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# Detailed Review on Pesticidal Toxicity to Honey Bees and Its Management

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## Abstract

This chapter deals with the effects of different pesticides used in agro-ecosystem on honey bees and other pollinators and probable measures to manage this escalating problem of global decline of managed as well as the wild insect pollinators. This chapter describes different routes from which pollinators, especially honey bees get exposed to the different toxicants, followed by poisoning symptoms in honey bees. Further, this chapter focuses on the classification of different toxicants in different classes as per their nature. Finally, the management of these different toxicants and their toxicity to avoid bee poisoning has been considered in the later portion of the chapter.

**Keywords:** pesticide, toxicity, honey bees, pollinator, management

## 1. Introduction

Honey bees contribute more than 90% of the global pollination of more than approximately 85% of the total cross-pollinated plant species in the world, the blessing of being able to hover around and pollinate this much diverse array of floral plant species comes with a curse to these bees, of being in unremitting contact with a wide array of stresses like, parasites, predators, diseases, chemical, etc. present in the environment [1–3]. As being the most successful and commercially exploited pollinators in agro-ecosystems not just for their pollination duties but for commercially valuable by-products such as, honey, wax, propolis, etc. as well, honey bees faces more diverse stresses in nature. Honeybees (*Apis mellifera*) are exposed to an ever changing array of xenobiotics from both natural and synthetic sources. Thousands of older foraging worker honey bees travel as far as 10 km from the hive in the course of collecting the nectar, pollen, water, and propolis needed to sustain a colony of tens of thousands of young adult workers, immature bees, and male reproductive or drones [4]. While foraging over this large area for collecting pollen and nectar to satisfy the carbohydrate needs of the colony, bees forage in various flowering plants with different nature, but these food sources are not always entirely pure every time, having either different plant derived chemicals or the widely used toxic agro-chemicals mixed with them. With the ever increasing use of synthetic chemical pesticides in agriculture honey bees and other wild pollinators have faced a serious threat to their global biodiversity in recent decades [5–7]. Nectar and pollen may contain environmental pollutants or

systemic pesticides drawn from the soil, or they can be contaminated from topical pesticide applications or drift from such applications. Different agro-chemicals like, herbicides, fungicides and most importantly the insecticides, alone and in combination with other factors such as elevated temperature, production of hybrid varieties with lesser quantity of pollen and nectar in their flowers, have caused a devastating effect on honey bees at a global level [2, 8, 9]. Bee foragers may bring such contaminated floral rewards back to the colony for feeding and storing as a resource for future generations [10]. Pesticides which are being used in agriculture crops are highly toxic to bees as they kill the bees through many ways such as, direct killing of foraging workers with their acute toxicity, drifting out from agricultural land to nearby apiaries, thus, making the whole colony more susceptible to different pathogens and to some point reduce their possibility to thrive in the nature by getting accumulated in the pollen inside the colony. Nectars produced by some flowering plant species also contain plant-synthesized chemicals which are toxic to different pollinators [11].

The introduction of chemical pesticides and further increase in its demand in the market is not actually the basic requirements of the farmer; rather it is their mere ignorance. The farmers discriminately use these agro-chemicals with a purpose to manage the pests; instead, they end up with killing their own beneficial insects, i.e., the pollinators. Honey bees and other pollinators get exposed to different toxic agro-chemicals in nature through different paths and these different pesticides affect honey bee colonies to different levels thus; to minimize the losses to pollinators from the adverse effect of pesticide poisoning is a burning topic of interest for human to protect the pollinators.

