Chapter 10
IPM and Pollinator Protection in Canola Production in the USA

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10.1 Canola Production in the USA and Pollination

Among oilseed crops, brassicas are the second largest group of crops grown globally after soybean (*Glycine max* (L.) Merr.). Oil-producing brassicas are generally derived from two species, *Brassica napus* L. and *Brassica campestris* L. (Gupta 2016). The Canola Council of Canada defines canola as "Seeds of the genus *Brassica* (*B. napus*, *B. rapa* (=*B. campestris*) or *B. juncea*) from which the oil shall contain less than 2% erucic acid in its fatty acid profile and the solid component shall contain less than 30 micromoles of any one or any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3 butenyl glucosinolate, and 2-hydroxy- 4-pentenyl glucosinolate per gram of air-dry, oil-free solid" (Canola-council.org 2018). These all traits of oil are considered to be healthy for human consumption (Canolacouncil.org 2018). In Canada, a low erucic acid rapeseed was developed and released as the cultivar "Oro" in 1968. Several other cultivars with low erucic acid levels were also released later, and the first canola cultivar "Tower" was released in 1974 (Gupta 2016). Besides Canada, canola is also produced in Europe, Asia, Australia, New Zealand, and the United States. After 1985, concerted efforts to grow canola on a large scale began in the USA (Raymer 2002). It has been mainly grown in North Dakota, followed by Oklahoma, Kansas, Texas, Minnesota,

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Montana, Idaho, and Oregon. Currently about 1.7 million acres of canola are grown in the USA (uscanola.com 2018).

Canola plants are self-fertile and mostly self-pollinated. Wind pollination is common (Buntin et al. 2017), but studies have reported a modest dependency on pollinators (Klein et al. 2007; Westcott and Nelson 2001). Although insects are often considered as only supplemental pollinators, canola is highly attractive to pollinating insects because it is an early and a rich source of nectar (Buntin et al. 2017). Canola provides a nutritional balance of amino acids, protein and fats to the bees (Somerville 2002). Common insect pollinators of canola include honey bees, bumble bees, large carpenter bees, and some native solitary bees (e.g., Andrenidae, Colletidae, Halictidae, Megachillidae, and Xylocopidae) (Badenes-Pérez et al. 2017; Buntin et al. 2017). Although honey bees are considered to be responsible for 90% of insect pollination on canola, other foraging insect families such as Diptera (Syrphidae, Bombyliidae, and Calliphoridae) also play an important role in cross pollination, while species of Lepidoptera, Coleoptera, Hemiptera and Neuroptera also frequently visit canola crops (Westcott and Nelson 2001; Badenes-Pérez et al. 2017). Several reports have found higher seed yields in the presence of honey bees. Research in Australia in 1997 found an increase in yield of 18% on the variety Karoo (Manning and Boland 2000), while research in Canada found an improvement in seed yield of 46% in the presence of honey bees (Sabbahi et al. 2005). Increase in the number of fertile pods due to pollination causes a greater yield (Manning and Wallis 2005). The presence of pollinators [(*Apis dorsata* Fabricius, *A. florea* Fabricius (both Apidae), and *Halictus* sp. Latreille (Halictidae)] on canola has been reported to increase both the number and weight of seeds per pod (Ali et al. 2011; Shakeel and Inayatullah 2013). Bees may also cause earlier seed set, resulting in shorter, more compact plants with an even seed maturity, making such canola crops easier to harvest and less prone to the pod shattering (Somerville 2002; Gavloski 2017). According to the canola council of Canada, pollinators are vital for hybrid seed production as they are necessary for the pollen delivery from the male parent lines to female parent lines (Clay 2009; Durán et al. 2010). Both *Apis mellifera* L. (Hymenoptera: Apidae) and alfalfa leafcutting bees, Megachile rotundata Fab. (Hymenoptera: Megachilidae) play an important role in pollination, with an opportunity to provide diversified honey bee products (Hoover and Ovinge 2018). Seed germination rate also has been reported to increase in the insect pollinated canola crops (Kevan and Eisikowitch 1990). Moreover, bees promote higher yields through better ripening of seeds. More uniform flowering and earlier pod-setting (Abrol 2007), greater number of pods per plant and seeds per pod, an overall increase in seed weight, and a reduction in initiation of blooming time (Sabbahi et al. 2005; Gavloski 2017) are the other benefits from the presence of insect pollinators. It is also reduces the flowering period. Although it has never been directly tested, the fungal disease stem rot, *Sclerotinia sclerotiorum* (Helotiales: Sclerotiniaceae) could be reduced by a shorter flowering period (Gavloski 2017). Similarly, another beneficial aspect of insect pollination in canola is the dispersal of entomopathogenic fungi; one study done in Canada found higher mortality of *Lygus* sp. (Hemiptera: Miridae) when honey bees were used to spread *Beauveria bassiana* (Al Mazra'awi et al. 2006; Gavloski 2017).

