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REVIEW

The use of insecticides to control insect pests

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Abstract
Pesticides are used as plants protection products. Among those, insecticides serve as agents to control insects. When incorrectly applied, however these substances may negatively affect people's health and natural environment. Administration routes of insecticides depend on many factors and vary from spraying to fertilizers. These different methods influence how insects prey and how pests develop. Additionally, too frequent use of the same chemicals can lead to development of resistance of insects to these insecticides. In order to prevent occurrence of negative effects of insecticides on surroundings, the effects of these compounds should be studied.

Key Words: pesticides; insecticides; pest insects

Introduction

Insects are now the largest group of animals (Tsakas, 2010). Moreover, owing in large part to their staggering diversity, insects are in more different places in the world than virtually any other organism. There are insects in habitats ranging from the high Arctic to tropical rainforests to petroleum pools to glaciers to mines a mile below the surface to caves to sea (Resh and Cardé, 2003). Currently, there are more than a million described species and it is assumed that is only a small percentage of this large group of animals. Only few species of insects live in seawater, whereas ca. 100,000 species (especially larvae) in habit freshwater after their secondary aquatic adaptation. The insects can to adapt the life in the water or on the water surface (Chapman, 2013). On land, insects are present in all biotopes: in the mountains, caves, hot springs, polar zones. The greatest biodiversity of insects are found in warm climates. The warm climatic conditions favor the development of biodiversity, such as environmental conditions and food availability (Resh and Cardé, 2003; Chapman, 2013). Biological adaptation of insects allows them to adjust to specific environment and survive in almost all climate zones. Some species can even fall into a state of diapause as a way to survive adverse conditions. Such insects exhibit high fertility, large populations reaching a million or a billion individuals, and ability to feed on everything that contains organic matter (from wood to blood). For some species as little as one ingredient is enough to survive, *e.g.,* wine barrel sediment rich in acidic potassium bitrate (cream of tartar). Insects' life span varies between species: mayflies live for one day, queen of bees for 10 years, and termites can live up to 50 years.

Insects play a very important role in biocenosis, interaction of insects with other species in the environment is beneficial for participating parties. Moreover, insects also take part inhuman life, health, and the economy. Unfortunately, that role instead of being beneficial is harmful. Insects can be parasites, human pathogens and carry diseases. They're involved in transmission of malaria, yellow fever, typhus, plague, dengue, various forms of encephalitis, relapsing fever, river blindness, filariasis, sleeping sickness, and innumerable other debilitating or even fatal diseases, not just in warmer climes (Resh and Cardé, 2009).

Characteristics of selected harmful insects species

Harmful insects, in various developmental stages such as larvae or adults, attack different parts of plants: roots, stems, leaves. If plant is attack by harmful insects usually this plant die (Chapman, 2013).

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Ceutorhynchus napi are 3.2 - 4 mm grey in color beetles. Females of these beetles puncture plant stems and lay eggs inside. Larvae hatch after approximately 10 - 20 days. During growth and development of larvae, abnormal bulbous growth appears on the stem, which then ruptures, leading to deformation of the stem (Chapman, 2013). Larvae also tunnel through stems leading to damage that can facilitate pathogen's access to plants. This species produces one generation per year (Taiz and Zeiger, 2010).

Ceutorhynchus quadridens are brown beetles with a length of 2.5 - 3 mm, and possess characteristic whitish dots on the wing covers. In the spring the females lay eggs and their development takes up to 3 months. White larvae up to 6 mm has a brown head. Its chrysalis is yellowish and has a long snout. The larvae are feeding inside and tunnel through stems without distorting them. This strong damage inhibits the plant growth, where as the tunnels create sites for infection (Chapman, 2013).

Baris spp. are 3 - 4 mm beetles with a blue or dark green metallic sheen. Females deposit eggs in the roots of plants. The larvae tunnel through the roots and poison the roots at the same time. The pupae are whitish, they don't like move, size similar to adults (Chapman, 2013). This leads to inhibition of plant growth and allows for easier access of pathogens.

Wireworms - the larvae *Elateridae* are beetles with length of 7 - 15 mm and a brown-gray color. The larvae are covered with cooper color chitin. These insects feed on the underground parts of plants what damages the roots system leading to plants withering. Click beetle larvae (wireworms, *Elateridae*) are generally plant or detritus feeders, but some are predatory in soil or rotting logs (Resh and Cardé, 2003).

Bibionidae are flies with a stocky and hairy body (8 - 10 mm in length). Females have gold-red coloration, males are black. The larvae *Bibionidae* live in the soil, damage the seeds, and chew on the roots. This leads to disruption of water management in plants and excessive lowering of the plant level. The stout, dark-colored adults feed on flowers. The worm-like larvae are general detritivores and can be found in organic soils and compost heaps in abundance (Resh and Cardé, 2003).