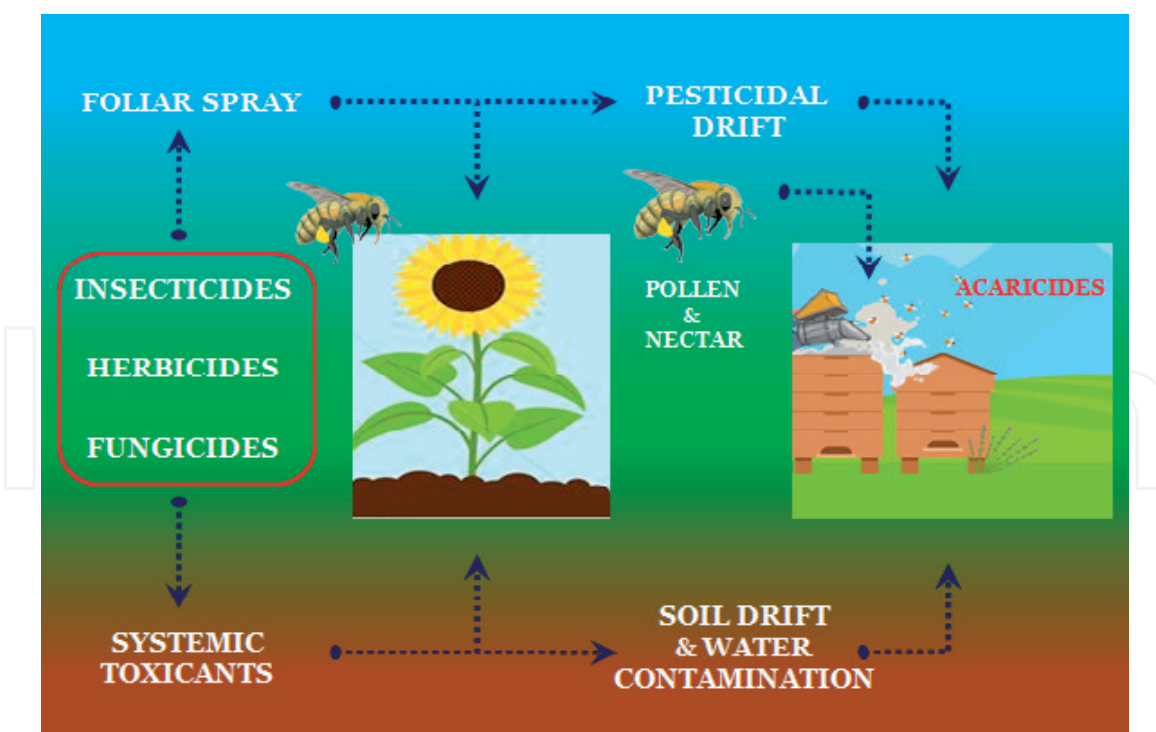
## **2. Routes of exposures to different pesticides**

The different types of pesticidal formulations travel across the plant through different ways in order to protect the plant or part of it from different factors such as weeds, pathogen, insect pests or rodents, etc. According to the nature of the different pesticides, three principal application methods that are often used to treat crops are: direct spray, which is often used around homes and gardens; soil applications and seed applications, typically used in larger treatment systems. These different methods of application play a crucial role in the exposure of these chemicals to the insect pollinators, visiting a crop (**Figure 1**).

Thus, on the basis of different application methods and the persistence of different pesticides in nature, bees get exposed to different pesticides through these major routes:

1. Direct contact with chemical during foraging on a treated plant
2. Pesticide particles of dust formulations sticking to the foraging bees or to whole colony via drift through wind
3. Pesticidal runoff from the treated fields to nearby water reservoirs
4. Pesticidal drift to non-treated foraging plants growing nearby to the treated crop [12]
5. Pesticidal residues in pollen through seed treatment [12]

These different routes for exposure of various pesticides to honey bees facilitate their entry into a honey bee colony system, but still the mode by which, these



**Figure 1.**  
 Different routes of pesticidal exposure to honey bees.

chemicals are pulled out by the forager bees from the fields are quite different being either by oral, respiratory or dermal intake. These different modes of intake of such chemicals are described here.

### 3. Mode of intake of toxicants

#### 3.1 Oral intake

Oral intake of chemical pesticides from fields is facilitated through the foraging worker bees. Plants treated with different systemic insecticides, produce nectar and pollen containing these insecticides and thus, worker bees collecting this floral resource carries to the colonies to store it into the colony and further use to feed the young developing brood [13]. Several reports of an extremely high concentration of different pesticidal compounds, including insecticides, fungicides, miticides and herbicides have been reported from pollen samples of several crops [12, 14]. These events, from collecting the pollen in the field to feeding to the developing brood results in to a chain of catastrophic events as: foragers are killed during collecting and transporting such contaminated pollen, nurse bees are killed while storing and feeding pollen and the brood are killed by consuming the toxic pollen, thus, leading to a total collapse of the colony.

#### 3.2 Respiratory intake

Respiration of pure oxygen plays a vital role in an organism's growth and development since it ensures proper functioning of various organs in the organism. But, respiration of air admixture with toxicants causes various abnormalities such as abrupt behavioral changes and degradation of learning ability [15]. Pesticide formulations like, dust and fumigants travels through the air called 'drift' can either be carried out onto the body surface of foraging bees or can be absorbed through trachea (respiratory organs) in sufficient concentrations to be toxic to the bees (**Table 1**).

	N <sub>2</sub> O	CO <sub>2</sub>	Ammonium nitrate	Control
With pollen	0	0	0	15
Without pollen	16	33	25	25

Source: Data extracted from Mackensen [22].