In the USA, honey bees are an important part of agriculture as managed pollinators. In 2000, an estimated 2.9 million bee colonies were recorded in the United States (as reported by beekeepers with five or more colonies) (Morse and Calderone 2000). Lately, US agriculture has shown increased dependence on pollinators (from 1992 to 2009) in several crops (Calderone 2012). In canola, both managed and wild bees play an important role (Morandin and Winston 2005). Wild species of pollinators can provide pollination services in the absence of managed pollinators. For instance, the stingless bees *Plebeia emerina* Friese and *Tetragonisca fiebrigi* Schwarz (both Hymenoptera: Apidae) showed similar pollination efficiency as *A. mellifera* in terms of fruit setting in canola (Witter et al. 2015).

10.2 Integrated Pest Management (IPM) for Canola

The major insect pests of canola in USA are the cabbage seedpod weevil, *Ceutorhynchus assimilis* (Paykull) (syn. *Ceutorhynchus obstrictus* [Marsham]); bertha armyworm, *Mamestra configurata* Walker; *Phyllotreta cruciferae* Goeze; crucifer and striped flea beetle, *Phyllotreta striolata* (Fabricius) (Coleoptera: Chrysomelidae); tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae) and diamondback moth, *Plutella xylostella* (Linnaeus) (Lepidoptera: Plutellidae). A number of minor pests also attack canola in the USA, including cabbage and turnip aphid, *Brevicoryne brassicae* (Linnaeus) (Hemiptera: Aphididae), *Hyadaphis erysimi* (Kaltenbach) Hemiptera: Aphididae) and various grasshoppers (Weiss et al. 2018; Reddy 2017). Several bacterial, fungal, viral, and phytoplasmal pathogens also reduce yield in canola (Kharbanda et al. 2018). In general, all groups of pesticides including herbicides, insecticides, fungicides and seed treatments are used in the USA on canola crops to increase yield (Raymer 2002; Johnson et al. 2010).

The main role of IPM techniques is to promote the integration of all available pest control techniques to reduce pest populations. Such techniques should be economically justifiable and minimize risks to human health and the environment. Two important components of canola IPM are cultural controls (planting dates, increased seeding rates) and insecticide treatments. Determining an accurate action threshold and the development of pest prediction models for pest monitoring could help to reduce the insecticide application without losing yield due to insect infestation (Sekulic and Rempel 2016). IPM strategies for the majority of the important insect pests of canola include monitoring and forecasting of insect populations to achieve their proper management. To accurately estimate damage, proper trapping methods and correct estimation of thresholds are extremely important for the effective management of insect pests (Gavloski 2017).

Flea beetles (P. cruciferae and P. striolata) are the most economically damaging insect pests of canola in the northern USA and Canada, and foliar damage from flea beetles can causes yield reduction of 10–50% during medium to high level of population outbreaks (Sekulic and Rempel 2016). Cultural strategies for controlling flea beetles include higher seeding rates, planting bigger sized seeds, early seeding, and reduced tillage (Elliott et al. 2008; Cárcamo et al. 2008). The use of resistant varieties with greater trichome density can also be helpful in reducing flea beetle damage (Gavloski 2017). However, at present no resistant varieties of canola are known for flea beetle (Gavloski 2017). Entomopathogenic fungi (*Beauveria bassiana* (Bals.-Criv.) Vuill. (Hypocreales: Cordycipitaceae) and *Metarhizium brunneum* Petch (Hypocreales: Clavicipitaceae)), and the nematode *Steinernema carpocapsae* (Rhabditida: Steinernematidae) are potential biocontrol agents useful against flea beetles (Reddy et al. 2014), but these agents have not been studied on a wide scale. Neonicotinoid insecticides used as seed treatments provide early season protection for a short period, and season long control may require an additional foliar application (Reddy 2017). Various pyrethroid, carbamate, and organophosphate insecticides are foliar insecticides used for control of flea beetles in canola (Gavloski 2017), as well as for suppression of other major insects (*P. xylostella, M. configurata* and *L. lineolaris*). Moreover, the larval parasitoids *Diadegma insulare* (Hymenoptera: Ichneumonidae) and *Microplitis plutellae* (Hymenoptera: Braconidae), and the pupal parasitoid *Diadromus subtilicornis* (Hymenoptera: Ichneumonidae), also serve as biological control agents for control of diamondback moth *P. xylostella.* For *M. configurata,* fall tillage as a cultural control has been found to reduce outbreaks of this pest, while the native endoparasitoid, *Banchus flavescens* (Hymenoptera: Ichneumonidae) can cause up to 40% parasitism (Wylie and Bucher 1977), and a nuclear polyhedrosis virus also causes some level of mortality for insect pests (Gavloski 2017; Reddy 2017).