Zabrus tenebrioides is beetle with length of 12 - 15 mm. This beetle is black in color, has a characteristic light brown abdomen, and red-brown antennae, and legs. In the fall, larvae damage germinating seeds. They feed on the leaf bases and blades, leading to their withering and death. This species, in contrast to other beetles, which are mostly carnivorous species are herbivorous (Chapman, 2013).

Thripidae is a slender, black-brown insect with length about 1 - 2 mm and narrow wings. Lives mainly on flowers, under the tree bark, or in plant litter. The legs of adults lack typical insect tarsal claws, but each tarsus has an eversible bladder-like arolium (Resh and Cardé, 2003). The larvae and individual adults damage the seeds. Pathogens can easily use the damage to penetrate to the interior of the plant and infect it. Often the infected plant dies (Chapman, 2013).

Grubs - the larvae of beetles (*Melononthidae*) have a specific white, curved body with a darker head and 3 pairs of strong legs. Grubs live in soil and can damage the root system of plants causing their withering and death (Chapman, 2013).

Cabbage aphid (*Brevicoryne brassicae*) reach a length of 2 - 2.5 mm, are gray-green in color and their bodies are covered with waxy coating. Winged or wingless forms of adults can be distinguished. They are herbivores suck the juice from plants, partially digesting it, and the residues excrete. The larvae of these insects are similar to the adult form. They attack the inflorescence stems, petioles and leaf blades leading to withering and death of plants (Chapman, 2013).

Phorbia brassicae belong to flies with a body length of 5 - 6 mm and have characteristic red spots on silver-white foreheads. Females are bigger than males. This species exhibits a sexual dimorphism: the male is black-gray and the female is brown-gray. The larvae attack the roots causing the death of plants (Chapman, 2013).

Pieris brassicae belong to the butterflies with white wings (Brzeziński, 1922) with a span of 5 - 6 cm. Female Large Whites have a pair of prominent black spots in the median area of the forewings, but these are absent in the male. The spots are visible on the underside forewings of both sexes. Caterpillars of this butterfly are yellowish with black spots and have a body length of about 4.5 cm. They feed on leaf blades and siliques. Caterpillars scrape the parenchyma off the bottom side of the leaf blades which often leads to the death of plants (www.learnaboutbutterflies.com).

Methods of insects pests control

Different procedures and methods can be used to control harmful organisms.

1) Physical methods: According to their mode of action, physical control methods can be active or passive. The level of efficacy of active methods is proportional to both intensity of the energy and duration of its application to the target. Active methods include thermal shock (heat, cold), electromagnetic radiations (microwaves, radio frequencies, infrared, ionizing radiations, UV and visible light), mechanical shock and pneumatic (blowing or vacuum). Passive methods do not require further energy to achieve desired effect. Examples are traps, airtight or hermetic storage, barriers of various kinds and trenches (Vincent *et al*., 2009).

2) Biological methods: their goal is to reduce the population of the pest below the economic threshold. Examples would be: introduction of non-native, natural enemy of pests into the environment: use of pathogens including bacteria, viruses and fungi that would infect pests. Other insect can also be used against insects pests (Commission Directive 2008/113/EC of 8 December 2008 amending Council Directive 91/414/EEC to include several micro-organisms as active substances; Can Ulu *et al*., 2016).

3) Chemical methods: associated with the use of chemicals that affect particular insects. These compounds may be of natural origin, *e.g.*, attractants, repellents, antifeedants, pheromones,

and hormones: synthetic origin, and/or combination of natural and synthetic compounds. Chemical compounds and mixed compounds of synthetic and natural origin are called pesticides. Chemical measures should be considered only as a complementary. In selecting a pesticide and the appropriate formulation, consideration should be given to its biological effectiveness (including residual activity where appropriate) against the pest concerned, the susceptibility of the target organism, the methods of application, its safety to humans, its toxicity to non-target organisms (WHO, 2006; WHO, 2012).