**Table 1.**  
*Pollen gathering by bees after anesthetic treatments.*

**3.3 Dermal intake**

This is the major mode of intake of toxicants by the bees since they are exposed to direct contact of pesticides in the fields while foraging on the crops. Honey bee foragers come in direct contact with several pesticides while foraging and such chemicals can be lethal even in small quantities. Dermal toxicity through topical spray has been reported for various insecticides and thorax has widely been regarded as a major route of dermal exposure of pesticides to the honey bees [16, 17]. Other than thorax, insect wings have been reported as a more lethal route of exposure to the bees [18]. Some of the majorly important and frequent ways of dermal intakes are following:

- Majority of bee poisoning is due to application of insecticides to crops during blooming period.
- Bees coming in contact of treated areas.
- Bees coming in contact with insecticides residues on plants and collect insecticide dust with pollen.
- Bees drinking or touching contaminated water or honeydew on the ground or foliage or from nearby water bodies.
- Contamination through treated nectar sources. Dimethaote is the only systemic insecticide known to be excreted in hazardous amount in nectar under field conditions.

**4. Symptoms of bee poisoning**

- One of the obvious signs of pesticide poisoning is the presence of a large number of dead or dying bees at the hive entrance. These bees are foragers who have been exposed to pesticides sprayed in the fields.
- Another common symptom includes the presence of a moist and sticky mass of dead bees at the hive entrance. This results from poisoning by some fast-acting pesticides, e.g., organophosphorus pesticides. Dying bees extend their tongues through which nectar is regurgitated resulting in sticky and moist dead bees. Bees that have been exposed to a pesticide may regurgitate a thick and dark fluid.
- Swiftly-acting insecticides kill foraging bees in the field itself, while only some of them manage to return to the hive. Sometimes, while spraying is done in the nearby fields to the apiaries, if such chemicals come in direct contact with colony, the whole colony may also die instantly. Stronger colonies suffer greater



losses from pesticidal poisoning than weaker ones, because they have larger numbers of foraging bees.

- Foraging bees often carry residual pesticides in their pollen loads while returning to the hive. As a result, the behaviour of bees in the hive changes abruptly. Honeybees in such colonies become more aggressive or agitated. When a hive containing pesticide-affected bees is opened, the bees fly out of the hive sometimes straight at the face of the beekeeper handling them.
- Other symptoms include stupefaction, paralysis, aggressiveness and abnormal behaviour, jerky, spinning movements. Slowing down of activity and crawling of bees around the hive entrance. They lose their ability to fly and ultimately die 2 or 3 days after poisoning. Poor egg laying patterns or abnormal supercedure of queens.
- Within the hive, a break in the brood cycle (stages of young bees) or a spotty pattern of the brood could also indicate a pesticide problem.

## 5. Classification of toxicants

Classification of different toxicants to honey bees can be done either on the basis of levels of toxicity or on the basis of sources in the nature. Different toxicants have variable toxicity levels, according to their mode of action on bees and this toxicity level is measured as LD<sub>50</sub>, which is the dose at which 50% of the bee population dies due to the intoxication. On the basis of their LD<sub>50</sub> levels, toxicants have been classified into four different categories [19].

- highly toxic (acute LD<sub>50</sub> < 2 µg/bee)
- moderately toxic (acute LD<sub>50</sub> 2–10.99 µg/bee)
- slightly toxic (acute LD<sub>50</sub> 11–100 µg/bee)
- nontoxic (acute LD<sub>50</sub> > 100 µg/bee) to adult bees

Second type of classification is based on the type of toxicants which are originated from different sources, due to human interventions. These toxicants include:

### 5.1 Inorganic toxicants

#### 5.1.1 Carbon dioxide

The modern time has become an era of the greenhouse gases and global warming. The ever-increasing concentration of various poisonous gasses in the atmosphere has affected a vast majority of the living beings in this world and honey bees are also not any exception with carbon di oxide being the most important of these gasses. Several scientists have worked on the toxicity of carbon dioxide on honey bees and have found some drastic effect of this gas on honey bee at both the levels including individual bees as well as at the colony level, which includes narcosis in foraging honey bees [11], earlier oviposition of queen [20], reduction in life expectancy [21] and reduction in pollen gathering by foraging bees [1].

#### 5.1.1.1 Narcotic effect of CO<sub>2</sub>

Bees treated with a mixture of air and CO<sub>2</sub> for 5 min have shown to stop their movement and went motionless but regaining their activity, once it was left for 30 min. The same experiment when repeated with only air for comparative study showed that only air did not anesthetize the bee. Thus, it can be concluded that the CO<sub>2</sub> at even low concentrations is detrimental to honey bees since they have a narcotic effect [1].

