Chapter 37
Physiological and Ecological Selectivity of Pesticides for Natural Enemies of Insects

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37.1 Introduction

Every year, agricultural production in South American countries increases, mainly due to the use of cultivars that are more productive and with different resistance levels to pests and diseases, better soil preparation, balanced fertilization, and agrochemicals use.

Despite this scenario, several factors have contributed to prevent an even greater increase in agricultural production, highlighting the presence of numerous pests and diseases, forcing the farmers to use agrochemicals intensively. However, the high number of chemicals applications and the lack of prior knowledge of their impacts on agroecosystems can lead to an increase in production costs and cause negative consequences for the environment. An example is the reduction or elimination of beneficial populations of organisms, such as natural enemies. Consequently, ecological imbalances may occur, resulting in the appearance of secondary pests, resurgence, and selection of resistant pest populations to the compounds.

Due to negative effects of chemicals on humans and in the environment, the concept of integrated pest management (IPM) was developed focusing in the continuous incorporation of new technologies, aiming the reduction of these products in crops. Within this concept, the main objective is to maximize the effects of phytosanitary products on pests, with minimal impact on the beneficial organisms present in agroecosystems. This is very important, since in Latin America there is a great occurrence of natural enemies that can be applied in IPM programs (Melo et al. 2004; Zucchi et al. 2010).

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Therefore, this chapter covers several aspects related to the selectivity of phytosanitary products. There will be emphasized selectivity concepts and results of experiments regarding the effects of agrochemicals to natural enemies, as well as their implications in IPM in different crops.

37.2 Selectivity of Agrochemicals Versus MIP

To ensure the success of IPM programs, monitoring of the pest population must be carried out constantly (Gallo et al. 2002). In this way, it is recommended to divide the cultivated area into smaller subareas, aiming at the execution of specific management strategies in each one. Monitoring is done by sampling insects in the plants, and this sampling can be done with the presence of an operator (direct collect, entomological net) or without its presence (traps, with or without attractiveness), depending on the insect to be sampled. For some pests, damage to some parts of plants (fruits, leaves) is sampled instead of insect presence (e.g., in the case of coffee borer, *Hypothenemus hampei* (Ferrari) (Curculionidae), or in a complementary manner to insect sampling (such as the tomato pinworm, *Tuta absoluta* (Meirick) (Gelechiidae)).

From the collected data, it is possible to estimate the population density of the insect in the area and thus compare with literature information to determine if the population of the insect reached a level that requires human intervention for its reduction (economic threshold). If this occurs, the responsible farmer or technician must decide which control methods should be applied, basing his decision on economic, social, and environmental factors (Gallo et al. 2002). In addition, for some specific situations, there is the nonaction level, which is the population density of natural enemies capable of naturally control a pest. An example is the case of the coffee leaf miner, *Leucoptera coffeella* (Guérin-Mèneville & Perrottet) (Lyonetiidae). In this case, coffee leaves presenting mines (pest damage sign) are sampled, and in addition the state of the mines is taken into account, as they may show signs of predation. If this occurs, it is an indicative that natural enemies present in the area are exerting biological control on the pest. In the specific case of the coffee leaf miner, if more than 60% of the mines sampled show signs of predation, it is not necessary to adopt other control measures (Picanço 2010).

In this way, the sampling of pests and natural enemies is one of the foundations of IPM. If an intervention with insecticides is required, it is interesting that these products cause the least possible impact to natural enemies, released or naturally present in the area. In this context, the integration between biological and chemical control tactics should be stimulated by the use of selective products to natural enemies (Parra 2014). According to Ripper et al. (1951), selectivity can be defined as the capacity of a product to control the target pest, causing the least possible impact on beneficial organisms such as predators, parasitoids, and pollinators, and can be divided into:

Physiological Selectivity Related to the chemical nature of the insecticide and its relation to insects. Differences in the processes of absorption, penetration, transport, activation, and degradation of insecticides in each insect species may cause a product to be more toxic to the pest than to its natural enemy in a situation in which both have contact with the compound or its residues.

Ecological Selectivity Intrinsic to the beneficial organism and its habitat, this occurs due to behavior differences between pests, natural enemies, and pollinators, causing the chemical to have contact only with certain species, especially with pests. Thus, to obtain this type of selectivity, it is necessary to know the pest bioecology and beneficial arthropods that are present in the different agroecosystems.

