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Impact and Selectivity of Insecticides to Predators and Parasitoids

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Abstract. Problems with the use of insecticides has brought losses, such as, negative impact on natural enemies. When these beneficial insects reduce cause the eruption of pests and resurgence it's more common. Thus principles of conservation these arthropods are extremely important in the biological natural control of pests, so that these enemies may present a high performance. Because of the negative impacts caused by insecticides on agriculture and their harmful effects on natural enemies, the objective of this article is to approach two important subjects, divided into three parts. Part I relates to the description of the main crop pests and their natural enemies; Part II involves the impact of insecticides on predators and parasitoids and Part III focuses on the selectivity of several groups of insecticides to natural enemies. Before spraying insecticides, it is necessary to choose a product that is efficient to pests and selective to natural enemies. So, it is indispensable to identify correctly the groups and species of natural enemies, since insecticides have an impact on their survival, growth, development, reproduction (sexual ratio, fecundity, longevity and fertility), and behavior (motility, orientation, feeding, oviposition and learning) of insects. The mechanisms of toxicity and selectivity of insecticides are related to the properties of higher or lower solubility and molecular weight. Besides, characteristics of the cuticular composition of the integument of natural enemies are extremely important in the selectivity of a product or the tolerance of a certain predator or parasitoid to this molecules.

Keywords: Natural Enemies, Selective, Tolerance, Toxicity

FÓRUM

Impacto e Seletividade de Inseticidas à Predadores e Parasitóides

Resumo. Problemas com uso de inseticidas têm trazido inúmeros prejuízos, dentre estes, o impacto negativo sobre inimigos naturais. Quando se reduz a população de inimigos naturais problemas com erupção de pragas, ressurgência são muito comuns em agroecossistemas. Dessa forma princípios com objetivos de conservação desses artrópodes, são extremamente importantes no controle biológico natural de pragas. Tendo em vista os impactos negativos dos inseticidas na agricultura e os seus efeitos adversos sobre os inimigos naturais, este artigo visa abordar dois assuntos importantes, que para isso é dividido em três partes. A parte I relacionada com o reconhecimento das principais pragas agrícolas e seus inimigos naturais; a parte II envolve o impacto dos inseticidas sobre os predadores e parasitóides e a parte III sobre a seletividade dos diversos grupos de inseticidas aos inimigos naturais. Antes de se utilizar um inseticida é necessária à escolha de um produto que seja eficiente contra pragas e seletivo a inimigos naturais, assim é imprescindível identificar de forma correta os grupos e espécies de inimigos naturais, uma vez que os inseticidas possuem impacto sobre a sobrevivência, o crescimento e desenvolvimento, a reprodução (razão sexual, fecundidade, longevidade e fertilidade) e o comportamento (mobilidade, orientação, alimentação, oviposição e aprendizado) dos insetos. Os mecanismos de toxicidade e seletividade dos inseticidas estão relacionados às suas propriedades de maior ou menor solubilidade e peso molecular. Além disso, características da composição cuticular do integumento dos inimigos naturais são de extrema importância na seletividade de um produto ou a tolerância de determinado predador ou parasitóide a essas moléculas.

Palavras-Chave: Inimigos Naturais, Seletivo, Tolerância, Toxicidade

Insects become pests when they interfere with human well-being and esthetics and when they cause economic losses (DENT 2000). Pests may affect men directly or indirectly. The direct form may be due to the transmission of diseases, while the indirect form may occur through the attacks to animals and crops (GULLAN & CRANSTON 2000).

Several insects are pests for crops. These pests may be divided into two large groups, depending on the pattern of host use: specialist insect (oligophagous and monophagous) and generalist insects (polyphagous). Many of these organisms are considered serious pests in agriculture and in urban centers (BERNAYS 2001).

The insecticides used in agricultural pest control may cause several problems, such as the selection of resistant lineages (METCALF 1980), environmental contamination and its consequences, raise in the costs of pest control and, mainly, the death of natural enemies.

The reduction of these beneficial arthropods caused by non-selective insecticides may bring serious problems for crops all over the world. One of the problems is the resurgence of new pests and the eruption of secondary pests. When resurgence occurs, the pest reappears in subsequent harvests, come from places of refuge and individuals that survived in the crop, in population levels higher than that of the previous harvest. On the other hand, the eruption of pests is the change of the pest status: from secondary pest to key pest, especially due to the reduction of the natural enemies that keep pests below the level of economic loss (FERNANDES *et al.* 2008).

One of the forms to avoid the resurgence of pests is the use of selective insecticides, which were defined as the property of controlling the target pest, with the lowest possible impact on the other components of the ecosystem, namely, the insecticide must present low impact on natural enemies, under the same conditions in which the pest is successfully controlled (DEGRANDE *et al.* 2002).

Hence, it is very important to preserve natural enemies, so that they may present a good performance in pest biological control, which is a critical control method used in the programs of integrated pest management (IPM).

Due to the negative impacts of insecticides on agriculture and their unfavorable effects on natural enemies, this article seeks to approach two important subjects and is divided into three parts. Part I relates to the acknowledgement of the main agricultural pests and their natural enemies; Part II involves the impact of insecticides on predators and parasitoids and parte III focuses on the selectivity of several groups of insecticides to natural enemies.