#### 5.1.1.2 Effect of CO<sub>2</sub> on pollen gathering ability of the forager

The drastic effect of different chemicals used in the apiaries has been shown to decrease the pollen gathering ability of the forager bees. This decrease in the pollen supply during the blooming seasons can cause a severe threat to the reserves of the colony during winter season, where most of the pollen is consumed for the survival of the colony. This decrease in pollen gathering ability in the worker bees have been observed by different workers and such chemicals like, carbon dioxide, nitrous oxide and ammonium nitrate have been found to be decreasing the pollen gathering capacity of as many as 40 treated worker bees with a threatening outcome of no bee being able to gather pollen after the exposure to abovementioned chemicals, which are widely used in apiaries for different purposes [22].

#### 5.1.2 Metal toxicity

Continued anthropogenic pressure due to the ever-highest human population, which has no signs to slow down in near future have put an alarming metal and metalloid pollutants pressure over the past century because of anthropogenic emissions into the environment. These pollutants may have negatively impacted the pollinators that reside in the soul of machinery responsible for the food production that sustains this human population. Metal pollutants are discharged into the air, water, and soil through different human activities including mining, agriculture, coal burning, hydraulic fracturing to extract gas and oil, and industrial and municipal waste production. Of all the toxic metals collected cadmium, copper and lead have been proved to be the most toxic to bees [23]. These three metals (Cd, Cu and Pb) have also been reported to change the feeding behavior in bees with increased sensitivity towards sucrose.

Once in soil, Cd and Cu is actively absorbed by plant roots, transferred via vascular bundles into the nectar and pollen, and subsequently accumulates in the pollinators and bee products since the pollinators collect the contaminated pollen and nectar. Copper is an essential trace element in plants and is able to accumulate in different plant tissues. Cu co-acts with several essential proteins to enhance growth and development of honey bees but it is toxic when it exceeds the cellular needs.

As lead is not easily trans-located within plants, thus, is also shown to be having a residual effect on forager honey bee. Lead gets trans-located within bees due to transfer through air and dislodgeable residues, resulting from deposition on surface contacted by bees [23].

### 5.2 Toxins used in bee keeping

A proper maintenance of an apiary depends upon the sanitation aspect of beekeeping but a proper and timely application of different synthetically formulated chemicals is also important for avoidance or management of severe health

problems. Different health problems like infestation of *Varroa destructor*, wax moth (*Galleria mellonella*), tracheal mite and other pathogenic diseases along with the long debated CCD of U.S. apiaries exerts a severe pressure and a serious threat of total loss of millions of honey bee colonies throughout the world and have been successfully managed by the use of various chemical treatments known to be less harmful to the honey bees. These chemicals have been shown to be far more successful than the other treatments, but at the same time, their toxicity towards bees has been highly neglected or has been less explored. One of the best examples for this has been the introduction of formic acid and oxalic acid, for the better management of honey bee parasitic mite, *Varroa destructor*. Medicated strips impregnated with synthetic acaricides such as, fluvalinate-tau and coumaphos have been used for many years for the management of this pest but both the coumaphos and fluvalinate are known to be highly toxic to older bees than young bees [24–26]. Workers that were subjected to less stress appear to be more resistant to fluvalinate and coumaphos poisoning [27, 28]. However, the appearance of resistant mite populations has resulted into a sharp rise in the practice to use formic acid (FA) and oxalic acid (OA). Both of the two organic acids, are varroacides in nature and serve as an attractive natural options for chemicals like coumaphos and fluvalinate as both of them have been reported to be naturally present in *A. mellifera* honey [29, 30]. These pesticides have lower efficacy against the *Varroa* mite but when used in an integrated pest management strategy, they have known to provide an efficient way to control *Varroa* populations. FA is most effective by evaporation of an impregnated substrate with 65% FA inside the hive and OA is most effective when applied in honey bee colonies either by dripping or spraying or through fumigation [9].

Both FA and OA have been proved to be effective to control *Varroa* mite but very less work has been done to establish its negative effect on honey bees. Schneider et al. [31] highlighted the detrimental effects of FA and OA on honey bees which include:

1. Increased mortality
2. Negative effects on brood development
3. Reduced fitness of treated colony
4. Decreased division of labour
5. Reduced hive cleaning and increased self-grooming

#### 5.2.1 Formic acid toxicity

The mode of action of FA against *Varroa* is by inhibition of electron transport into the mitochondria via binding to the last enzyme of electron transport chain, cytochrome c oxidase [32]. Formic acid may produce different toxicity symptoms in honey bees, including reduced longevity of the worker bees [33] and reduced rate of brood survival [34]. Other negative effects of formic acid treatments to honey bee colony mainly includes, increased number of dead bees in front of colonies during the FA treatment period, rejection of queen, worker bees may repel from the colony and a comparatively lower honey yield from the FA treated colony [9].