10.3 Impact of IPM Methods on Pollinators

Along with managed bees, populations of wild pollinators (*Bombus* spp.) are strongly influenced by various pesticides in specific weather conditions (Turnock et al. 2006), and it has been estimated that 20% of all honeybee colonies are adversely affected while 5% of bee colonies in the USA die during the winter due to severe pesticide exposure. This mortality of the bees is responsible for crop production loss of 13.3 million dollars each year (Pimentel and Burgess 2014; Meikle et al. 2017). In North America, the main crops, including canola, wheat, maize, soybean and cotton, represent approximately 115 million hectares of annual production. Neonicotinoid insecticides are routinely applied to seeds to protect these crops from early season insect pests (Krupke and Long 2015). The use of neonicotinoid insecticides as seed treatments in canola to control flea beetle populations (*P. cruciferae*, *P. striolata, Psylliodes punctulata* Melsh) began in the mid-1990s (Cutler et al. 2014). Seed treatments (imidacloprid, clothianidin, and thiamethoxam) are used to prevent damage at the most vulnerable initial stage of the canola crop. Use of seed treatments reduces the number of foliar insecticide applications needed, and seed treatments are thought to be less harmful than foliage treatments to pollinators, as well as having a low pesticide residual effect for human health (Sekulic and Rempel 2016). Insecticides applied as seed coatings move from seeds into the young growing roots and leaves, and provide post emergence protection to young plants. These pesticides are then transported systemically within the developing plants to the leaves and flowers where, although they occur only in small quantities, they can pose a threat to pollinators, especially to bees (Sur and Stork 2003). In general, exposure of bees to neonicotinoids applied as seed treatments through pollen and nectar of treated crops has been found to be negligible (Maus et al. 2003), and seed treatments have less of the active ingredient per unit area compared to foliar application, which reduces the damage to non-target pollinators, minimizing the likelihood of exposure (Sekulic and Rempel 2016).

Canola has bright, visible flowers and produce copious amounts of nectar and pollen that attract pollinators (Thom et al. 2016). In canola the seed treatment has been found to have an almost negligible effect on honey production by the managed honey bee colonies, exposed to the treated canola crop (Cutler and Scott-Dupree 2007; Cutler et al. 2014). However, wild bee populations showed a decline after being exposed to conventional seed treatment insecticides in canola crops (Scott-Dupree et al. 2009). The direct contact toxicity of imidacloprid, clothianidin, deltamethrin, spinosad and novaluron as seed treatment and foliar application was tested on populations of common eastern bumble bees [*Bombus impatiens* (Cresson) (Hymenoptera: Apidae)], alfalfa leafcutting bees [*Megachile rotundata* (F.) (Hymenoptera: Megachilidae)], and blue orchard bee [*Osmia lignaria* Cresson (Hymenoptera: Megachilidae)] (Scott-Dupree et al. 2009). Among five insecticides used, only novaluron was nontoxic to the tested pollinators in laboratory. The other four chemicals (imidacloprid, clothianidin, deltamethrin, spinosad) showed high but varying degrees of toxicity between the three-pollinator species (Scott-Dupree et al. 2009) (Table 10.1). This research also indicates the need to test on wild bee species as well as honey bees, as wild bees are more representative of the specific agricultural system (Scott-Dupree et al. 2009), and also raise the point that determining the impact of seed treatment on bees cannot allow us to predict the effect of these treatments on all pollinators. Furthermore, new laboratory approaches are needed to infer real-world consequences of exposure to realistic field levels of neonicotinoids, since only field based studies have to date predicted the negative effects of such exposure (Lundin et al. 2015).