When implementing IPM programs, the compatibility or integration between control methods is recommended. The preservation of natural enemies in the agroecosystem is one of the most important strategies in IPM programs, since the use of chemical compounds can negatively impact their populations (Degrande et al. 2002). The synthetic insecticides used to control agricultural pests belong to different chemical groups, and their modes of action can act upon different groups of insects. Unfortunately, few farmers use safe ways to assess the risks that their investment may be subject to and suffer from the attack of pests on their crops. In many cases, in order to reduce pest populations, chemical compounds are sprayed without technical orientations, generating even greater instability in the agroecosystem due to the elimination of controlling agents of these undesirable organisms. Thus, successive imbalances are generated by the impact promoted by chemical interventions, often leading to a general lack of pest control (Bueno et al. 2017).

Biological control may be responsible for population of pest arthropods stability in agroecosystems. In addition to keeping their populations in equilibrium and below the economic threshold, either by maintaining existing natural enemies or releasing mass-reared insects on field, the biological method still minimizes human intervention compared to other control methods (Bueno et al. 2017).

The use of chemicals with high toxicity and broad action spectrum is recognized as the main cause of ecological imbalances in agroecosystems. Most of the used insecticides are neurotoxic, that is, they act on the nervous system of the insects (e.g., pyrethroids, neonicotinoids, and organophosphates). In general, these products have a broad spectrum of action; therefore, they tend to be less selective (Foerster 2002). To avoid this situation, the use of selective products is considered a feasible strategy, justifying studies in this research line (Degrande et al. 2002; Foerster 2002). Many biological characteristics of natural enemies may interfere with their susceptibility to phytosanitary products, such as sex, age, size, daily habit, and development stage (Foerster 2002). In this context, works are being developed by researchers taking into account some of these characteristics, as exemplified below.

37.3 Studies of the Effects of Agrochemicals on Beneficial Organisms

Most of the results were obtained according to a methodology standardized by the "International Organization for Biological and Integrated Control of Noxious Plants and Animals" (IOBC), which takes into account the mortality caused by the products and reduction in beneficial activities (predation and parasitism), as well as biological characteristics. Other selectivity tests will also be discussed, such as persistence of the effect of pesticide residues on natural enemies, behavioral changes of these organisms, and exposure of beneficial insects to plants originated from treated seeds.

Predators of the Chrysopidae Family (Green Lacewings) Although adults of Chrysopidae feed on plant sources (pollen, nectar, and honeydew), larvae are polyphagous predators. Therefore, these insects are important agents of biological control for several species of pest arthropods in several crops of economic interest.

However, in order to maintain the population of lacewings in IPM programs that include the use of phytosanitary products, it is necessary to evaluate the impact of insecticides on these organisms. These studies allow selecting products that cause low or no-negative effects on the predator. Thus, it is possible to integrate chemical and biological methods, using selective insecticides associated with the release of these natural enemies or aiming their maintenance in agroecosystems.

In this context, Godoy et al. (2010) carried out a study regarding the effect of insecticides (thiamethoxam, imidacloprid, milbemectin, pyriproxyfen, and spirodiclofen) on adults of *Chrysoperla externa* (Hagen) and *Ceraeochrysa cubana* (Hagen) (Chrysopidae). They concluded that milbemectin, pyriproxyfen, and spirodiclofen were harmless to predators and could be recommended in the IPM programs aiming the maintenance of these natural enemies in citrus crops.

Lacewings are frequently found in coffee crops, acting as regulators of pest populations, and, therefore, Vilela et al. (2010) performed a study aiming to evaluate the effects of spirodiclofen, fenpropathrin, sulfur, and abamectin on the first three larvae instars of *C. externa*. They found that fenpropathrin (in two dosages, 0.15 and 0.30 g a.i./L) and abamectin at the highest dosage (0.0225 g a.i./L) were the most harmful products to predator larvae. These products affected the survival of nymphs of the three instars, in addition to causing changes in the larval period. Spirodiclofen (0.12 g a.i./L) caused a moderate effect, while sulfur (4.0 and 8.0 g i.a./L) was harmless to *C. externa* larvae.

Haramboure et al. (2013) evaluated the effect of different concentrations of cypermethrin, via topical application, on *C. externa* larvae in Argentina. The larvae showed symptoms of insecticide intoxication, such as tremors, reduced movement, and knockdown effect (paralysis due to insecticide intoxication). The proportion of specimens that exhibited these symptoms was higher as the dosage increased. However, at all evaluated dosages, insects recovered after 96 hours, probably due to enzymatic action related to detoxification. These results indicate that *C. externa* larvae present high tolerance to this pyrethroid. Another study, also conducted in Argentina, showed that pyriproxyfen and acetamiprid may decrease survival and increase the duration of the first larval instar of *C. externa* (Rimoldi et al. 2017).

