

Mini Review

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Side Effects of Insecticides on Beneficial Insects: A Practical Tool to Identify Organic Agroecosystems

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Abstract

In order to achieving sustainability, integrated pest management (IPM) represents a remarkable improvement over previous conventional approaches, so optimizing the effectiveness of the entomophagy activity of natural enemies of pests is a determining factor. IPM does not necessarily require the suppression of insecticides, but rather affects the need to reduce their dependence, by eliminating unnecessary applications. However, the correct integration of chemical and biological control is essential part of sustainable pest management, for which a correct interpretation of the impact of insecticide treatments, is required. In IPM agroecosystems a great proportion of non-target insects are mainly affected by sublethal dose/concentration values. A sublethal dose/concentration defined as inducing no apparent mortality in the experimental population. The effects induced have been described affecting biology, physiology, or behavior of individuals or populations that survive to the exposure to a toxicant at lethal or sublethal dose/concentration. The set of behavioral modifications provides insects with an escape mechanism from the toxic effects of pesticides, which has been called behavioral resistance, as the first barrier or detoxification mechanism.

For the correct integration of insecticide applications and biological control, the influence of the insecticide side effects on beneficial insects should be evaluated. Recent studies suggest that, as in both conventional olive / IPM orchards, these species frequently show behavioral resistance, while in organic crops, their populations lack it. There seems to be a close relationship between the application of insecticides and the development of behavioral resistant populations. This finding has suggested establishing a practical procedure based on the realization of small-scale field applications, to subsequently monitor beneficial insect reactions, useful for identifying ecological agroecosystems. The implications of the implementation of this new methodology are discussed.

Keywords: Sublethal effects; Insecticides; Behavioral resistance; Beneficial insects; Olive pests; Predators; Parasitoids; Conventional management; IPM; Organic management

Introduction

In order to achieving sustainability, integrated pest management (IPM) represents a remarkable improvement over previous conventional approaches [1]. This crop production and phytosanitary protection model combines different management strategies and practices for healthy crops, to bring the pest organism to acceptable limits with the least possible ecological disturbance [2]. This includes the establishment of population thresholds for pests, which determine the need for chemical control, minimizing risks to human health and beneficial organisms. Currently, an area of 392,362 hectares of olive groves corresponds to IPM in Andalusia (southern Spain), which according to the regional government, it represents 71% of the total area dedicated to olive cultivation.

IPM does not necessarily require the suppression of insecticides, but rather affects the need to reduce their dependence, by eliminating unnecessary applications. A well-developed IPM

program, based on science, provides a wide range of techniques and offers new possibilities for pest control, which is obviously dependent on the use of pesticides [3]. In spite of this, insecticides represent essential elements on which the sustainability of an integrated management program depends, and it is very likely that this will continue as long as these products are available, effective and economically available [4]. With this objective, IPM programs resulted in safer and more judicious use of pesticides, flexible enough to integrate information about their impact on pests and their natural enemies, maintaining the quality of the ecosystem [3,5].

Among the IPM objectives are to successfully prevent the emergence of resistant populations, protecting beneficial insects by enhancing their action [6], which has been focused on: i / The conservation / enhancement of natural populations of beneficial

insects through to effective management of the agricultural environment (natural control), and ii /The increase of their populations through mass releases in the area of cultivation (biological control). Both allow to manage the pests efficiently and are compatible with the environment and with other control tactics [7,8]. First point includes habitat management, such as the establishment of an herbaceous plant cover, which, in addition to limiting the erodibility [9], is intended to enhance the natural control mechanisms [10-17].

Since insecticides constitute an essential part of IPM, this approach makes it necessary to evaluate their impact on beneficial fauna [4]. Most of the existing studies analyze the lethal effect of insecticides, including synthetic and natural products, but research on the sub lethal effects is still scattered. In field crops, lower doses / concentrations of insecticide occur, after the application is degraded by factors such as rainfall, temperature and sunlight. This means that a great proportion of non-target insects are mainly affected by sublethal dose/concentration values [18]. A sublethal dose/concentration defined as inducing no apparent mortality in the experimental population [19]. It is stated that, in general, doses / concentrations of insecticide below the lethal median (LD50 / LC50) are considered sublethal [20]. Sublethal effects have been described affecting biology, physiology, or behavior of individuals or populations that survive to the exposure to a toxicant at lethal or sublethal dose/concentration [4,20]. The sublethal effects may be manifested as reductions in life span, development rates, population growth, fertility, fecundity, changes in sex ratio, deformities, feeding, searching and oviposition [21-23]. The sublethal doses / concentrations of insecticides cause many alterations in the behavior of insects, interfering with their chemical communication system, thus reducing the chances of efficient localization of a pheromone source [20]. Among the induced symptoms have been described: jerky movements, overexcitation and hyperactivity [24-27]. Stimulation, as well as depression, of general locomotor behavior has also been cited, both for walking and for flying, causing uncoordinated or even convulsive movements, which therefore negatively affect reproductive processes, host location, dispersion, migration and food [4,21-23]. Nonetheless, these effects do not necessarily cause mortality of affected individuals, since the use of the term "insectistatics" [28] is suggested to apply it to those agents that can interfere with the processes of growth and reproduction, without necessarily killing. Quite the contrary,