Major groups of insecticides, including neonicotinoid, pyrethroid, organophosphate, and carbamate insecticides have been found to be the most toxic for bees in the USA (Frazier et al. 2015; Lundin et al. 2015; Hladik et al. 2016). Oxadiazines (indoxacarb), thiourea derivatives (diafenthiuron), avermectins (emamectin benzoate), spinosyns (spinosad), diamides (chlorantraniliprole), benzoylureas (flufenoxuron, lufenuron), pyridine azomethine derivatives (pymetrozine), phenylpyrazoles (fipronil), neonicotinoids (thiamethoxam, clothianidin, imidacloprid) and organophosphate (profenofos) are the insecticides commonly applied to control insect pests worldwide (for an example, *P. xylostella*), and all of these groups have been found to be harmful to pollinators to some extent (Badenes-Pérez et al. 2017; Abrol and Thakur 2016).

Laboratory studies have shown a variety of harmful effects on bees from systemic neonicotinoid pesticides, such as impaired learning and memory loss (Ciarlo et al. 2012; Rortais et al. 2005). In France, low levels of imidacloprid were found in

Table 10.1 Impact of pesticides on pollinators reported on canola

Pollinator	Location	Pesticide used	Impact on pollinator	Sources
Bombus impatiens, Megachile rotundata, Osmia lignaria	Canada	Imidacloprid, clothianidin, deltamethrin, spinosad, and novaluron	From highly to moderately toxic	Scott-Dupree et al. (2009)
Apis mellifera	Canada	Clothianidin	No long term impact	Cutler and Scott-Dupree (2007)
Apis mellifera	Canada	Clothianidin	Low risk	Cutler et al. (2014)
Apis mellifera	Canada	Carbaryl	Presence in pollens	Kevan et al. (1984)
Apis mellifera	France	Imidacloprid	Presence in pollens	Chauzat et al. (2006)
Apis mellifera	Germany	Clothianidin	Mortality	Heimbach (2015)
Apis mellifera	India	Oxadiazines thiourea derivatives avermectins spinosyns diamides benzoylureas pyridine azomethine derivatives phenylpyrazoles neonicotinoids organophosphate	Toxic	Abrol and Thakur (2016)

a high percentage of pollen samples of canola, along with maize and sunflower (Chauzat et al. 2006). It has also been found that fungicides and adjuvants can disrupt nest recognition in solitary bee species (Artz and Pitts-Singer 2015). In the USA, insecticides, fungicides and herbicides were detected in tissues of native bees (Hladik et al. 2016). In some cases, combination of insecticides, fungicides, herbicides and adjuvants cause more severe effects than any one item alone (Hooven et al. 2013; Mullin et al. 2015). Seed treatments contaminate soil, water, and plant products such as pollen and nectar, and these contaminated materials can have a negative impacts on bee health (Krupke and Long 2015). In the USA, foraging of *A. mellifera* is reported to be reduced on crops like cotton, blueberries, alfalfa, corn, and pumpkins in the presence of different pesticides (Frazier et al. 2015). Pesticide drift and the collection of nectar and nesting material from pesticide-contaminated plants can also cause poisoning of bees. The classic indications of bee poisoning due to pesticides are unusual numbers of dead and dying honey bees in front of the hives, increased defensiveness, abnormal behavior of being extremely lethargic or aggressive and confused, disorientation, dead brood, and poor queen development (Hooven et al. 2013). It has been found that neonicotinoid insecticides can harm populations of both managed and wild bees (Mullin et al. 2010; Goulson 2013; van der Sluijs et al. 2013).

The use of pesticides, herbicides, and the introduction of genetically modified (GM) crops have influenced natural population of pollinators. For instance, a study was conducted in northern Alberta, Canada, in organic, conventional, and herbicide-resistant, genetically modified (GM) canola fields (*Brassica napus* and *B. rapa*). When wild bee populations were assessed in those fields, the greatest pollination deficit was recorded in GM fields, followed by conventionally managed fields, while in organic fields no pollination deficit was recorded (Morandin and Winston 2005). A study in Finland (Hokkanen et al. 2017) found drastic decline in yield trends of canola associated with neonicotinoid use and simplified landscapes. Genetically modified herbicide resistant crops have increased the use of nonselective herbicides and hence causes change in habitat diversity, which in turn causes nutritional stress for pollinators (Sharma et al. 2018). Genetically modified canola such as Roundup ready and Cibus are available in the USA, and these cultivars provide opportunities to the use of non-selective herbicides on canola. Although not much is known about the impact of herbicide resistant canola on pollinators, however, in general an increase in herbicide use due to availability of GM crops impacts pollinators. The main reason of poisoning is the addition of adjuvants, which are added to increase the efficiency of herbicides (Mullin et al. 2015; Shrestha et al. 2017; Sharma et al. 2018).