Pesticides

Pesticides are synthetic or naturally-occurring chemicals used to target and destroy harmful organisms. The goal of their use is to reduce or completely eliminate pests, weeds and diseases (Sánchez-Bayo and Ortega, 2012; Satyavani *et al.*, 2012). Pesticides can also affect plant's growth regulation. The name comes from the Latin words *pestis* - pest and *cedeo* - destroy. The number of pesticides used in the world is enormous: more than 1000 different pesticide formulations containing substances with high biological activity are available. The classification of insecticides by chemical composition and examples of commercial products is presented in the Table 1. Pesticides play a significant role in the quality and efficiency of agricultural production (Rodrigues Macedo and Freire, 2011), they also impact the environment and unfortunately, not always in a positive way (Bazok *et al.*, 2012; Cardoso and Alves, 2012). The new pesticides are systemic, meaning they can be taken up by the plants and animals and distributed through their tissues without accumulating in any particular organ or structure (*e.g.*, fatty tissues) (Sánchez-Bayo and Ortega, 2012).

Plant protection products exhibit high toxicity toward targeted pests. Additionally, these substances should show short persistence in the environment, a high susceptibility to degradation in such a way that after reaching its destination these chemicals would quickly disappear from the soil, water and air (Grosicka-Maciąg, 2011; Lofty *et al.*, 2013). Apart from targeted pests, pesticides affect surroundings and organisms that live in the area where agents are used. That is why it is so important to study the effects of specific pesticides on environment prior to use of these substances. They should be applied in accordance with the principles of integrated vector management, an evidence-based decision-making process adapted to local settings, which rationalizes the use of vector control methods and resources and emphasizes the involvement of communities (WHO, 2006; WHO, 2012).

The use of insecticides

Insecticides are commonly used to protect against insects in households, restaurants, hospitals, farms, forest plantations, etc. These substances protects from the harmful insect-borne diseases, insects pests in warehouses, and agricultural and forest pests (Cardoso and Alves, 2012). A list of insecticides is presented in the Table 2. Effective control measures must be based on a clear understanding of the bionomics and behavior of the target species. Effective vector and pest control also requires careful training, supervision of control operations and periodic evaluation of the impact of the control measures on the targeted vectors or pests and on disease incidence or prevalence. Chemical measures should be considered only as a complementary addition to basic sanitation, as far as possible. In selecting a pesticide and the appropriate formulation, consideration should be given to its biological effectiveness (including residual activity where appropriate) against the pest concerned, the susceptibility of the target organism, the methods of application, its safety to humans, its toxicity to non-target organisms. In addition, the extensive use of chemical pesticides, which allowed farmers a better pest control and more effective producing food (Meissle *et al.*, 2010).

One of the most known diseases carried by insects in tropical countries is malaria. Its epidemic is associated with the mass occurrence of mosquito (*Anopheles maculipennis*). Even though in moderate climates mosquitoes aren't responsible for carrying malaria, these insects cause inconvenience, especially female mosquitoes that bite causing skin itching (Gliniewicz *et al.*, 2003). The spread of yellow fever and dengue as the vector mosquito *Aedes aegypti* dispersed throughout the tropics, and of malaria to Brazil with the introduction of its vector *Anopheles gambiae*, are notable examples of human diseases vectored by introduced insects (Simberloff, 2009).

Another harmful and troublesome insect particularly in the warmer seasons is a fly, especially housefly. The house fly, *Musca domestica*, is a well-known cosmopolitan pest of both farm and home. This species is always found in association with humans or the activities of humans. This insect sits on food, faeces, and carrion, which makes it great candidate for spreading diseases and parasites. Housefly carries pathogenic bacteria, dysentery, paratyphoid fever, anthrax, and different forms of invasive parasites (*e.g.*, eggs of threadworms). The house fly has a complete metamorphosis with distinct egg, larval or maggot, pupal and adult stages. The house fly overwinters in either the larval or pupal stage under manure piles or in other protected locations. Warm summer conditions are generally optimum for the development of the house fly, and it can complete its life cycle in as little as seven to ten days. Fly also spreads agents that cause conjunctivitis. It is also an intermediate host for the larvae of some tapeworms (Sanchez-Arroyo and Capinera, 2014). Blue bottle fly (*Calliphora womitoria)* with a characteristic blue color and a green fly (*Lucilla sericata*) (WHO, 2008) are typical insects on farms and meat processing plants. Flies such as *Drosophila melanogaster, Drosophila funebris* occur mainly where fruits, juices, and jams ferment. Flies carry mold, bacteria, and are particularly dangerous when their development is carried in the faeces (WHO, 2008).