this set of behavioral modifications provide insects with an escape mechanism from the toxic effects of pesticides, which is why they have been called behavioral resistance since it provides the first barrier or mechanism of detoxification. The affected insects having this skill show hyperreflexia, with a trend to start the flight more easily [29-31].

Among the side effects of insecticides, it has been reported that beneficial arthropods are severely affected by sublethal effects [4,19,20], although their impact has often been overlooked or underestimated. The determination of the side effects of insecticides acquires special relevance when considering the evolution of their populations in agricultural ecosystems. In the European Union, the registration and selection of insecticides for inclusion in IPM programs requires knowing their side effects on non-target organisms [32, 33]. As indicated in Table 1, *dimethoate* stand out in olive growing, being the most common insecticide, in both Conventional and IPM, among which the main difference consists in the criteria that determine the application of the insecticide. In the first case they are applied routinely, while in IPM their use is determined by the establishment of pest's population thresholds, which implies a considerable saving of insecticides with respect to conventional management. In view of the notable differences between them, the need to assess the impact of this reduction in the application of insecticides on the behavior of the populations of beneficial insects has been raised [34,35]. Since Insecticide applications induce behavioral modifications in natural enemies' insects affected by sublethal doses, it is likely their effects have an impact on the capture rates recorded in monitoring commonly used in olive growing, devices, such as the sticky chromatic traps, [15,36]. In order to detect anomalies in the capture rates of non-target insects, field experiments based on experimental insecticide applications on a small scale have been carried out, as a trigger for behavioral reactions of insects affected by sub lethal doses. The hypothesis of these studies is based on the statement that the beneficial insects under the managements that commonly include the application of insecticide (conventional, IPM) have most likely developed behavioral patterns that are a first step in acquiring resistance [4]. Therefore, insect species affected by sublethal doses would have developed lineages with behavioral modifications that would allow them to adapt to relatively frequent contact with insecticides, unlike what would happen in ecologically managed agroecosystems.

Table 1: Characterization of the different types of olive management according to pesticide applications (Period 2007- 2017; Spanish Agricultural Committee of Organic Agriculture).

Olive Pest	Active Principles	Management		
		Conventional	IPM	Organic
		Volume-Weight	Volume-Weight	Volume-Weight
		(avg/ Ha&year)	(avg/ Ha&year)	(avg/ Ha&year)
<i>Aceria oleae</i>	S (80%)	1,4 kg/Ha	0,75 kg/Ha	---
<i>Prays oleae</i>	Dimethoate 40%	0,9 L /Ha	0,3 L /Ha	---
<i>Euzophera pinguis</i>	Chlorpyrifos 48%	1,5 L /Ha	0,75 L /Ha	---
<i>Phloeotribus scarabaeoides</i>	Dimethoate 40%	0,9 L /Ha	0,45 L /Ha	---
<i>Bactrocera oleae</i>	Dimethoate 40%	1,8 L /Ha	0,9 L /Ha	---

Discussion

It is obvious to consider that the frequency of the insecticide application constitutes the main limiting factor of the diversity and abundance of the community of beneficial insects. It was also one of the main triggers for the implementation of Integrated Pest Management [1-3]. However, not all IPM models have allowed the desired sustainability to be achieved, nor have they achieved the desired effectiveness, frequently due to the lack of integration and coordination of the different program elements [37]. The integration of chemical and biological control can be part of sustainable pest management; therefore, it is essential to know the lethal and sublethal effects of insecticides on natural enemies to maximize the compatibility between these two tactics. This has led to the return of insecticides as a central element in pest control, which explains why recent studies do not allow to establish a clear differentiation between the IPM and Conventional management, while its deficiencies are especially evident when comparing any of these two managements with organic management [38]. Although compared to conventional management, IPM represents an average reduction in the use of insecticides of at least 50%, it has been proven to be nonetheless insufficient to ensure the sustainability of the populations of beneficial insects and optimize their entomophagous effectiveness [35,38].