PART I- CROPS AND THEIR MAIN GROUPS OF NATURAL ENEMIES

Agroecosystems have biotic and abiotic components. Examples of biotic components are: plants (crops and weeds), microorganisms, invertebrates (such as annelids, insects and mites) and vertebrates (mammals, reptiles and birds). Few species of these organisms reached the *status* of pests, causing economic losses by attacking cultivated plants. So, when we apply a pesticide, our objective is to achieve an impact on the target species (pests) in order to reduce their populations to prevent economic losses on the crop productivity (FERNANDES *et al.* 2008).

One of the natural enemies of agricultural pests is the group of insects and mites. To select insecticides for pest control, it is necessary to identify the main key natural enemies (KNE) in crops (Tables 1 and 2). The KNE preservation is the most direct way to protect the effective agents of control, since several insects and mites with less effective functions in pest control live in the area. It does not mean that they are less important than the KNE, but that the complexity of the relations between prey x environment x plant x natural enemies does not facilitate the choice of the products.

So, it is necessary to use sampling of cultivated areas to identify the KNE of a certain pest, since this measure is extremely important for the safe selection of insecticide according to their effectiveness and potential to cause less damage to the predators and parasitoids of the target pest. In Brazil, there are several sampling apparatus that can be used for KNE surveys. The main devices are listed in Table 3.

PART II- INSECTICIDE IMPACT ON NATURAL ENEMIES

The decrease in the number of natural enemies caused by the use of non-selective insecticides may bring serious consequences for the pest population dynamics. One of them is the important phenomena of resurgence and eruption of secondary pests (GALLO *et al.* 2002). So, high risks of occurrence of pest population outbreaks are expected.

Predators and parasitoids may get in touch with insecticides via host, direct contact or by the ingestion of nectar and pollen in flowers.

The negative effects of insecticides on organisms may be classified into acute, subacute and chronic. In the acute intoxication, the result is usually observed after the contact with a single dose of the pesticide, when the symptoms appear very fast, some hours after the excessive exposure, for a short period, to products extremely or highly toxic. It may be mild, moderate or severe, depending on how much compound was absorbed (WALKER *et al.* 1978).

The subacute intoxication occurs by moderate or small exposure to products highly or moderately toxic. This kind of intoxication is a low process. On the other hand, the chronic

Table 1. Main groups of key natural enemies (KNE) in great crops and Vegetables and their respective agricultural pests.

KNE	E.P.	Group	Crops	Target pest
Great crops				
Physmasticus coffea	A	I	Coffee plant	*Hypothenemus hampei*
Azia luteipes	L,A	II	Coffee plant	*Coccus viridis*
Brachygastra lecheguana, Protonectarina sylveirae, Protopolybia exigua	A	II	Coffee plant	*Leucoptera coffeella*
Cotesia flavipes Trichogramma galloi Palmistichus elaeisis	A	I	Sugar cane	*Diatraea sacharalis*
Doru luteipes, Megacephala sp.	A	II	Maize/Cotton plant	*Spodoptera frugiperda*
Trissolcus basalis, Trichopoda nitens	A	I	Soybean	*Piezodorus guildinii Nezara viridula*
Trichogramma spp.	A	I	Soybean	*Anticarsia gemmatalis*
Podisius nigrispinus	N,A	II	Cotton plant/Soybean	*Anticarsia gemmatalis, Alabama argilácea, Heliothis virescens*
Cycloneda sanguine, Chrysoperla externa	L,A	II	Cotton plant	*Aphis gossypii*
Encarsia formosa	A	I	Cotton plant/Soybean/Bean plant	*Bemisia tabaci*
Trichogramma spp.	A	I	Cotton plant	*Heliothis virescens Spodoptera frugiperda Pectinophora gossypiella*
Orius sp.	A	II	Bean plant	*Empoasca kraemeri*
Neodusmetia sangwani, Cycloneda sanguinea	L,A	II	Pastures	*Antonina graminis, Schizaphis graminum*
Vegetables				
Trichogramma spp.	A	I	Tomato plant	*Tuta absoluta, Neoleucinodes elegantalis*
Orius sp.	A,N	II	Tomato plant	*Tuta absoluta*
Cycloneda sanguinea	L,A	II	Potato plant /brassica	*Myzus persicae Macrosiphum euphorbiae Brevicoryne brassicae*
Phytoseiulus longipes	A	II	Tomato plant	*Tetranychus evansi*
Podisius nigrispinus, Brontocoris tabidus, Doru luteipes	A,N	II	Brassica/Cucurbitaceae	*Ascia monuste orseis Diaphania spp Trichoplusia ni*
Apanteles sp., *Oomyzus sokolowiskii, Diadegma* sp., *Actia* sp.	A	I	Brassica	*Plutella xylostella*
Zellus sp.	A	II	Cucurbitaceae	*Diabrotica speciosa, Acalymma spp*
Orius sp., *Geocoris* sp.	A,N	II	Liliaceae	*Eryophes tulipae, Thrips tabaci, Rhizoglyphus* sp.

I= Parasitoid; II= Predator; L= Larva; A=Adult; L,A= Larva and adult; N= nymph; N,A= Nymph and adult; E.P.= Effective phase; KNE= key natural enemies

Table 2. Main groups of key natural enemies (KNE) in fruit trees and their respective agricultural pests.