From the sanitary viewpoint it is important to control cockroaches. Their representatives are *Blattella*

Table 1 The classification of insecticides by chemical composition and examples of commercial products

Insecticide	Chemical compound	Commercial product
Organophosphorus insecticides	TEEP - tetraethyl pyrophosphate	FYFANON 440EW
	Dianizion	ANTHON
	Parathion	BOVINOX
	Paraoxon	PROXOL
	Trichlorfon	DANEX
	Malathion	
Polychlorinated insecticides	Bischlorophenyl:	AZOTOX
	DDT	DITOX
	Metoxychlorine	TRIOX
	Derivatives cyklodiene:	ANOTEX
	Aldrin	CESAREX
	Dieldrin	CHLOROPHENOTHANE
	Ceptachlorine	DEDELO
	Endosulfan	DINOCIDE
	Chlordon	DIDIMAC
	Derivatives cycloparaffinic:	DIGMAR
	Hexachlorocyklohexane	GENITOX
	Lindane	GUESAPON
	Chlorinated terpenes:	IXODEX
	Camphenes	NEOCID
	Pinenes	R50
Carbamate insecticides	Carbanil	PRIMOR 500W
	Carbofuran	MARSHAL 250DS
	Primor	PRIFLOR AE
	Izolan	PRIMIX AL
	Aldikarb	PRIMIX AE
	Bindokarb	
	Thiamethoxan	
Neonicotinoids	Imidaclopirid	ACTARA 25WG
	Firponil	MOSPILAN 20SP
	Clothianidin	
	Natural:	
Pyrethroids	Pyrethrins	CYFLOK 50EW
	Jasmolin	K-OTHRINE
	Cynarin	BROS INSECT SPRAY
	Synthetic:	ABC
	Allethrin	AC
	Alphamethrin	INSEKTUM A 01 AL
	Bioresmethrin	SPRUZIT 04EC
	Cyfluthrin	DECIS 2.5EC
	Cypermethrin	
	Deltamethrin	
	Permethrin	
	Rosmethrin	
	Trousfluthrin	
	Fenvalerate	
Others	Calcium oxide	
	Boric acid	
	Trioxane	
	Nicotine	
	Zyklon B	

germanica and *Blatta orientalis*. They demonstrate a high mobility and exhibit an unpleasant odor coming from their glands. *B. germanica* is tolerant of a wider range of conditions and may even be found in dry places, provided it has access to water. *B. orientalis* generally prefers cooler, moist conditions. Cockroaches spread many diseases; can carry about 40 species of bacteria, protozoa, viruses, and fungi which are dangerous to people and pets. German cockroaches usually prefer a moist environment with a relatively high degree of warmth. The insects are mostly scavengers and will feed on a wide variety of foods (WHO, 2006; Jacobs, 2013).

All the mentioned insects are very unpleasant and dangerous, not only in our homes and catering points, but seem to be constitute a health hazard in hospitals where hygiene is the priority (WHO, 2006, 2008).

As total coverage can rarely be achieved, the focus should be on areas where people congregate, *e.g.*, high-density housing, schools, hospitals and areas where cases of disease or high vector densities have been recorded. The most common insect pests in hospitals are: ants (*Monomorium pharaonis*, fleas (*Siphonoptera*), mosquitoes (*Culicidae*), flies (*Diptera*), bedbugs (*Cimex rectularius*) and others. These insects can be found in virtually all areas including kitchens, laundry rooms, patient's rooms and operating rooms (WHO, 2006; Resh and Cardé, 2009).

In order to control insects hospital rooms are sprayed with insecticides from the group of pyrethroids, *e.g.*, deltamethrin, permethrin, cypermethrin, alphacypermethrin, and the group of carbamates, eg. bendiocarb. Elimination of harmful

Table 2 A list of insecticides and the insect species to which these substances apply to

Insecticide	Insects species
Cyflok 50 EW	Cockroaches: *Blatella germanica L.,* *Blatta orientalis L.* Black beetles litter, eg. *Spondylis buprestoides* *Monomorium pharaonis L.* *Lepisma saccharina* *Plodia interpunctella*
VIGONEZ	Ants (*Formicidae*) Beetles
Getox ULTRA	Cockroaches: *Blatella germanica L.,* *Blatta orientalis L.* *Monomorium pharaonis L.* Bugs (*Cimex rectularius*) Fleas *Lepisma saccharina*
K-othrine 25 SC	Cockroaches: *Blatella germanica L.,* *Blatta orientalis L.* Fly (*Musca domestica, Calliphora vomitoria*) Mosquites (*Anopheles maculipennis, Culex pipiens*) Bugs (*Cimex rectularius*) *Monomorium pharaonis L.*
Actellic 500 EC	*Sitophilus granarius* *Tribolium confuscum* *Oryzaephilus surinamensis L.*
Getox	Cockroaches: *Blatella germanica L.,* *Blatta orientalis L.* Bugs (*Cimex rectularius*) *Monomorium pharaonis L.* *Lepisma saccharina*
Karate Zeon 050 CS	Caterpillars - *Pieris brassicae, Pieris rapae* Aphids *Thrips tabaci, Kakothrips robustus* *Delia antiqua* *Hoplocampa brevis* *Bembecia hylaeiformis*
Magus 200 SC	*Tetranychidae* at different developmental stages
Mospilan 20 SP	*Leptinotarsa decemlineata* - larvae and beetle Aphids *Leucoptera xitella* *Hoplocampa testudinea* *Dasyneura piri* Caterpillars
Actara 25 WG	*Leptinotarsa decemlineata* *Hoplocampa testudinea* *Anthonomus pomorum* Aphids *Eriosoma lanigerum* *Psylla piri*