In addition to the lower diversity and abundance, the influence of the side effects of insecticides in the beneficial insects must be assessed for the correct interpretation of data from population monitoring. Recent studies suggest that, as in conventional agroecosystems, in IPM these species show very frequently behavioral resistance (BR+), while in organic crops, they lack it (BR-) [34,35]. A close relationship seems to exist between insecticide application and the development of behavioral resistant populations. This finding has suggested establishing a practical procedure based on the realization of small-scale field applications, to subsequently monitor the reactions of beneficial insects, useful to identify ecological agroecosystems, characterized by the absence of behaviorally resistant lineages. Among the species of beneficial insects potentially capable of developing behavioral resistance in agroecosystems subject to insecticide application, are species of the common green lacewings of the *carnea*-complex, such as *Chrysoperla agilis*, of special importance in Spanish olive groves [35,39], the thysanopteran *Aeolothrips intermedius* predator, [34] and the parasitoids *Pnigalio mediterraneus*, *Ageniaspis fuscicollis* and *Chelonus eleaphilus* [35]. These species have a higher capture rate in chromatic traps, which is attributed to symptoms caused by the sub-lethal doses [24-27], such as spasmodic movements, overexcitement, hyperactivity, irritation / repellency reaction, thus avoiding contact with surfaces treated. These effects are common to a wide range of insecticides, including organochlorine [40,41], pyrethroids [31,41-43], organophosphates [41,44] and carbamates [41]. The set of behavioral effects are intended to avoid contact with the impregnated surfaces by the insecticide, thus chromatic traps represent shelter areas. These behavioral adaptations should lead to greater survival of the affected insects, as a first step in the selection

of physiologically resistant lineages to insecticides. Regarding common green lacewings, resistance of *Chrysoperla carnea* has been indicated to pyrethroids, organophosphorous insecticides, carbamates [45] abamectin and organochlorine insecticides [37]. Therefore, for this type of insects, capable of developing behavioral resistance (BR +), we conclude that its higher frequency of capture in chromatic traps of treated areas can be considered as an indicator of the disturbance caused by insecticide applications.

Among the beneficial insects, a wide range of susceptibility to insecticides has been reported [37,46], which manifests itself in a different response in post-treatment behavior patterns. In this regard, it has been possible to verify that some species have practically negligible population values or are very absent in the agroecosystems subject to insecticidal applications (Conventional, IPM) while they are relatively common in ecological management [31,35]. This group includes predatory species such as snakefly, *Harraphidia laufferi* (Raphidioptera: Raphidiidae), ladybugs (Coleoptera: Coccinellidae) and pirate bugs such as *Temnostethus* sp. (Hemiptera: Anthocoridae). Its low population values in olive groves where insecticides are frequently applied could probably be due to their greater susceptibility to commercial doses of dimethoate, which would exceed the LD50 for them. Unlike species with behavioral resistance, these show a significantly lower capture rate in post-treatment chromatic traps, which allows them to be classified as BR-.

The integration of chemical and biological control is an essential part of sustainable pest management; to maximize the compatibility between these two tactics [37], for which a correct interpretation of the impact of sublethal doses on beneficial insects is required [37,47-49]. The possibility of a more accurate interpretation of the monitoring data of the field experiments based on the application of small-scale inductor treatments opens up new possibilities of practical uses and applications. Among them, it can be used in the identification of organic olive groves, since it allows a clear differentiation from those that are object of insecticides applications (conventional, IPM). It is also very useful to define more clearly the period of conversion of a crop to obtain the certification of "organic farming." This process involves the replacement of highly polluting practices (such as the use of fertilizers, chemical pesticides, and deep soil tillage), for others that allow maintaining biodiversity, achieving the balance of fauna and flora, and ensuring the long-term productivity of the soil. During this period of agronomic conversion, agricultural exploitation is subject to frequent inspections by the institution in charge of granting certification, whose purpose is to verify the disappearance of pesticide residues and fertilizers, not allowed in organic production. This period is currently set at 3 years [50], although until now it has not been verified whether this period is sufficient to revert genetic lineages resistant to the behavior of beneficial insects to their wild form.

Conclusion

The studies whose results are here discussed have made it possible to classify the beneficial insects into capable / incapable of

developing behavioral adaptations or behavioral resistance (BR + / BR-) against the commercial doses of the dimethoate insecticide. The presence / absence of behavioral resistance would ultimately allow them to have / lack insecticide escape mechanisms.

The beneficial insects capable of developing behavioral resistance, only manifest itself as BR+ in agroecosystems that are frequently treated by insecticides. While populations of these species lack it (BR-) in organic agroecosystems.

The beneficial insects unable to develop behavioral resistance very probably do not survive the exposure of the commercial doses applied, so their presence is very often indicative of organic agroecosystems, so they are very scarce or even absent in insecticide-agroecosystems.

The implementation of small-scale insecticidal treatments in target crops, and the monitoring of the behavioral response of beneficial insects is proposed as a useful tool to identify true organic agroecosystems.

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Conflict of Interest

No conflict of interest.

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