KNE	E.P.	Group	Crops	Target pest
Chrysoperla externa, Chrysoperla carnea	L,A	II	Apple tree	*Anastrepha fraterculus, Grafolita molesta, Bonagota cranaodes*
Trichogramma pretiosum	A	I	Peach-tree	*Grafolita molesta*
Cycloneda sanguinea, Eriopsis conexa	A,L	II	Papaya tree	*Aphis* sp., *Myzus persicae*
Phytoseiulus longipes	A	II	Banana Tree	*Frankliniella* spp.
Ageniaspis citricola	A	I	Citrus	*Phyllocnistis citrella*
Diachasmimorpha longicaudata	A	I	Citrus	*Anastrepha* spp., *Ceratitis capitata*
Lysiphlebus testaceipes	A	I	Citrus	*Toxoptera citricida*
Brachygastra lecheguana, Protonectarina sylveirae, Protopolybia exigua	A	II	Citrus	*Phyllocnistis citrella*
Syrphidae	L	II	Guava Tree	*Triozoida* sp.
Vespidae predadores	A	II	Guava Tree	*Triozoida* sp.

I= Parasitoid; II= Predator; L= Larva; A=Adult; L,A= Larva and adult; N= nymph; N,A= Nymph and adult; E.P.= Effective phase, KNE= key natural enemies

Table 3. Main sampling apparatus for pests and KNE in crops.

Apparatus	Pests	Crops	KNE
Beating of white plastic tray	*Bemisia* spp., Mites, Aphids, Thrips	Tomato plant Cucurbitaceae, Bean plant, Potato plant, Maize, Brassica	*Trichogramma* spp., *Encarsia formosa*, *Orius* sp., *Geocoris* sp., Predatory bugs, *Doru luteipes*
Beating cloth	Bed bugs and Caterpillars	Soybean, Cotton plant	*Podisius* spp., Predatory bugs
Light traps	*Diatraea saccharalis*, *Neoleucinodes elegantalis*, *Grapholita molesta*, *Heliothis virescens*, *Pectinophora gossypiella*	Cotton plant, Sugar cane, Appletree, Tomato plant	Predatory bugs, Predatory Vespidae
Attractive Traps (adhesive or any other form of capture)	Aphids, *Diabrotica speciosa*, Lepidoptera, *Hypothenemus hampei*, *Ceratitis capitata*	Potato plant, Tomato plant, Bean plant, Coffee plant, Cotton plant	Several Parasitoids and predators
Direct counting	Nymph and Adult Miners (motionless), Borers	Several Crops	Mainly larvae and adult predators
Scanning network	Spittlebug Eggs, Whiteflies, Bed bugs	Pastures, Cotton plant, Soybean	Several Parasitoids and predators
Entomologic network	Pest Lepidoptera	Several Crops	Adult predators

intoxication appears months or years later and is caused by small or moderate exposure to a toxic product or multiple products, provoking irreversible damages.

A toxic substance can only show its activity on the biology of a non-target organism after penetrating the cells and spreading in the organism through the blood stream. For such, two barriers must be overcome: first, the membranes that surround any animal cell and, secondly, the whole tissue, until reaching the modes of transport already mentioned (JEPSON 1989).

Generally, after surpassing these barriers, insecticides may block some physiological or biochemical process. The interference on these processes may produce impacts on the survival, growth, development, reproduction and behavior of organisms (HAYNES 1988; DELPUECH *et al.* 1998; DELPUECH & MEYET 2003). Such effects will be the next topic of discussion.

The application of insecticides may cause the mortality of target and non-target species. Such substances kill non-target species by blocking some physiological or biochemical process (TOMIZAWA & CASIDA 2003). The main target of the insecticide action has been the nervous system, due to its high efficiency and high response in pest control (MEDVED & KAGAN 1966).

The understanding of the mechanism of insecticide action is essential to learn the causes of mortality of non-target organisms. The action mechanisms are divided into: neurotoxic, growth regulators, inhibitors of cell breathing and others (GALLO *et al.* 2002).

Neurotoxic insecticides are the main cause of insect mortality. The main groups of insecticides that act on the nervous system and the mechanisms involved are: organophosphates and carbamates (inhibitors of the acetylcholinestase enzyme); nicotine, neonicotinoids and spinosyns (acetylcholine agonists); cartap (antacetylcholine agonists); avermectin and milbemicins (GABA agonists); cyclodiene and Phenil pirasol (GABA antagonists); formamidines (octopamin agonists); pyrethroids and DDT (sodium channels+) and oxadiazins (sodium channels blockers) (MATSUMURA 1963; GALLO *et al.* 2002). BACCI *et al.* (2006) and FERNANDES *et al.* (2008) found toxicity from neurotoxic insecticides to predatory wasps in coffee plants (*Coffea arabica* L). GUSMÃO et al (2000), when studying the selectivity of insecticides to predatory wasps of *L. coffeella*, verified high toxicity of organophosphates to *P. versicolor versicolor*, *Apoica pallens* (Fabricius) and *Brachygastra lecheguana* (Latreille). FRAGOSO *et al.* (2001) observed a high mortality of the Vespidae *B. lecheguana*, *P. exigua* and *Polybia paulista* (Ihering) when they were exposed to chlorpyrifos in the concentrations achieved from the estimate of the CL99 for *L. coffeella*. Besides predatory wasps, larvae of the predator *Coccinella undecimpunctata* (Coleoptera: Coccinellidae), exposed to the recommended dose of the insecticide buprofezin, reduced the survival in 33%, compared to the control (without insecticide) (CABRAL *et al.* 2008). Other works have shown the high toxicity of neurotoxic insecticides to parasitoids. BACCI *et al.* (2007a) verified that the insecticides cartap, imidacloprid, malathion, metamidophos, acephate, acetamiprid and abamectin caused more than 61% of mortality of the parasitoid Encarsia sp.