insects from hospital rooms is quite a challenge due to the variety of buildings and different features in each room. Presence of sick people who might have a reduced immunity is an additional complication. Insecticides should combines strong selective activity against key pests with low vertebrate toxicity (Owens, 2002; Larson *et al*., 2012).

Products used by people in their homes or in restaurants mainly contain compounds from the group of pyrethroids, for example deltamethrin, alphamethrin, tetramethrin. These are effective for controlling mosquitoes, flies, and other insects. Additionally, repellents or substances acting dissuasive on mosquitoes can be used to protest against their bites. The formulations used for insect are available in different forms, *e.g*., sprays, concentrates, powders, sticks. All pesticides are toxic to humans to some degree. However, the doses that are acutely toxic to humans are usually far higher than those required for killing vectors and pests. The key to safe use of pesticides is to reduce to a minimum the possibilities of unsafe exposure during handling of hazardous chemicals. Therefore, care in handling pesticides, particularly by spraying staff and persons living in sprayed houses, should be a routine practice and form an integral part of any program involving the application of pesticides (WHO, 2006; Sánchez-Bayo and Ortega, 2012).

Change in crops technology brought economic importance to pest control. Intensive fertilization of crops as well as protection efforts against weeds and diseases are factors contributing to the development of different insects. The latter can significantly reduce crop yields (Kaniuczak, 2013). In recent years, many pollinators have declined in abundance and diversity worldwide, presenting a potential threat to agricultural productivity, biodiversity and the functioning of natural ecosystems (Piiroinen *et al.*, 2016). Unfortunately, all agrotechnical simplifications, new plants species, changes in agroclimate favor development of species of harmful insects that haven't been observed in the area ever before. Changing climate-soil conditions, simplification of crop rotation (Bazok *et al.*, 2012), and use of heavy equipment for field work affects oil. All of these mentioned factors can cause development of extra species which are harmful to crops. Insecticides are chemicals used for the protection of plants against harmful insects (Satyavani *et al.*, 2012). Of course, only approved and registered insecticides should be applied. Additionally, for effective treatments, these substances should be properly selected, applied at the optimum for the insecticide temperature while maintaining grace period and prevention. The crops should include effective management of target pests, decreased use of conventional insecticides, and reduced harm to non-target organisms (Prischmann *et al*., 2007; Gassmann *et al.*, 2014). Plant protection products should be used according to the label and with necessary precautions. The use of insecticides acting selectively on specific species allows for protecting the populations of beneficial insects such as bees, ladybugs, lacewings. Bumble bees are important pollinators whose populations have declined over recent years (Kaniuczak, 2012; Laycock *et al*., 2012). It is also possible to apply seed dressing, which eliminates the need for spraying. Females are the main target of used insecticides as reducing the number of females in the population decreases the number of laid eggs. Development of safer and more effective technologies insecticide significantly affected the longevity or reproductive capacity of emerged females, or the sex ratio of their progeny (El-Wakeil *et al*., 2013).

Ecological farming is another area of growing plants. Plant protection is seen in a different way than in conventional farming. The prophylactics in reducing weeds, pathogens or pests are preferred. Only exceptional situations allow direct applying permitted plant protection means (Szymona, 2009). Number of available chemicals used to protect plants from harmful insects is very limited. Insecticides used in agriculture are mainly pyrethriod synthetic compounds with molecular structure similar to natural compounds - pyrethrins. Pyrethroids are more resistant to oxidation and photo degradation. Currently, organic farming uses two active ingredients: deltamethrin and lambda-cyhalothrin (Lofty *et al.*, 2013; Thany *et al.*, 2015). Deltamethrin was synthesized in 1973, it is photostable, soluble in organic solvents but poorly soluble in water. Farmers, mainly at the beginning of the organic farm activity, demand biological plant protection products that could fully replace chemical pesticides. Unfortunately, it is impossible. It results from a very short list of permitted products as compared to a wide spectrum of synthetic pesticides and from complete lack of some groups. It exhibits contact-stomach action (Szymona, 2009) on insects such as: *Orthoptera* (*Caelifera)*, bugs (*Aphididae, Cimicidae*), butterflies (*P. brassicae*), beetles (*Chrysomelidae*, *Melolontha melolontha*, *Tenebrionidae*), *Diptera* (flies, midge). Deltamethrin is toxic to fish and bees by contact. Lambda-cyhalothrin belongs to a group of chemicals called pyrethroids. Pyrethroids are manmade chemicals that are similar to the natural insecticides pyrethrins. It exists in two isomeric forms, dissolves well in organic solvents, but is insoluble in water. Works mainly on contact and is used for bugs (*Aphididae*, leafhoppers, *Cimicidae*), butterflies (*P. brassicae*), beetles (leaf beetles, *Melolontha melolontha*) (WHO, 2006).