Predatory Hemiptera Selectivity tests have been performed for different species of predator bugs. These natural enemies, both nymphs and adults, are polyphagous and have predatory habit, feeding on eggs, caterpillars, mites, aphids, and thrips. Among studied species are *Orius insidiosus* (Say) (Anthocoridae), *Macrolophus basicornis* (Stål) (Miridae), and *Podisus nigrispinus* (Dallas) (Pentatomidae).

Moscardini et al. (2013) evaluated the effect of insecticides used in tomato crops on *O. insidiosus* eggs. Abamectin, cartap, spirotetramat + imidacloprid, and flubendiamide were harmful; pymetrozine was slightly harmful; pyriproxyfen and Rynaxypyr were innocuous; however, the last product affected reproductive parameters of *O. insidiosus*, demonstrating the importance of evaluation of sublethal effects in selectivity studies.

Insecticides recommended for control rosebush pests also had the lethal and sublethal effects evaluated in *O. insidiosus* eggs and nymphs. Predator's eggs were immersed in insecticide solutions for 5 seconds and then were kept in the laboratory. The insecticide deltamethrin was harmful to eggs and fifth instar nymphs, while formetanate and spinosad were slightly harmful. Formetanate did not negatively affected the reproductive characteristics of females originated from treated eggs. Spinosad reduced the number and viability of eggs placed by females from treated fifth instar nymphs (Torres et al. 2007).

To evaluate the effects of insecticides on *O. insidiosus*, topical application can be used, that is, the product to be tested is applied directly on the back of the insect. Thus, adults of this predator were submitted to the application of chemical products used in chrysanthemum crops, and chlorothalonil was found to be harmless. Mancozeb and dicofol were slightly harmful, and lufenuron showed to be moderately harmful. The other products, bifenthrin, triazophos, methomyl, and acetamiprid, were considered harmful. Due to the low toxicity of chlorothalonil, mancozeb, and dicofol, these compounds can be recommended in IPM programs aiming at the conservation of this predator in this culture (Albernaz et al. 2009).

The mirid bug *M. basicornis* is a potential biological control agent of the tomato pinworm, *T. absoluta*, but it can be negatively influenced by several phytosanitary products used to control pests in tomato. In the laboratory, Passos et al. (2017) treated tomato leaflets with insecticides recommended for the control of this lepidopteran, and then, nymphs and adults of *M. basicornis* were exposed to the leaflets. The products not classified as harmless in laboratory were also evaluated in greenhouse. Abamectin and chlorfenapyr were toxic to nymphs and adults of the predator in all bioassays. Cartap hydrochloride was slightly toxic to adults in laboratory, but toxic to nymphs in laboratory and moderately toxic in greenhouses. Chlorantraniliprole and teflubenzuron were harmless to *M. basicornis* in most of the bioassays, except for nymphs in laboratory test, where they were classified as moderately toxic and slightly toxic. Thus, these products should be preferred in IPM programs to conserve populations of this predator.

Another exposition route of predators to insecticides in agroecosystems is through contaminated extrafloral nectar when seed treatment is used, since many of these insects use these resources to complement their feeding. The effects of insecticides used as seed treatment of soybean (thiamethoxam and chlorantraniliprole) were evaluated on the zoophytophagous predator *P. nigrispinus*. Thiamethoxam caused a mortality increase, besides affecting the fecundity, the preoviposition period, and the females' survival when compared to chlorantraniliprole. However, life expectancy of *P. nigrispinus* females was prolonged by chlorantraniliprole, which also increased the intrinsic rate of population increase (r_m) and finite growth rate (l) and reduced population doubling time (TD) when compared to thiamethoxam. Other parameters such as net reproductive rate (R_0) and mean intergenerational interval (T) were not affected by any of the insecticides. In addition, the distance traveled and mean velocity of females exposed to these products were evaluated, but these parameters were not influenced. Thus, seed treatment with these insecticides presented low (chlorantraniliprole) and moderate (thiamethoxam) risk for *P. nigrispinus* (Gontijo et al. 2017).

***Doru lineare* (Dermaptera: Forficulidae)** This is one of the most common predators in the corn crop, preying mainly *Spodoptera frugiperda* (JE Smith) (Noctuidae) eggs and caterpillars. This natural enemy is present during the whole cycle of this crop, from the seedlings emergence until harvest, and should be preserved in agricultural systems by the use of selective pesticides.