#### 5.2.2 Oxalic acid (OA) toxicity

As OA is generally provided to the honey bee colony in sugar syrup, in order to increase its efficacy against the *Varroa* mite by increasing its stickiness on to the



mite body, thus, its repeated application to a colony can be proved as lethal to the honey bees as well. A high queen mortality and reduced number of sealed brood have been reported in the colonies treated with OA [35]. The OA treatment has also been reported to be associated with an increased apoptosis in bee midgut [36]. Worker bees have been reported to be showing an abnormal age-related patterns problem while treated with oxalic acid during their early life stages. A dose of 3.5% oxalic acid dehydrates at after 24 h of emergence have been reported to have a disturbance in the normal age-related patterns of worker honey bees. All the age-related patterns of the workers appear in the natural chronology: they shows first events of behavioral patterns for nursing, followed by, honey or pollen manipulation, wax manipulation and patrolling at the same time but in different intensity. The bees start showing all age-related patterns somewhat earlier than the normal. Treated bees show an increased self-grooming, a superior tendency to inactivity and decreased nursing behavior. For all other behavioral patterns, including trophallactic interactions, house-cleaning, honey manipulation and patrolling, bees show no significant changes than the normal chronology [27].

### **5.3 Agrochemicals**

#### *5.3.1 Insecticides*

Chemical control for insect pest management contributes as the major part of insect pest management strategies used all over the world [37]. Insecticides have been used since early 1940s for the effective pest management and have been a successful tool for the pest management as saving serious crop losses through insect pest infestations [38]. But, at the same time, the negative effects of these synthetic chemicals have created havoc throughout the world by suppressing the overwhelming populations of several non-target insect species, mainly including the biological control agents and the pollinators. Honey bees are susceptible to many insecticides and different harmful effects of these insecticides are believed to be the prime most reason for the decline in global honey bee populations [9, 39, 40]. The different insecticides have been highly criticized for their possible role in widely discussed and seriously concerning worldwide losses of honey bee colonies [41, 42]. Since the first detailed report and description of the term ‘colony collapse disorder’ (CCD) in 2006 [43] in America and followed by Europe, had again initiated the long term agitation of banning the use of insecticides, posing a serious threat to the billion dollar industry. Since the CCD, possible role of insecticidal residues in weakening the honey bee colonies for an increased susceptibility towards different environmental and pathogenic pressure on different colony levels has widely been discussed in scientific community [7, 44–50].

Lethality of any pesticide to honey bee is measured during toxicological tests of lethality by observing the mortality of bees after the application of pesticides either by oral administration or by topical application. The bee is usually considered dead when it exhibits “no movements after prodding”. Investigation on lethality of any insecticide includes the use of correlation metrics to link the lethality and dose of a toxic chemical or substance to the bees [51, 52]. List of lethality of different class of insecticides was compiled from supporting information from Hardstone and Scott [53], and for the same information regarding fungicides and herbicides was compiled through ECOTOX database [54].

The different class of chemical insecticides poses variable threat to the individual honey bee and a colony level health, thus, the toxic effects and toxicity symptoms of different insecticides can be discussed under one umbrella of major classes of insecticide causing toxicity to the honey bees which is described here.

5.3.1.1 Acetyl cholinesterase Inhibitors

The two widely used groups of insecticides, organophosphates and carbamates acts on insects in a similar way as acetyl cholinesterase (AChE) inhibitors which in normal conditions, inhibits the activity of neurotransmitter acetylcholine in the insect nervous system [53]. These two groups of insecticides have deeply investigated for their toxic effects on honeybees and have been reported to have high larval as well as chronic toxicity to the adult bees causing toxicity symptoms like memory loss and behavioral agitations [55–60]. These two classes of insecticides have a variable amount of topical toxicity to the bees with LD<sub>50</sub> ranging between 0.018 and 31.2 µg/bee [61, 62], with some of the widely used insecticides enlisted in **Tables 2** and **3**.

Insecticide (organophosphate)	LD50 (µg/bee)		Risk ranking
	Mean	Range	
Chlorpyrifos	0.01	—	High
Coumaphos	31.2	—	Low
Diazinon	0.2	—	High
Dicrotophos	1.62	0.410–3.05	High
Dichlorvos	2.73	0.290–5.01	High
Fenitrothion	1.66	0.180–3.83	High
Malathion	0.2	—	High
Methidathion	0.236	—	High
Methyl parathion	1.66	0.610–3.24	High
Paraoxon	0.600	—	High
Parathion	1.36	0.100–3.50	High
Phorate	2.45	0.910–3.20	High
Phosmet	1.06	—	High
Phosphamidon	4.89	0.020–14.5	High
TEPP	0.410	0.010–1.20	High

Source: Data compiled in Hardstone and Scott [53].