Besides the neurotoxic insecticides, growth regulators may affect natural enemies. Such insecticides are considered physiological because during the development of the insects, there is the occurrence of metamorphosis, which are regulated by hormones such as the steroid 20-hydroecdysone, known as the hormone of the metamorphosis and sesquiterpenoids. Therefore, any changes in these hormones may cause morphological and physiological disturbances during the different stages (GULLAN & CRANSTON 2000).

Studies on the impact of insecticides have unveiled a sublethal effect on predators and parasitoids. Such effect is related to malformation during the development phases, which may decrease their parasitism and predation performance. Larvae and adults of the predator *Mallada signatus* (Neuroptera: Chrysopidae) presented malformation of internal organs due to the sublethal effect of botanical insecticides that use azadirachtin (QI *et al.* 2001). The insecticide spinosad reduced the emergence of adults of the endoparasitoid *Hyposoter didymator* (Hymenoptera: Ichneumonidae) in larvae of its host (SCHNEIDER *et al.* 2004).

Insecticides may also directly affect biological parameters of the growth ratio, which may influence the intrinsic growth rate (rm) and the phenological synchrony of natural enemies with their hosts and their preys. The increase in the growth ratio may bring disadvantages for parasitoids, causing disturbances in their synchrony with the susceptibility of their hosts. The insecticide fenoxycarb prolonged the time of development of the predator *Chysoperla rufilabris* (Neuroptera: Chrysopidae) in all the stages (LIU & CHEN 2001). CÔNSOLI *et al.* (1998) reported that pupae of *T. pretiosum* demonstrated higher sensitivity to pesticides as to the time of development than eggs and larvae. A prolonged development stage has been reported with the use of other predators and neurotoxic insecticides (GEORGE & AMBROSE 1999; GALVAN *et al.* 2005) and parasitoids with botanical insecticides (CHARLESTON *et al.* 2005).

Insecticides may influence the physiology of insects, by inhibiting the formation of imaginal organs, as in bees, which indirectly influence the larval development. This effect may serve as a model for the natural enemies that are sensitive to insecticides. In analyses carried out by WILLIAMS *et al.* (2003), it was detected that 55% of the insecticide spinosad is accumulated in the ovaries of the parasitoid *H. didymator*. The authors report a sublethal effect of these insecticides, with a reduction in the rate of fecundity and size of this insect.

There are several insect reproductive parameters that may be affected by the action of insecticides. Some of the most affected parameters are the sexual ratio, fecundity, fertility and longevity (FIGA-TALAMANCA *et al.* 2001; FERNANDES *et al.* 2008).

The insecticides applied on beneficial arthropods may affect differently males and females in population, because of the differences in the physiology and behavior of male and female organisms. The asymmetrical mortality of males and females alters the sexual ratio (CROFT 1990; ALIX *et al.* 2001). Parasitoid hymenoptera reduced the number of females when submitted to the insecticide organophosphate chlorpyrifos.

Impacts of the chemical consumption on sexual ratio are expected because females may suffer ovary deformations (GEORGE & AMBROSE 2004; MEDINA *et al.* 2004; SCHNEIDER *et al.* 2004), reduction in the fertilization of the eggs during the oviposition phase, mainly in haplodiploid species, in which egg fertilization is controlled by the female itself (IDRIS & GRAFIUS 1993). Besides, the age of the females may be important to determine the sexual ratio when they are exposed to insecticides.

Although insecticides may affect the sexual ratio of the natural enemies, there are few works on this impact. The parasitoid *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) presented variation in sexual ratio when submitted to the insecticides pirimicarb in the tomato plant *Lycopersicon esculentum* (CARVALHO *et al.* 2002). Such decrease in the number of females may occur because the female hymenoptera come from fertilized eggs and the male, from non-fertilized eggs. In addition, egg fertilization is a voluntary action of the females. Such egg fertilization behavior may be altered by the impact of insecticides in the nervous transmission of the females (HAYNES 1988; DESNEUX *et al.* 2007).

The reduction in arthropod fecundity may be associated to the effects of insecticides on the behavior and physiology of the insects (KRESPI *et al.* 1991; BRUNNER *et al.* 2001; CORRALES & CAMPOS 2004). The effect on the behavior will be discussed in the next topic. Some physiological mechanisms have been approached and they may be explained by the fact that insecticides link to the ecdysteroid receptors, causing disturbance in the processes of vitellogenesis, ovulation and promoting the growth of the immature organisms, which involves ecdysteroid hormones (HASEEB & AMANO 2002).

Growth regulators (GR) may present a stronger effect on fecundity than the neurotoxic insecticides (DESNEUX *et al.* 2007). The predator *Micromus tasmaniae* (Neuroptera: Hemerobiidae), when in contact with both neurotoxic and GR insecticides, were more severely affected by the GR (RUMPF *et al.* 1998).

Effects on the longevity of adults due to the exposition of doses and subdoses of insecticides seem to be more frequent in parasitoids than in predators. Depending on the study, the population longevity reduction may be considered sublethal or latent mortality. However, it is difficult to extrapolate such effects for the population because of the particular biology of each organism.