Pollinator populations can potentially be reduced due to exposure to different kinds of pesticides, exotic pathogens, agricultural intensification, habitat alteration and fragmentation, nutritional stress, and the loss of genetic variation (Calderone 2012). Two possible causes of the decline of populations and genetic variability of invertebrate pollinators, particularly native bees in North America, were suggested by Cane and Tepedino (2001): (1) monoculture grain crops do not provide sustainable food to pollinators, and (2) widespread habitat destruction due to removal of other flowering plants. Therefore, the restoration of plant biodiversity improves habitats for domestic and wild bees and other beneficial insects. Floral resource availability is known to be the primary direct factor influencing bee population abundance, while invasive parasites, pathogens, foraging range, and diet breadth are known to limit bee populations (Roulston and Goodell 2011). Tolerating certain weed species within crop fields can provide food resources and habitat to pollinators, as will the appropriate management of hedgerows, field margins and non-cropped areas (Nicholls and Altieri 2013). Variation in response to insecticides is due to variation in direct (food resources, nesting resources and incidental risks) and indirect factors (grazing, invasive species, habitat complexity and land management). Although food availability is a major regulating factor affecting pollinator populations, manipulative experiments to explore different factors and relationships between indirect factors and floral resources based on environmental circumstances are still needed (Roulston and Goodell 2011). Canola itself provides an excellent source of pollen and sugars to bees (Westcott and Nelson 2001). Hence, canola as a crop certainly provides diversification to the landscape otherwise dominated by grain crops, and increases the economic value of the landscape by providing a good food source to pollinators (Eberle et al. 2015).

Hooven et al. (2013) examined the impact of pesticides on bee behavior and proposed a number of ways to reduce bee poisoning. The selection of low toxicity pesticides with less residual toxicity, reducing pesticide drift and water contamination, and avoiding tank mixing can reduce bee poisoning. Moreover, it is important that pesticide applicators should be informed about the effects of both active and inert components of the products which they apply. The inclusion of pollinator management in IPM is necessary in the present circumstances (Biddinger and Rajotte 2015), which includes the accommodation of pollinator protection by adjusting the pesticide regime, and selecting of new and less harmful pesticides. This also includes concentrating on alternative pollinators and improving the insect pollinator community (Wheelock et al. 2016).

10.4 Conclusion

Canola production in the USA has a promising future for growers as well as for the overall economy, despite the presence of some important insect pests, pathogens and weeds. Although conventional pesticides seem to be most reliable tool at present to deal with canola insect pests, pathogens and weeds, caution should be taken in choosing the pesticide, timing and method of application. Even though canola can be self-fertile, pollinators find the copious amount of nectar from the blooming flowers of canola quite attractive, and this attraction of pollinators strengthens the economic value of canola by increasing landscape diversity and improving the health of pollinators. Improving the public understanding on the importance of biodiversity of insect pollinator community, both around canola crops and in general, is urgently needed. Bees are the most abundant pollinators in canola. Therefore, caution regarding pesticide application and blooming time of canola should be taken by growers. Both growers and beekeepers should be appropriately informed about how to reduce the bee poisoning. Various biological control methods have shown great potential to perform the same service as various pesticides without the harm to the pollinator community, and these control methods should be promoted among growers. Since canola is a natural attractant for pollinators, better communication between growers and beekeepers is required to reduce possible pesticide drift and the collection of contaminated nectar by bees (Fig. 10.1).

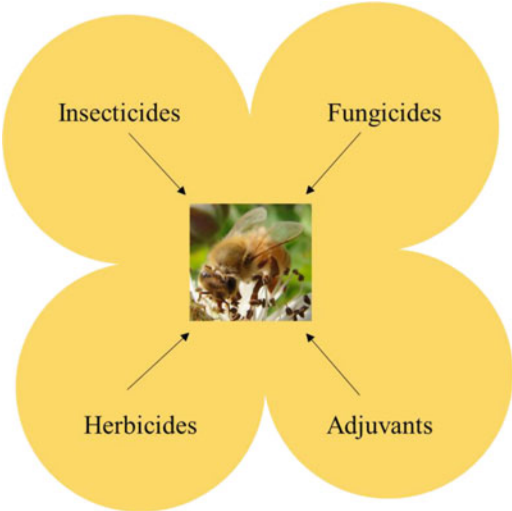

Fig. 10.1 A cumulative and synergistic effect of pesticides on pollinators could be greater than their individual impact. (Photo credit: Dr. Ramesh Sagili)

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