In recent years inhibitors of chitin synthesis and pyrethroids were introduced to protect forests against harmful insects. Restrictive measures established by European Union significantly narrowed the list of substances authorized for use in forests. Number of allowed chemicals has been cut, but number of harmful insects did not decrease. Forest protection and health program aim to assist, advise and support countries to protect the health and vitality of forests, forest ecosystems and trees outside forests, with special reference to insects, diseases and other harmful biotic and abiotic agents (Moore, 2009). Harmful forest insect and insecticides used to control them is presented in the Table 3.

Table 3 Harmful forest insect and insecticides used to control them

Insect	Insecticide	Insecticide class
Hylobiusabietis and other weevils	FASTAC LAS 15 SC SHERPA 100 EC	Pyrethroids
Lymantria monacha, Dendrolimus pini	FORAY 76 B DIMILIN 480 SC * MOSPILAN 20 SP SHERPA 100 EC *	 Chitin Synthesis Inhibitor Neonicotinoids Pyretroids
Panolis flammea, *Bupalus pinaria*	SHERPA 100 EC	Pyrethroids
Diprion pini	DIMILIN 480 SC SHERPA 100 EC MOSPILAN 20 SP	 Pyrethroids Neonicotinoids
Acantholyda posticalis	SHERPA 100 EC MOSPILAN	Pyrethroids Neonicotinoids
Larvae *Hymenoptera*	SHERPA 100 EC	Pyrethroids
Torix vinidiana, Operopthera brumata	FORAY 76 B SHERPA 100 EC	 Pyrethroids
Cacoecia piceana L., Exoteleia dodecella, butterfly caterpillars	SHERPA 100 EC	Pyrethroids
Imagines of cockchafer, *Coleophora laricella,* springtails	MOSPILAN 20 SP	Neonicotinoids
Aphids (*Aphidoidea*)	MOSPILAN 20 SP AGRO PIRYMIKARB 500 WG PRIMOR 500 WG PINOIL 012 AL.	Neonicotinoids
Tetranychus urticae	ORTUS 05 SC	-
Parthenolecanium pomeranicum	PINOIL 012 AL. PROMANAL 60 EC	-

* Not recommended by the FSC- Forest Stewardship Council

Decades ago, a new group of insecticides with a contact and stomach action (Hardy, 2014) has been developed. These insecticides are called neonicotinoids because of their resemble to nicotine. These substances act mainly by contact and stomach on insects belonging to different rows, *e.g., Heteroptera*, flies, and butterflies. Neonicotinoids exhibit action against forest leaf-eating insect pests, thus have high toxicity toward targeted insects, but low toward warm-blooded animals and other insects that aren't at aim. In forestry neonicotinoids are used to control: *Lymantria monacha*, beetles, *Dendrolimus pini*, and other species of folivorous insects. Mospilan 20SP with an active ingredient - acetamiprid - is an example of neonicotinoid used to protect crops and forests. It acts as neuropeptide acetylcholine agoniston the central nervous system of insects. This formulation is used to control number of sucking and biting insect sand acts both on the plant surface and inside by deep-penetrating into the plant. Insects feeding on the sprayed plant will die. However, it is important that the insecticide does not adversely affect non-target insects, *e.g*., Bumblebees, bees (Laycock *et al*., 2012). Through biting the plant tissue insects suck toxic nourishment which ruins their digestive system. This measure may be applied in cultivation of: potatoes (larvae and beetles, *Leptinotarsa decemlineata*), rapeseed (*Ceutorhynchus assimilis*, *Meligethes aeneus*), fruit trees such as cherries (aphids), apples (*Cydia pomonella*), pears, and plums (aphids) (Sánchez-Bayo and Ortega, 2012).