Studies demonstrate a high relation between longevity and fecundity of adult arthropods. The infertility caused by insecticides may be one of the main factors for the reduction of arthropod longevity. Besides, infertility in adults may influence the dynamics of populations, since mating does not generate fertile eggs (DESNEUX *et al.* 2007).

The fertility of arthropod adult females may be affected by the action of the active principles of insecticides. These compounds may cause repellence for feeding and oviposition. Insects rarely oviposit on plants protected by pesticides. It may cause decrease in fertility, number of eggs and population. In addition, adult arthropods may suffer a direct impact from pesticides, which may generate changes in behavior and delay copulation, reducing the period of fertility (DESNEUX *et al.* 2007).

Immature phases of *Chrysoperla externa* (Neuroptera: Chrysopidae) exposed to the insecticide tebufenozide, presented a deleterious effect on adults of this predator, negatively affecting the production, viability and fertility of eggs (CARVALHO *et al.* 2003).

Behavioral changes have been observed in natural enemies exposed to a sublethal dose of insecticides. In general, the sublethal effect of insecticides on behavior is a syndrome that affects motility, orientation, feeding, oviposition and learning. In many cases, insecticides act as repellents that are associated to the behavior of food searching. In some cases, repellence is the result of the contact with the host or prey treated with insecticides. These cases are classified as parasitoid oviposition reduction or acceptance of the prey by the predator.

The impact of the insecticides on the motility behavior, or the movement of beneficial arthropods has not been directly studied. It is so because the measures do not present accurate quantitative statistical data. However, insecticides have caused several changes in the movements of beneficial arthropods. The behavioral alterations in their motility include lack of motor coordination, tremors, downfalls, abdomen tucking and rotational movement for abdomen cleaning (SUCHAIL *et al.* 2001). Secondary consequences such as changes in arthropod behavior (SALERNO *et al.* 2002), may lead to the reduction in the detection of kairomones (DELPUECH *et al.* 2005), generating an increase in the speed in which the stimuli of the attractive or repellent substances are noticed.

Insecticides may cause repellence in arthropods (KJAER & JEPSON 1995; LONGLEY & JEPSON 1996), and may irritate more or repel by acting directly on the central or peripheral nervous system (DDT and pyrethroids). Chemical compounds with enzymatic mode of action, namely, inhibitors of acetilcolinesterase (carbamates and organophosphates), may repel with less intensity.

Arthropods may guide themselves with great accuracy in the environment. This accuracy is due to their sensorial system, which can capture external stimuli. The parts of the sensorial system with the function of capturing or perceiving such stimuli are formed by the visual and olfactory systems (KLOWDEM 2002). The visual system is responsible for habitat localization, light perception and also perceptions of the form and size of objects. The olfactory system is responsible for the chemical perception of the substances used to attract or repel (BERNAYS & CHAPMAN 1994).

So, when these systems are modified by the action of insecticides, their orientation behavior is impaired. Considering that natural enemies spend a good part of their life time searching for hosts or preys, and that their nervous system is constantly affected by insecticides with different action modes, it is understandable that their activity and the capacity of guiding themselves, parasite or prey are extremely affected.

Parasitoids submitted to subdoses of the insecticide Lambdacyhalothrin and increased doses of carbamates presented a reduction in the capacity of guiding themselves to the host plants with aphis attack. Females of *Microplitis croceipes* (Cresson) (Hymenoptera: Braconidae), parasitoid of *Heliothis* spp. (Lepidoptera: Noctuidae), directly sprayed with fenvalerate and methomyl, presented a reduced flying activity 20 h after the treatment (STAPEL *et al.* 2000). With predators, doses of cypermethrin reduced their capacity of finding and capturing preys. Males of *Thrichogramma brassicae* (Bezdenko) (Hymenoptera: Trichogrammatidae) treated with low doses of the insecticide deltamethrin did not respond to the signals of females, while the females treated with these insecticides also reduced their capacity of attracting untreated males of this parasitoid (DELPUECH *et al.* 1999).

Insecticides may interfere in three different ways in the feeding behavior of insects. The first way is their repellent effect, which reduces the amount of food of these insects. The second form relates to their anti-food properties, which reduce the feeding stimulus (POLONSKY *et al.* 1989). The third form is the loss of the insects' ability to find food soon after the exposition of the insecticides due to the reduced olfactory capacity (DECOURTYE & PHAM-DELÉGUE 2002).

Insecticides may affect the nervous and hormonal systems of arthropods, leading to physiological changes and oviposition behavior. Indirect disturbances in the oviposition behavior may be induced by the repellent effect of insecticides, which may reduce the chances of the natural enemies to find their hosts for oviposition (LONGLEY & JEPSON 1996; UMORU *et al.* 1996). In addition, exposure to insecticides may change the motor coordination during the oviposition behavior (ALIX *et al.* 2001; DESNEUX *et al.* 2004).

PART III- INSECTICIDE SELECTIVITY

Following the determination of the need for controlling pests and KNE groups through sampling, the choice of the product must consider the effectiveness in control and the selectivity to natural enemies, since they are the main controlling agents of the pest population density (MAREDIA *et al.* 2003).