**Table 2.**  
List of organophosphate insecticides with respective toxicity to the bees.

Insecticide (carbamates)	LD50 (µg/bee)		Risk ranking
	Mean	Range	
Oxamyl	0.094	—	High
Methomyl	0.16	—	High
Carbaryl	1.1	—	High
Carbofuran	1.55	1.49–1.60	High
Aldicarb	2.36	1.52–2.85	High
Bendiocarb	2.64	1.00–4.28	High
Aminocarb	4.40	0.85–11.2	High

Source: Data compiled in Hardstone and Scott [53].

**Table 3.**  
List of carbamates insecticides with respective toxicity to the bees.

#### 5.3.1.1.1 Toxic symptoms of organophosphates

- Regurgitation of ingested food
- Disoriented movements
- Distended abdomens
- Erratic movement of the bees
- Wings hooked together, held away from body
- Extended tongues
- Death of the bee

#### 5.3.1.1.2 Toxic symptoms of carbamates

- Erratic movement of the bees
- Stupor (numb)
- Paralysis
- Break in brood cycle
- Queen ceases egg laying
- Development of superseded queen bees
- Most bees die at colony

#### 5.3.1.2 Nicotinic acetylcholine receptor agonists

Leaves of *Nicotiana tabacum*, the plant producing the nicotine which mimics the neurotransmitter acetylcholine, activates the nicotinic acetylcholine receptor (nAChR), and promotes the generation of action potentials in postsynaptic nerve cells, contain up to 90,000 ppm of the nicotine, its pollen may contain up to 23 ppm and nectar 0.1–5 ppm alkaloid content [21, 46]. Adult bees have been proven to be successfully detoxifying nicotine in nectar with a median lethal concentration of 2000 ppm for nicotine [21], whereas the larva are sensitive to nicotine and usually die at the third or fourth larval instar at 5 ppm [46].

The neonicotinoids which are synthetic analogs of nicotine insecticides have a greater affinity to nAChR in the insect nervous system, including bees as well. In recent years, several studies and workers have portrayed these insecticides as the most serious cause of well discussed CCD [63–66]. However, these studies have been criticized for using unrealistic doses and duration of exposure [67]. The nitroguanidine neonicotinoids, including imidacloprid, clothianidin and thiamethoxam have been reported to be highly toxic to bees [68], with toxicity levels ranging from 0.004 to 0.075 µg/bee [69, 70] (**Table 4**). The insecticides like, thiacloprid and acetamiprid which are the member chemicals of cyanoguanidine neonicotinoid group, were much less toxic to the bees with topical or contact LD50 in a range of

Insecticide (neonicotinoids)	LD50 (µg/bee)		Risk ranking
	Mean	Range	
Acetamiprid	8.1	—	Moderate
Imidacloprid	0.0039	—	High
Thiacloprid	17.32		Low
Thiamethoxam	0.0005	—	High
Clothianidin	0.00368	—	High
Dinotefuran	0.0023	—	High
Source: Data compiled in Hardstone and Scott [53].			

**Table 4.**  
List of neonicotinoid insecticides with respective toxicity to the bees.

7.1–14.6 µg/bee [70]. This relatively lesser toxicity of cyanoguanidines to the bees is probably due to rapid cytochrome P450 detoxification.

The nitroguanidine insecticides also show their toxic effect through impairing the ability of foraging honey bees to return to the hive [28, 71, 72].

5.3.1.3 Voltage-gated Na<sup>+</sup> channel agonists

Pyrethrin insecticides, produced by pyrethrum flowers (*Chrysanthemum cinerariaefolium*) are again a widely used group of insecticidal compounds. Even though, the pyrethrin has a natural origin, still these chemicals are known to be highly toxic to the bees (LD<sub>50</sub> = 0.05–0.21 µg/bee) [73] (Table 5).

Other than pyrethrins, the pyrethroids, and organochlorine insecticides, show their action on the voltage-gated Na<sup>+</sup> channel in the axons of nerve cells, by delaying the closing of the Na<sup>+</sup> channel and prolonging the recovery period of the nerve cells, following the transmission of an action potential [74]. Bees show more tolerance towards some of the pyrethroids because of their rapid detoxification by cytochrome P450s. Being a pyrethroid, tau-fluvalinate a widely used miticide also

Insecticide (organophosphate)	LD50 (µg/bee)		Risk ranking
	Mean	Range	
Bifenthrin	0.0146	—	High
Cyfluthrin	0.037	—	High
Esfenvalerate	0.017	—	High
Fenpropathrin	0.05	—	High
Gamma-Cyhalothrin	0.0061	—	High
Lambda-cyhalothrin	0.038	—	High
Permethrin	0.024	—	High
Pyrethrin + PBO	0.002	—	High
Pyrethrum	0.022	—	High
Zeta-cypermethrin	0.181	—	High
Source: Data compiled in Hardstone and Scott [53].			