Some of the chemicals used are Forest Stewardship Council (FSC) certified. Awarding the certificate was established in 1993, it promotes a worldwide system of responsible forest management. The use of the FSC logo indicates that the wooden product has a known origin and has no negative influence on the environment, which is socially beneficial and economically viable. The FSC label is dedicated for wooden products and means that the harvesting of wood for this product did not disturb the environment (https://us.fsc.org/en-us/certification).

Laboratory conditions can be used to evaluate the effect of insecticides on individual groups and species of insects (Korrat *et al.*, 2012). Analysis of chemical compounds produced by insects that were treated with insecticides is a useful technique (Georghiou and Metcalf, 1961). Such analysis is performed using a gas chromatography-mass spectrometry GC/MS (Lockey, 1988; Buckner, 1993; Cerkowiak *et al.*, 2013). Different chemical compounds are present on the external body surface of insects such as lipids or body fat (Gołębiowski *et al.*, 2012; Cerkowiak *et al.*, 2015). Larvae exhibit much higher accumulation of those compounds than adults (Ahammao-Sahib *et al*., 1994) due to the fact that the body fat supports the juvenile hormone during the transformation of the larvae. Juvenile hormone (JH) is a sesquiterpenoid produced by the corpora allata and is present throughout nymphal and larval life in all insects (Riddiford, 2009).

The problem of insects' resistance to insecticides

The widespread use of insecticides leads to development of resistance of insects to the chemicals (Roush, 1995) used to protect plants (Feyereisen, 1999; Hardy, 2014). Insecticides eliminate susceptible individuals from the population while resistant individuals remain. Subsequent generations will inherit traits that determine resistance and as a result, a population of resistant individuals is favored (Manchao *et al.*, 1995). Pyrethroid with two active ingredients 1) deltamethrin and 2) alphamethrin (Laycock *et al*., 2012) is used for folivorous pest control (*Lymantria monacha*, *Dendrolimus pini* and attacking conifers (*Hylobius abieti*s).

The problem of resistance to chemicals is not limited to the insects, but also applies to plants and animals including nematodes, bacteria, mites, crustaceans, fish, amphibians, fungi, rodents and some species of weeds (Malinowski, 1997).

Insecticide resistance is one of the best examples of microevolution, or evolution occurring on an ecological time scale. The study of insecticide resistance is important, both because it leads to a better understanding of evolutionary mechanisms operating in real time, and because of its economic relevance. The development of insecticide resistance in pest insects has been an increasing problem for agriculture, forestry and public health. Agricultural practices usually include the systematic application of a wide array of active compounds at variable dosages and frequencies, which represent a wide range of selective regimes. Therefore, identifying the molecular and genetic adaptations responsible for insecticide resistance will offer new opportunities for developing pest management strategies. The study of insecticide resistance makes it possible to classify adaptations into three main mechanisms: reduction of insecticide uptake, by reducing the permeability of insect cuticle, detoxification, through alteration in the levels or enzyme activities that degrade or sequester insecticides and, insensitivity due to point mutations in genes encoding for proteins that are the target site of insecticides (Silva *et al*., 2012).

In 1956, the World Health Organization (WHO) developed an international program to collect information about resistant populations of pests, methods of detection and evaluation of the resistance, and the use of alternative plant protection products. Manufacturers of plant protection products designated International Group of National Associations of Manufacturers of Agrochemical Products (GIFAP) to look at insects' resistance to insecticides. Within this group, a special committee was established- Insecticide Resistance Action Committee (IRAC)- to provide expertise on insects' resistance to specific pesticides. This action aims to help producers prolong usability of produced insecticides (Malinowski, 1997; Irving, 1995).

Immunity is associated with natural selection observed in the environment. Darwin observed that only fraction of offspring survives and reproduces by passing their genetic traits to future generations (Malinowski, 1997).

