bactrocera oleae* (Diptera: Tephritidae). Experiments conducted in Chios, Greece. In: Development of Improved Attractants and Their Integration into Fruit Fly SIT Management Programmes. – IAEA, Vienna, 5-7 May 2005. Proceedings Book: 33-42.

LEBLANC L., RUBINOFF D., VARGAS R.I., 2009 – Attraction of nontarget species to fruit fly (Diptera: Tephritidae) male lures and decaying fruit flies in traps in Hawaii. – Environ. Entomol. 38: 1446-1461.

LONGO S, BENFATTO D., 1982 – Observation on olive fly (*Dacus oleae* (Gmel.)) — Population dynamics in Sicily. – Proc CEC/IOBC Int Symp, Fruit Flies of Econ Importance. Athens, Greece. - AA Balkema, Rotterdam: 612-615.

MANOUKIS N.C., LEATHERS J., BEUCKE K., CARVALHO L.A.F.N., 2023 – Jackson trap efficiency capturing *Bactrocera dorsalis* and *Zeugodacus cucurbitae* with male lures with and without insecticides. – J. Appl. Entomol. 147: 231-238.

MAZOMENOS B.E., A. PANTAZI-MAZOMENOU, D. STEFANOU, 2002 – Attract and kill of the olive fruit fly *Bactrocera oleae* in Greece as a part of an integrated control system. – Bull. OILB/SROP. 25: 137-146.

MARTÍN A., ETXEBESTE I., PÉREZ G., ÁLVAREZ G., SÁCHEZ E., PAJARES J., 2013 – Modified pheromone traps help reduce bycatch of bark-beetle natural enemies. – AgrForest Entomol. 15: 86-97.

MCCLAIN D.C., ROCK G.C., WOOLLEY J.B., 1990 - Influence of Trap color and San Jose Scale (Homoptera: Diaspididae) pheromone on sticky trap catches of 10 Aphelinid Parasitoids (Hymenoptera). - Environ. Entomol. 19: 926-931.

MIRANDA M.Á., BARCELÓ C., VALDÉS F., FELIU J.F., NESTEL D., PAPADOPOULOS N., SCIARRETTA A., RUIZ M., ALORDA B., 2019 – Developing and implementation of Decision Support System (DSS) for the control of olive fruit fly, *Bactrocera oleae*, in Mediterranean olive orchards. – Agronomy. 9.

NEUENSCHWANDER P., 1982 – Beneficial insects caught by yellow traps used in mass trapping of the olive fly, *Dacus oleae*. – Entomol. Exp. Appl. 32: 286-296.

ORDANO M., ENGELHARD I., REMPOULAKIS P., NEMNY-LAVY E., BLUM M., YASIN S., LENSKY I., PAPADOPOULOS N., NESTEL D., 2015 – Olive fruit fly (*Bactrocera oleae*) population dynamics in the Eastern Mediterranean: influence of exogenous uncertainty on a monophagous frugivorous insect. – PLoS ONE. 10: 1-18.

ORTEGA M., MATALLANAS B., RICARTE A., PASCUAL S., 2023 – A complex landscape favours the abundance and species richness of syrphids (Diptera: Syrphidae) in olive groves. – Ecol. Entomol. 48: 568-581.

PASCUAL S., 2022 – Landscape composition and configuration affect bees in the olive agroecosystem. – J. Appl. Entomol. 146: 1-18.

PASCUAL S., RESCIA A.J., ONDUL B.A., PAUL C., ORTEGA M., 2022 – Effects of landscape structure on abundance and family richness of hymenopteran parasitoids in the olive agroecosystem. – Agr. Ecosyst. Environ. 332:107914.

PORCEL M., RUANO F., SANLLORENTE O., CABALLERO J.A., CAMPOS M.., 2009 – Short communication. Incidence of the OLIPE mass-trapping on olive non-target arthropods. – Spanish J. Agricult. Res. 7: 660-664.

PROKOPY R.J., ECONOMOPOULOS A.P., MCFADDEN M.W., 1975 – Attraction of wild and lab-cultured *Dacus oleae* flies to small rectangles of different hues, shades, and tints. – Entomol. Exp. Appl. 18: 141-152.

RAGOUSSIS N., 2005 – Contribution to the biological olive agriculture. Efficient control of the olive fruit fly by the ECO-TRAP. – OILB/wprs Bull. 28: 29-35.

RAMOS P., CAMPOS M., RAMOS J., 1984 – Estabilización del ataque de Prays oleae Bern. y de la actividad de los depredadores oófagos sobre el fruto del olivo. – Bol. Sanidad Vegetal. Plagas. 10: 239-243.