**Table 5.**  
List of pyrethroid insecticides with respective toxicity to the bees.

appears to be less toxic or safer to the honey bees but in higher concentrations this chemical has been reported to affect the health of different castes of honey bee colony. Colonies exposed to high doses of tau-fluvalinate had smaller queen bees [75]. Drones exposed to tau-fluvalinate during development were also reported to be affected with lesser chances of attaining sexual maturity [14].

5.3.1.3.1 Toxic symptoms of synthetic pyrethroids

- Regurgitation of ingested food
- Erratic movement of the bees
- Paralysis
- Many bees die between foraging area and colony

5.3.2 Fungicides

“A fungicide is a specific type of pesticide that controls fungal disease by specifically inhibiting or killing the fungus causing the disease.”

It is believed to be nontoxic to bees by farmers and hence it is mostly applied during the flowering of plant coinciding with maximum bee activity. Thus, fungicides often account for most of the pesticide content of pollen [9]. An alarming concentration of fungicide chlorothalonil (99 ppm) has been reported from the honey bee pollen [76]. Other than chlorothalonil, in other studies, fungicides like vinclozolin (32 ppm) and iprodione (5.5 ppm) captan (contact) and difenoconazole [77] have also been reported from beebread. While fungicides are considered to be fairly safe for use around adult honey bees, beekeepers have reported losses of brood in larval and pupal stages coinciding with fungicide use during bloom. Fungicide applications also have been determined to trigger hypothermia in adult honey bees [78]. Fungicide was causing toxic effects to honey bee brood based on finding malformed, and frequently wingless, pupae and recently emerged adult bees. The affected bees accumulated on the bottom boards and at the entrance so hives about 2 week after applications. The toxicity levels for different fungicides lies in the range of LD<sub>50</sub> > 200 to as small as 0.2 µg/bee (Table 6).

Active ingredient	Trade name	LD50 (µg/bee)
Dicloran	Botran	0.2
Captan	Captan	10
Dodine	Syllit FL	12.5
Propiconazole	Bumper	25
Ziram	Ziram	46.6
Thiram	Thiram	74
Sulfur	Disperss	>100
Mancozeb	Dithane	178.9
Trifloxystrobin	Flint	>200

Source: Data compiled from ECOTOX database [54].

**Table 6.**  
List of fungicides toxic to bees.



Herbicide	LD50 (µg/bee)
2,4-DB acid	14.5
2,4-DP-P, dimethylamines	25
Trifloxysulfuron-sodium	25
Pendimethalin	49.5
Triclopyr, butoxyethyl ester	62.5
Alachlor	68.1
Simazine	96.7
Atrazine	97
Picloram, potassium salt	100
Glyphosate, isopropylamine	100
2,4-D, 2-ethylhexyl ester	100

Source: Data compiled from ECOTOX database [54].

**Table 7.**  
*List of herbicide toxic to bees.*

5.3.3 Herbicides

Even though the main purpose of using different herbicides is to control the unwanted weed populations in the fields and there is no such objective to kill insects through them. The toxicity level of herbicides is known to be very less to most of the insects and due to this these pesticides are applied without any restrictions regarding insects. Bees usually come across these chemicals in higher concentrations [79] and toxic effects of these have also been reported on honey bees. Toxicity levels in LD<sub>50</sub> values differ from one chemical to another with a range of 14.5–100 µg/bee (Table 7). A widely used herbicide, paraquat has been reported to be toxic to the bees in laboratory conditions, causing median life of worker ten times reduced than the normal, on injecting at the rate of 15 µg per worker and death within a span of 3 days’ time, when sprayed at the rate of 4.5 kg AI/ha [79]. These pesticides may harm the bees in other way around as well as they reduce the number of plants offering floral resources to the bees.