In order to know the insecticides' impact on *D. lineare*, a work was carried out evaluating products used in corn on eggs and first instar nymphs of the predator. Triflumuron, deltamethrin, diflubenzuron, lambda-cyhalothrin + thiamethoxam, alpha-cypermethrin, methoxyfenozide, lambda-cyhalothrin, chlorpyrifos, lufenuron, tebufenozide, azadirachtin, carbaryl, and spinosad were evaluated. It was concluded that triflumuron, diflubenzuron, lambda-cyhalothrin + thiamethoxam, lambda-cyhalothrin, chlorpyrifos, lufenuron, and carbaryl reduced egg viability. The nymph survival from treated eggs was reduced by deltamethrin, diflubenzuron, lambda-cyhalothrin + thiamethoxam, lambda-cyhalothrin, chlorpyrifos, and carbaryl. For nymphs in the residual contact test, all insecticides were harmful within 96 hours after exposing the insects to their residues (Zotti et al. 2010).

Predatory Coccinellids Coccinellidae family insects are important biological control agents in several crops of economic importance. Larvae and adults of some species, such as *Coleomegilla maculata* (DeGeer) and *Hippodamia convergens* (Guérin-Méneville), are voracious predators of aphids, thrips, eggs, and small caterpillars. Moscardini et al. (2015) evaluated the effect of the insecticides thiamethoxam and chlorantraniliprole, used in sunflower seed treatment, on the biological and reproductive characteristics of these predators. *C. maculata* and *H convergens* larvae and adults were exposed to the products by feeding on treated plants' extrafloral nectaries. Both insecticides extended the pupal period of *C. maculata* exposed in the larval stage. For *H. convergens*, there was a reduction in egg viability and an increase in the embryonic period of exposed insects in the larval stage, as well as a change in the sex ratio caused by thiamethoxam. These insecticides also prolonged the pupae stage of insects originated from exposed adults.

The physiological selectivity of insecticides used in cotton for eggs and third instar larvae of *Cycloneda sanguinea* (Linnaeus) (Coccinellidae) was evaluated by Pedroso et al. (2012). The insecticide triflumuron was harmless to *C. sanguinea* eggs and slightly harmful to larvae. Spinosad was slightly harmful to eggs and larvae, while the other products (chlorfenapyr, clothianidin, and imidacloprid + ß-cyfluthrin) were harmful to the predator's eggs and larvae.

In Argentina, the selectivity of four insecticides used in horticulture (pyriproxyfen, teflubenzuron, acetamiprid, and cypermethrin) to *Eriopis connexa* (Germar) (Coccinellidae), an important control agent of horticultural pests in the Neotropical region, was evaluated. All compounds caused lethal and/or sublethal effect on the predator. However, neurotoxic insecticides were more toxic than growth regulators, and the pupa presented greater susceptibility to the products in relation to the adult stage (Fogel et al. 2016).

Parasitoids *Trichogramma pretiosum* Riley (Trichogrammatidae) is one of the most used species in biological control programs in the world. Insects of this genus are generalist egg parasitoids, used mainly to control lepidopteran pest, through inundative releases in agroecosystems. *T. pretiosum* has been recorded in several countries of Latin America (Zucchi et al. 2010), assuming importance in the control of several phytophagous insects. In Brazil, for example, it is registered for some crops to control defoliant lepidopterans, such as the tomato pinworm (*T. absoluta*) and the fall armyworm (*S. frugiperda*). Therefore, it is essential to carry out studies aiming the determination of selective products to this natural enemy.

The effect of insecticides used on the tomato crop (acetamiprid, lufenuron, imidacloprid, novaluron, triflumuron, and pyriproxyfen) was evaluated on immature stages of *T. pretiosum*, and acetamiprid, imidacloprid, lufenuron, and pyriproxyfen were toxic to the parasitoid (Carvalho et al. 2010b). When these insecticides were evaluated on adults, pyriproxyfen was slightly harmful, due to reduction in parasitism capacity of female of the maternal generation. Acetamiprid, imidacloprid, lufenuron, and triflumuron were harmless to *T. pretiosum* adults and could be recommended in tomato IPM programs in order to preserve this parasitoid (Carvalho et al. 2010a).

In order to investigate the effect of other products recommended for the tomato pests' control, abamectin, acetamiprid, cartap, and chlorpyrifos were tested for *T. pretiosum* at different stages of development. The parasitism of the females exposed to the products in *Ephestia kuehniella* (Zeller) (Pyralidae) eggs was evaluated. It was observed a reduction up to 98.3% in the parasitism caused by acetamiprid and 100% reduction due to the effect of the other insecticides evaluated (Moura et al. 2006).