Selectivity can be classified into ecological and physiological (RIPPER *et al.* 1951). The ecological selectivity is the use of insecticides selectively, namely, minimizing the exposure of natural enemies to insecticides. This selectivity is usually accomplished through insecticide applications at hours of the day when temperatures are mild, because that is when there is less movement of natural enemies and other organisms. On the other hand, the physiological selectivity employs insecticides with low toxicity to the natural enemies or those which are more toxic to pests than to natural enemies (BACCI *et al.* 2006).

Pattern techniques to test the physiological selectivity of insecticides to natural enemies were developed by the International Organization of Biological Control (IOBC/OILB). Insecticides were classified according to the regulations established by the IOBC into: class 1 - innocuous ($E<30\%$); class 2 - slightly noxious ($30<E<79\%$); class 3 - moderately noxious ($80<E<99\%$); class 4 - noxious ($E>99\%$) (HASSAN 1997). In the table 5 are the selective insecticides in their recommended dose in more relevant crops.

INSECTICIDE BIOCHEMISTRY

The rate of penetration of the insecticide in the integument of the insect is related to the physical and chemical characteristics of the compound, cuticle thickness and chemical composition (WINTERINGHAM 1969). So, considering that the lipophilicity is inversely proportional to the solubility of insecticides in water, lipophilic compounds generally penetrate the insect body in higher rates, due to the similarity with its apolar waxy cuticle (LEITE *et al.* 1998).

Therefore, in the following topics, we are going to focus on the main groups and mechanisms of selectivity.

Neurotoxics

Pyrethroids. Some works have demonstrated the selectivity of some groups of insecticides to natural enemies. For example, the pyrethroids batacyfluthrin 50 EC and zetacypermethrin 400 CE presented physiological selectivity to the Vespidae predators *Protonectarina sylveirae*, *Polybia scutellaris* and *Protopolybia exigua* in the dose and subdose.

The possible mechanisms of physiological selectivity of these insecticides are not duly explained because of the lack of biochemical and physiological studies for the elucidation of such mechanisms. Nevertheless, we are going to clarify some mechanisms involved.

The selectivity of the pyrethroids to natural enemies may be associated to the low rate of penetration in the integument due to the changes in the place of action of these compounds and/or the high metabolization rate of the insecticide. The rate of insecticide penetration in the integument of these insects is a result of the relation between the affinity of the insecticide and the cuticle thickness and chemical composition. Thus, considering that the lipofilicity is inversely proportional to the solubility of insecticides in water, lipophilic compounds usually penetrate the body of the insects in higher rates, due to the similarity with their cuticle. Changes in the sodium channels, which alter the sensitivity of the enzymes (Na-K)-ATPase and Mg2-ATPase may also be responsible for the reduction in the neurotoxic action of these insecticides.

Organophosphates. On the other hand, organophosphates have presented low selectivity to natural enemies. For example, the insecticide chlorpyrifos used for the control of the coffee leaf miner Leucoptera coffeella (Lepidoptera: Lyonetiidae) was not selective to Vespidae predators in coffee plants. GALVAN *et al.* (2002) found similar results for wasps P. sylveirae, *Brachygastra lecheguana* and *P. exigua* for the insecticides fenitrothion and fenpropathrin. GUSMÃO *et al.* (2000) also observed the maintainance of high mortality rates for the wasps *B. lecheguana*, *Apoica pallens* and Polistes versicolor versicolor with the decrease of the concentration of the insecticide chlorpyrifos in 50%.

The high toxicity of the organophosphates to predators may be associated to the pro-insecticide activity of this group. When these compounds penetrate organisms, they suffer reactions and become more toxic. Another factor possibly related to the toxicity of organophosphates is the lipophilic character of some insecticides associated to the thickness and lipidic composition of the insect cuticle. Such relation is the accountable for the penetration of the product in the insect cuticle and the translocation to the target of action. Lipophilic compounds present a greater affinity with the insect cuticle and are more easily absorbed and translocated to the place of action. Such hypothesis is based on the low solubility in water presented by the insecticides ethion (0.6 ppm), chlorpyrifos (2.0 ppm) and fenitrotion (21.0 ppm), which were highly toxic to the predatory wasps.

Carbamates. The selectivity of carbamates may be associated to changes in the acetylcholinestase enzyme in the body of predators and parasitoids or to the higher speed with which the acetylcholinestase enzyme catalyzes the hydrolysis of the neurotransmitter acetylcholine in insects, compared to the speed in pests (SILVER *et al.* 1995). The selectivity of the carbamates may also be associated to their higher metabolization rate by beneficial insects than by pests by P450-depending monooxygenase enzymes (BRATTSTEN *et al.* 1986). Similar results were observed with the parasitoid Cotesia sp. For the insecticide carbaryl MANI (1995) for Cotesia plutellae and PICANÇO *et al.* (2003) for Cotesia sp.

Nereistoxin (cartap). The high cartap toxicities to the natural enemies are possibly related to the low molecular weights of this compound (237.3) (BERG *et al.* 2003). According to STOCK & HOLLOWAY (1993), substances with lower molecular weights have greater capacity to penetrate in the insect cuticle. According to this hypothesis, it is possible to observe the low toxicity of abamectin [mixture of the avermectins B1a (80%) and B1b (20%)] and its high molecular weight (873.1 and 859.1) (BERG *et al.* 2003).
Table 2 shows the main selective insecticides and their respective target pests and the main natural key enemies in several crops.