6. Management of pesticidal toxicity to the honey bees

- **Use pesticides only when needed:** insect pests, pathogen or any environmental factor infest or infect the particular crops during specific growth stages of the plant and pesticide application should be done only after surveying the crop fields for the presence of weeds, pest population or disease incidence for threshold levels. This helps in safeguarding the population of insect pollinators, beneficial insects.
- **Do not apply pesticides while crops are in bloom:** use of different pesticides should only be performed only when the crop concerned is not in flowering stages.
- **Apply pesticide when bees are not flying:** the most pollinators are active during 8 a.m. to 5 p.m. and in such favorable conditions pesticides should not be sprayed to help in protecting the forager bees from coming in the direct contact

with pesticide applied. To avoid such condition of direct contact of the pollinators with the pesticides, the application can be mostly in the early evening hours. This late application of the pesticides allows time for these chemicals to partially or totally decompose during the night.

- **Do not contaminate water:** contamination of nearby standing water through pesticides run off should be avoided to prevent the bee losses, as the bees collect water from these water sources to cool down the temperature of the colony during the summer season.
- **Use less toxic compounds:** if the situation allows, then the compounds which are less toxic to the bees should be given preference over the highly toxic chemicals. The pesticide labels should notify the possible hazards to honey bees. If no other alternate option remains then the variations in dosages can be applied.
- **Use less toxic formulations:** many pesticides work equally, when prepared in different formulations.
- **Microencapsulated insecticides** are found to be more toxic to honey bees than any other formulation. As the size of these capsules is similar to that of pollen, thus, it facilitates their transport directly into the colony, where these compounds remain poisonous for long time and can also be fed to the developing brood. Use of this formulation should strictly be prohibited if; there is any chance of collection of pollen by a foraging bee from the treated crop.
- Dusts are more hazardous than the liquid formulations as these chemicals can reach and enter a honey bee colony through drifting along with the air current. Ultra-low-volume (ULV) formulations are also more hazardous than the other liquid formulations as they can enter or reach a colony in the same manner as well.
- Emulsifiable concentrates are less hazardous than wettable powders.
- Granular formulation is also safer for the bees as these chemicals are provided to the lower parts of the plant canopy, which minimizes their direct contact with any flower visiting pollinator.
- **Identify attractive blooms:** attractive blooms in and around the field to be sprayed should be checked before the application as most of the times such blooms of weed flora attract the foraging bees and the pesticidal drift to such blooms can be hazardous to the visiting pollinators. In order to avoid such incidents the blooms of weed plants can be removed before the application.
- **Notify beekeepers:** beekeepers should be notified well before the application, as this time period will allow them to move their colonies to a distance where, pesticidal drift is minimal. Colonies can also be covered with the cloth to confine bees into the box itself to avoid any foraging for 1 or 2 days.

## 7. Conclusion

Pollinators in general, either insects or the handful of other animal species are of utmost importance for their continuous support to most of the cross pollinated plant species for their reproduction. The honey bees, which is considered as the

most important among all the pollinators is responsible for achieving of global food production demand every year. With ever increasing population, human have constantly been searching for a way to maintain this demand of global food production and in order to achieve this goal, the conventional agriculture has evolved over the centuries. In this sequence, for the proper management of insect, plant pathogens and weed plants in agro-ecosystem various chemical pesticides were discovered in the nineteenth century. Ever since the introduction of these chemical pesticides, the serious debate on their effects on non-target insects and other organisms have also started. Thus, this chapter focuses on the different routes, modes and effects of interaction between various pesticidal applications and their toxic effects on honey bees, at both individual and colony level. Agrochemicals used in fields focusing mainly on minimize the crop losses are harmful for non-target organisms and hundreds of pollinator species, including honey bees are also no exception to this. Being the worker caste of the colony honey bee foragers visit various fields and gather pollen and nectar from different plant sources, which makes them in a phase of constant exposure to various chemicals, either natural or synthetic in nature. These foraging workers collect provisions from floral resources from chemically treated plants and carry them to their colony and thus, unknowingly with each visit they carry with them, a serious threat to their own life as well as to their colony as well. The different kinds of agrochemicals may be a fungicide residue, remaining in a plant after the seed treatment; a herbicide molecule, sprayed directly over the weed plants; an insecticide residue either coming through a direct spray or reaching the colony via air current (drift). Other than these agrochemicals, a serious threat for honey bee colonies has also been imposed by the various synthetic chemicals applied to the bees in apiaries itself for the proper management of honey bee health. Several such chemicals, used for the management of honey bee pests have also been reported to be toxic to the bees.


Although, several studies have been put forward regarding pesticidal toxicity to honey bees, but still a proper management strategy in order to minimize the honey bees exposure is still lacking. However, all pesticidal applications should be done in a way to minimize their exposure to honey bees, so as to prevent the further decline of honey bee population throughout the world. Furthermore, there exists a need of an extension program, for the farmers and beekeepers to spread the awareness regarding the hazardous effects of different agrochemicals to the honey bees, in order to make the existing management strategies more effective in future.

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