REI F.T., CAMPOS M., TORRES L.M., 2010 – Beneficial arthropods associated with the olive tree canopy in Alentejo (South region of Portugal). – IOBC/WPRS Bull. 53: 117-127.

RICE R., PHILLIPS P., STEWART-LESLIE J., SIBBETT G., 2003 – Olive fruit fly populations measured in Central and Southern California. – Calif. Agr. 57: 122-127.

RODRÍGUEZ E., GONZÁLEZ B., CAMPOS M., 2012 – Natural enemies associated with cereal cover crops in olive groves. – B. Insectol. 65: 43-49.

ROJO S., GILBERT F.S., MARCOS-GARCÍA M.A., NIETO J.M., MIER M.P., 2003 – Revisión mundial de los sírfidos depredadores y sus presas (Diptera, Syrphidae). – CIBIO Ed. Alicante, Universidad de Alicante, Servicio de Publicaciones: 219 pp.

RUANO F., LOZANO C., GARCIA P., PENA A., TINAUT A., PASCUAL F., CAMPOS M., 2004 – Use of arthropods for the evaluation of the olive–orchard management regimes. – Agricult. Forest. Entomol. 6: 111-120.

SARTHOU J.P., SARTHOU V., SPEIGHT M.C.D., 2001 – Clé de 88 Genres de Diptères Microdontidae et Syrphidae d'Europe Occidentale, 2001. – Cahiers Scientifiques du Conservatoire d'espaces naturels des Hauts-de-France: 116 pp.

SZENTKIRÁLYI F., 2001 – Lacewings in fruit and nut crops. In:

WHITTINGTON A.E., MCEWEN P.K., NEW T.R., Lacewings in the Crop Environment. – Cambridge University Press, Cambridge, UK: 172-238.

SHAKED B., AMORE A., IOANNOU C., VALDÉS F., ALORDA B., PAPANASTASIOU S., GOLDSHTEIN E., SHENDEREY C., LEZA M., PONTIKAKOS C., PERDIKIS D., TSILIGIRIDIS T., TABILIO M.R., SCIARRETTA A., BARCELÓ C., ATHANASSIOU C., MIRANDA M.A., ALCHANATIS V., PAPADOPOULOS N., NESTEL D., 2018 – Electronic traps for detection and population monitoring of adult fruit flies (Diptera: Tephritidae). – J. Appl. Entomol. 142: 43-51.

SHIMODA M., HONDA K., 2013 – Insect reactions to light and its applications to pest management. – Appl. Entomol. Zool. 48: 413-421.

TSCHORSNIG H-P., HERTING B., 2001 – The Tachinids (Diptera: Tachinidae) of Central Europe: Identification Keys for the Species and Data on Distribution and Ecology. Translated by R. RAYNER and C. RAPER, 2001 from an original, 1994. – State Museum of Natural Science, Stuttgart, 150 pp., 291 ill.

TZANAKAKIS M.E., 2006 – Insects and Mites Feeding on Olive: Distribution, Importance, Habits, Seasonal Development, and Dormancy. – Appl. Entomol. Library Ed. Brill. Leiden, Boston: 182 pp.

NOYES J., 2007 – Universal Chalcidoidea Database. In: Bánki O., Roskov Y., Döring M., Ower G., Hernández Robles D.R., Plata Corredor C. A., Stjernegaard Jeppesen T., Örn A., Vandepitte L., Hobern D., Schalk P., Dewalt R. E., Ma K., Miller J., Orrell T., Aalbu R., Abbott J., Adlard R., Adriaenssens E.M., et al. Catalogue of Life Checklist. – The Natural History Museum, UK.

VARIKOU K., ALEXANDRAKIS V., GIKA V., BIROURAKI A., MARNELAKIS C., SERGENTANI C., 2013 – Estimation of fly population density of *Bactrocera oleae* in olive groves of Crete. – Phytoparasitica 41: 105-111.

VARIKOU K., 2014 – *Bactrocera oleae* (olive fruit fly). – CABI Compendium. CABI. Available from: https://doi.org/10.1079/cabicompendium.17689

VARGAS R.I., STARK J.D., PROKOPY R.J., GREEN T.A., 1991 – Response of oriental fruit fly (Diptera: Tephritidae) and associated parasitoids (Hymenoptera: Braconidae) to different-color spheres. – J. Econ. Entomol. 84: 1503-1507.

Online supplementary material:

Table S1. Statistical results of ANOVA on the effect of attractant device on the captures of B. oleae *males and females, Apoidea, Chrysopidae, Coccinellidae, Syrphidae, hymenopteran parasitoids and Apoidea in each country.*

Table S2. Mean percentage of B. oleae *females (±SE) in the total catches for each tested device and country.*