GROUPS OF SPECIFIC PHYSIOLOGICAL INSECTICIDES

Insecticides such as cyromazine (WEINTRAUB & HOROWITZ 1996), abamectin, cartap and phenthoate were safer, in other words, besides presenting high efficiency in pest control, a small increase in the concentration of the insecticide does not produce a substantial increase in the mortality of the natural enemy, even when mixed with mineral oil (LEITE *et al.* 1998). Such effect occurs because these products are physiological. The cyromazine inhibits the larval development and does not inhibit the formation of chitin nor acts directly on adults. In addition, the abamectin, of the avermectin group, besides killing moth caterpillars and adults by the action of contact, may interfere in the female reproductive organs, leading to the laying of infertile eggs (NAUEN & BRETSCHNEIDER 2002).

ECOLOGICAL SELECTIVITY

As it has already been mentioned, the ecological selectivity may be achieved by the reduction in the exposure of natural enemies to insecticides. So, any measure used for this end will be employed in programs of natural biological control. There are several measures to achieve the ecological selectivity, among which the time of the day chosen for application is the most influential.

Time of application. The appropriate time of the day for application prevents the phytotoxicity to plants and is the time of less activity of the enemies (PICANÇO *et al.* 2000). It was concluded that the best period for the application of insecticides is from 6:00 to 7:00 a.m. for the control of the leafminer Liriomyza spp. (Diptera: Agromyzidae) of the potato plant Solanum tuberosum, since its activity is higher and the presence of natural enemies is reduced (Table 4) at this time, thus preventing high mortality and preserving the natural biological control (WEINTRAUB & HOROWITZ 1996).

NATURAL ENEMY SPECIES TOLERANCE

The tolerance of natural enemies to insecticides is similar to the tolerance of pests in crops. The rate of penetration of insecticides in the integument is related to physiological factors, chemical composition and thickness of the cuticle of the natural enemies. The main cause is related to the cuticular composition of insects and the chemical properties of the insecticides, since a more lipidic cuticle promotes more affinity to the insecticides, presenting less solubility in water and lower molecular weight. These compounds allow a higher rate of penetration in the body of these insects (LEITE *et al.* 1998).

Table 4. Average number of parasitoids and leaf miners (L. huidobrensis) collected along the day in a potato plant.

Hours	Parasitoids*	Adult leaf miners
07:00	18.8	3.3
09:00	22.7	1.8
11:00	35.2	1.3
13:00	29.5	1.7
15:00	37.3	1.7
17:00	44.3	0.7
19:00	28.3	1.2

* *Diglyphus isaea* and *Dacnusa sibirica*. Source: Weintraub & Horowitz (1996).

MOURA *et al.* (2000), working with insecticide selectivity to predatory wasps, verified that P. scutellaris is more tolerant to the organophosphate fenthion than P. sylveirae, which is about two times more tolerant to the cartap than the P. scutellaris. GALVAN *et al.* (2002) observed that *P. exigua* is more tolerant to the deltamethrin than P. sylveirae.

Similarly to the mechanisms that impart selectivity to insecticides, the tolerance of the natural enemies may be associated to the lower rate of penetration in the integument, higher metabolization rate of the compound and/or changes in the place of action of insecticides. So, the microsomal oxidase and esterase enzymes and the changes in the sodium channels of the insects may be related to their higher tolerance to pyrethroids (LENG & XIAO 1995; YU 1988). The ethion metabolization by cytochrome P450-dependent monooxygenase enzymes may be associated to the tolerance of natural enemies. These enzymes usually detoxify lipophilic compounds, turning them into metabolic, allowing their excretion (BRATTSTEN *et al.* 1986). Alterations in the acetylcholinestase enzyme in the body of P. scutellaris and/or the high speed with which the enzyme catalyzes the hydrolysis of the neurotransmitter acetylcholine may also be responsible for the ethion tolerance of this Vespidae (SILVER *et al.* 1995).

The nereistoxin insecticides are less studied, but, since these compounds act as antacetylcholine agonists, competing with their receptors (ETO 1990), changes in the receptors of this neurotransmitter may be associated to the tolerance of P. sylveirae to cartap (BACCI *et al.* 2006). SIQUEIRA *et al.* (2000) suggest the involvement of P450-dependent monooxygenase enzymes in the resistance of Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) to cartap. According to these authors, the enzymes glutathione-S-transferases and esterases have a secondary role in the resistance of T. absoluta to this insecticide.

Differences in tolerance related to sex have also been observed for the insecticides of the organophosphate and carbamate groups in the oriental fruit fly Bactrocera dorsalis (Hendel) (Diptera: Tephritidae) in the United States, pointing out that females were more susceptible than males (SHEARER & USMANI 2001). The predator Lasiochilus sp. (Heteroptera: Anthocoridae) was more tolerant to the dose and subdose of abamectin and the subdose of cartap than the parasitoid Encarsia sp. (BACCI *et al.* 2007b). This fact is probably related to the higher volume of the predator's body in comparison to the parasitoid. The higher the body volume, the lower the specific area and, consequently, there is a lower exposure to insecticides

Table 5. Main selective insecticides in their recommended dose in more relevant crops.