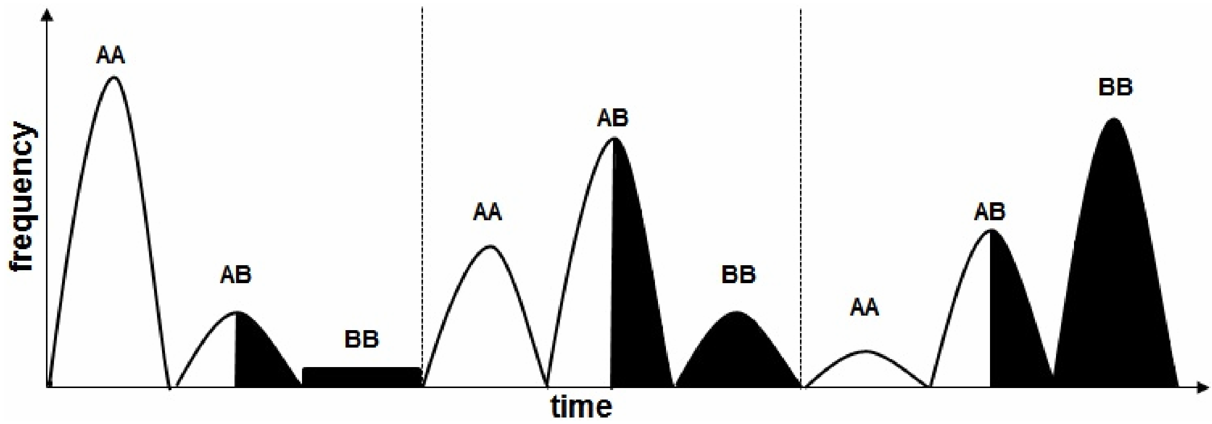

Fig. 1 Frequency of occurrence: sensitive homozygotes (AA), sensitive heterozygotes (AB) and resistant homozygotes (BB) in the population of insects subjected to an insecticide (based on Malinowski, 1997).

According to Crow the resistance causes genetic changes in response to selection. Changes can apply to individuals or to entire population. Development of resistance and its subsequent inheritance depends on the selection factor which acts on the organisms in the environment such as for instance insecticide. Of course, the frequency and time of use of the insecticide play an important role (Malinowski, 1997, Silva *et al.*, 2012).

Populations resistant to insecticide can develop when:

1) few heterozygotes resistant to insecticides are present in the population,
2) resistant homozygotes are practically non-existent in the studied population,
3) frequency of occurrence and gene dominance cause the maximum level of resistance and these genes will not be recessive,
4) genes responsible for resistance to the insecticide will be present in the final population (Winter *et al.*, 2005).

Initially, the population consists mainly of individuals that are sensitive homozygotes and few heterozygotes. No resistant homozygotes are observed. When the application of the insecticide extends in time, individuals cross breed and in the subsequent generations there are fewer sensitive homozygotes while heterozygotes and homozygotes become more resistant (Tang *et al.*, 1995; Winter *et al.*, 2005). As time passes, resistant homozygotes begin to prevail over the sensitive homozygotes and heterozygotes. This leads to the population consisting of resistant homozygotes (Fig. 1) (Winter *et al.*, 2005).

Building resistance to insecticide depends on:

1. Internal factors:

- Genetic - the frequency of occurrence of resistance genes, their number, and dominance. Expression of these genes as well as impact of insecticides applied to insects. The number of resistance genes in the initial population correlates well with the number of resistant individuals. Dominant homozygotes are more resistant than heterozygotes that exhibit incomplete dominance. The lowest resistance will be observed in sensitive homozygotes. Whether one single gene or combination of genes is present, this determines rate of selection of individuals and development of resistance.
- Biological - include biotic and behavioral factors. Biotic factors include the size of one generation in the population and how long this generation lasts. The development of resistance is higher when the duration of one generation is short. Behavioral factors, *i.e.,* isolation, population mobility, migration, have a large impact on the development of resistance. When the population is more isolated the process of building resistance will occur faster due to lower opportunity to exchange genetic pool.

2. External factors

- Operating - factors associated with the use of the chemical compound such as: chemical structure, similarity of this structure to the previously used formulation, accumulation in the environment, formulation, and longevity of threshold selection, dose, the stage of development of insects, the application route (Winter *et al.*, 2005).

Cross resistance has to be considered while using insecticides (Winter *et al.*, 2005). It can occur when chemicals are very similar in structure. Insects would then be resistant to the whole group of insecticides due to their structural similarities as the same genes regulate the resistance. It is assumed that the threshold selection influences the development of resistance and use the insecticide should remove 90 % of the population. It is clear that the inheritance of resistance is faster when genes are dominant. The applied dose of insecticide is an important factor. If the dose is so high that it causes the killing of sensitive homozygotes and resistant heterozygotes, the dominant genes would be functionally recessive, and only use of a lower dose will lead to their dominance (Winter *et al.*, 2005).

Conclusions

Insects are the largest group of organisms inhabiting Earth. Their role is very significant; these organisms can be beneficial, neutral, or harmful for the environment. The use of chemicals to eliminate harmful insects may have a negative impact on the lives and health of people and animals: however when used as intended and in doses declared by the manufacturers these substances can bring great aid in insects' control .Resistance of insects to insecticides is a growing problem and it is important to remember not to immunize insects against specific chemicals. If we ignore this fact, protection against a given insect species may not be available as a consequence.

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