Moura et al. (2004) reported the residual effect of acetamiprid, chlorfenapyr, imidacloprid, thiacloprid, and thiamethoxam on the first two generations of parasitoids from *T. pretiosum* females treated in laboratory. Imidacloprid and chlorfenapyr were the most detrimental; and thiacloprid reduced the rate of parasitism, although it did not affect longevity. The deleterious effects of chlorfenapyr and thiacloprid were transmitted to the subsequent generation of this parasitoid. As thiamethoxam and acetamiprid were selective under the evaluated conditions, they are suitable for use in IPM programs in tomato.

Nörnberg et al. (2011) verified the persistence (the harmful activity duration) of ten products, recommended in the integrated fruit production, on *T. pretiosum*. Adults were exposed to grapevine leaves treated with the products, and the residual effect on parasitism at 3, 10, 17, 24, and 31 days after spraying was evaluated. The active ingredients malathion and the fungicides, tetraconazole, mancozeb, and methyl thiophanate, were classified as short-lived (<5 days of harmful action); the insecticide/acaricide abamectin as slightly persistent (5–15 days of harmful action); the insecticide chlorpyrifos as moderately persistent (16–30 days of harmful action); and phosmet and carbaryl insecticides and sulfur fungicide/acaricide as persistent (>31 days of harmful action).

Aiming the use of *T. pretiosum* along with chemicals in conventional corn crops, Stefanello Júnior et al. (2008) investigated the effect of 16 commercial formulations of insecticides registered for this crop on the parasitism capacity of this species in laboratory. Alpha-cypermethrin and lufenuron were slightly deleterious; spinosad was moderately harmful; cypermethrin, deltamethrin, deltamethrin + triazophos, trichlorfon, parathion-methyl, triazophos, lambda-cyhalothrin, malathion, fenitrothione, beta-cyfluthrin, and chlorpyrifos were harmful to *T. pretiosum* adults in the initial toxicity test. The insecticides triflumuron and novaluron were innocuous; therefore, they should be preferred in maize IPM programs where this parasitoid is used.

Besides parasitoids of eggs, such as *Trichogramma* spp., there are also species that parasitize other stages of pests' development. Luna-Cruz et al. (2015) evaluated the effect of insecticides on *Tamarixia triozae* (Burks) (Eulophidae), a parasitoid of the psyllid *Bactericera cockerelli* (Šulc) (Triozidae) nymphs, common in Solanaceae crops in Central and North America. Parasitoid adults were exposed to tomato leaflets treated with insecticides recommended for the control of the psyllid (spirotetramat, spiromesifen, beta-cyfluthrin, pymetrozine, azadirachtin, imidacloprid, abamectin, and spinosad), and all of them had at least some level of toxicity to the parasitoid. Spinosad was classified as harmful; abamectin was moderately harmful, and the others were slightly harmful. Spinosad and abamectin also showed greater persistence of the lethal effect on the parasitoid (41 and 24 days, respectively), while the other insecticides did not exceed 13 days. Thus, products that caused lower mortality and had lower persistence in the environment can be considered in *B. cockerelli* management programs.

In summary, there is a great volume of works published in recent years regarding the effects of phytosanitary products on natural enemies in Latin America. However, researches must continue as new chemical molecules are commercially registered to collaborate in the IPM programs development.

37.4 Final Considerations

Researches about the effects of chemical compounds on beneficial organisms have been left aside for many years. However, the demand of society for better agricultural products and with less chemicals has been stimulating the increase of studies in this research line. Integration between chemical and biological methods for pest control is important for the development of IPM programs in different crops of economic value in the Neotropical region.

In the first studies on selectivity, only the mortality caused by the compounds on beneficial insects was emphasized. Researches that considered the sublethal effects of the products on the populations of these organisms were scarce. Over time, researchers have also become concerned about the effects of compounds on the behavior and reproduction of natural enemies and pollinators. In addition, the structure for research in Brazil and other Latin-American countries, such as Argentina and Colombia, has greatly improved. Therefore, there are better conditions for the study of pesticide selectivity to natural enemies in laboratory, semifield and field conditions.

Phytosanitary products are used in great quantity for pest control in Latin-American countries (especially in Brazil, considered the greatest consumer of chemical products in the world). Thus, it is of utmost importance to conduct researches that seek the rational use of these compounds, respecting the factors of natural mortality and the natural enemies' action in agroecosystems.

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