Insecticide	Group	Crops	Target Pest	Dose[1]	Natural Enemy	Reference
Betacyfluthrin 50 CE	Pyrethroid	Coffee plant	*Leucoptera coffeella*	0.009	*Protopolybia exigua*	Bacci *et al.* 2006
Ethion 500 CE	Organophosphate	Coffee plant	*Leucoptera coffeella*	1.2500	*Brachygastra lecheguana*	Gusmão *et al.* 2000
Lambda-cyhalothrin	Pyrethroid	Maize	*Spodoptera frugiperda*	0.0500	*Doru luteipes*	Simões *et al.* 1998
Tebufenozide	Diacylhydrazina	Cotton plant	*Alabama argillacea*	12.5000	*Chrysoperla externa*	Carvalho *et al.* 2003
Fipronil 200 SC	Phenyl-pyrazol	Cotton plant	*Anthonomus grandis*	0.0075	*Cycloneda sanguinea*	Soares *et al.* 2000
Teflubenzuron	Benzoyl phenylurea	Cotton plant	*Schizaphis graminum*	0.1500	*Cycloneda sanguinea*	Cosme *et al.* 2007
Clorfluazuron	Benzoylurea	Soybean	*Anticarsia gemmatalis*	0.0500	*Trichogramma pretiosum*	Bueno *et al.*2008
Deltamethrin 25 CE	Pyrethroid	Brassica	*Ascia monuste orseis*	0.0050	*Doru luteipes*	Picanço *et al.* 2003
Carbaryl 850 PM	Carbamate	Brassica	*Ascia monuste orseis*	0.6790	*Cotesia sp.*	Picanço *et al.* 2003
Pirimicarb 500 PM	Carbamate	Brassica	*Ascia monuste orseis*	0.1000	*Doru luteipes*	Bacci *et al.* 2002
Methyl parathion 600 CE	Organophosphate	Brassica	*Ascia monuste orseis*	0.1210	*Brachygastra lecheguana*	Crespo *et al.* 2002
Trichlorphon	Organophosphate	Brassica	*Ascia monuste orseis*	0.1287	*Podisus nigrispinus*	Picanço *et al.* 1997
Abamectin 18 CE	Avermectin	Sweet potato	*Bemisia tabaci*	1.8000	*Lasiochilus sp.*	Bacci *et al.* 2007a
Abamectin 18 CE	Avermectin	Sweet potato	*Bemisia tabaci*	1.8000	*Acanthinus sp.*	Bacci *et al.* 2007a
Abamectin 18 CE	Avermectin	Sweet potato	*Bemisia tabaci*	1.8000	*Discodon sp.*	Bacci *et al.* 2007a
Acetamiprid	Neonicotinoid	Tomato plant	*Tuta absoluta*	1.6800	*Trichogramma pretiosum*	Moura *et al.* 2006
Malathion CE 500	Organophosphate	Appletree	*Panonychus ulmi*	1.5000	*Neoseiulus californicus*	Monteiro, 2001
Triflumuron 480 SC	Benzoylurea	Citrus	*Phyllocnistis citrella*	0.1000	*Polybia sylveirae*	Fernandes *et al.* 2008
Abamectin 18 CE	Avermectin	Watermelon	*Bemisia tabaci*	0.0130	*Lasiochilus sp.*	Bacci *et al.* 2007b
Teflubenzurom	Benzoylurea	Peach-tree	*Grapholita molesta*	1.2500	*Trichogramma pretiosum*	Giolo *et al.* 2007
Deltamethrin 25 CE	Pyrethroid	Citrus	*Phyllocnistis citrella*	0.0075	*Protopolybia exigua*	Galvan *et al.* 2002
Deltamethrin 25 CE	Pyrethroid	Passion Fruit plant	*Dione juno juno*	0.1000	*Polybia scutellaris*	Moura *et al.* 2000
Malathion 500 CE	Organophosphate	Passion Fruit plant	*Dione juno juno*	1.3000	*Polybia sylveirae*	Moura *et al.* 2000

[1] mg of i.a./mL of liquid

(PICANÇO *et al*. 1997).

The mechanisms that impart selectivity to insecticides may be the same related to the insecticide resistance. Hence, the abamectin selectivity may be related to the lower penetration into the body of natural enemies than in the white fly, to the changes in the GABA receptors (aminobutyric acid) in the natural enemies and/or the higher metabolization, due to the action of detoxicative enzymes, which is greater in the body of natural enemies than in B. tabaci (HORNSBY *et al*. 1996).

CONCLUSIONS

The adequate use of insecticides must be taken to all crops, mainly because the new preservation of the agents of natural pest control. Therefore, the correct use of these pesticides is a less aggressive practice for biological components and is efficient in pest control, thus enlarging the commercial market for the agricultural products. Selective insecticides may present effectiveness against pests and low impact on the survival, reproduction and behavior of predators and parasitoids.

There are several works on insecticide selectivity to the natural enemies, but there are few correct measures for choosing such products. After the necessity for the control through sampling is determined, the choice of the product must take into account the effectiveness in pest control and selectivity to predators and parasitoids, because they are the main agents for the control of the pest population density. The differences in tolerance to insecticides between the species of natural enemies demonstrate the importance of their correct identification in the agroecosystem.

It is also possible to conclude that the results achieved with insecticides and several enemies present great variation. It is believed that the methodological differences are among the reasons for the changes in toxicity and selectivity of insecticides. Another factor to be pointed out is that the selectivity tests are carried out under controlled laboratory conditions. Hence, the insecticides which are selective under these conditions may present a high performance in the field, where weather and human conditions reduce their toxicity potential to natural enemies.

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