

1

Flea Beetles (*Phyllotreta* spp.) and Their Management

JANET J. KNODEL*

North Dakota State University, Fargo, North Dakota, USA

1.1 Introduction

Flea beetles (Coleoptera: Chrysomelidae), in the genus *Phyllotreta*, are important economic pests of canola production worldwide. The crucifer flea beetle, *Phyllotreta cruciferae* (Goeze), and the striped flea beetle, *Phyllotreta striolata* (Fabricius), are the two most common pest species in canola production in North America (Lamb, 1984; Weiss *et al.*, 1991; Palaniswamy and Lamb, 1992). Although there are five species of flea beetle that infest *Brassica* spp. crops, these other species are generally not a major threat to oilseed crop production (Burgess, 1977a; Wylie, 1979). *P. cruciferae* is widespread in Europe, Asia and Africa (Brown, 1967; Wylie, 1979). It was introduced into North America in the early 1920s in British Columbia and is now found across southern Canada and the USA (Wylie, 1979). *P. striolata* is native to Eurasia and was first discovered in North America in sediment dating before 1668 in Québec, Canada (Rousseau and LeSage, 2016). Its current distribution includes Canada, the eastern and western USA, Mexico, South America and South Africa (Chittenden, 1923; Wylie, 1979). Yield losses from *Phyllotreta* species in canola have been estimated at tens of millions of US dollars annually (Burgess, 1977a; Lamb and Turnock, 1982; Madder and Stemeroff, 1988). Lamb and Turnock (1982) reported that yield losses of 8–10% occur from flea beetle feeding injury even when the crop is protected with an insecticide. Control costs for *Phyllotreta* flea beetles have been estimated to be about US\$300 million annually in canola production areas of the northern Great Plains (Knodel and Olson, 2002).

1.2 Biology

Phyllotreta cruciferae and *P. striolata* have a single generation in their northern distribution and two or more generations in their southern distribution (Burgess, 1977a; Wylie, 1979; Lamb, 1983; Knodel and Olson, 2002; Andersen *et al.*, 2005). Adult *P. cruciferae* are about 2–3 mm long and black with an iridescent blue sheen on their elytra (Fig. 1.1). Adult *P. striolata* are black with two yellow stripes on their elytra and are about 1.5–2.5 mm long (Fig. 1.2). Adults of *Phyllotreta* flea beetles are often observed ‘jumping’ when they are disturbed, which is due to their enlarged femurs on their hind legs.

P. cruciferae prefer to overwinter in the leaf litter beneath shrubs and brush or in wooded areas (Andersen *et al.*, 2005; Ulmer and Dosdall, 2006). Turnock *et al.* (1987) found that the overwintering survival of *Phyllotreta* flea beetles was about 70% in temperate areas. It is suggested that females have a higher success rate of overwintering, since spring-emerging *P. cruciferae* have a sex ratio of 1.5 females to one male (Weiss *et al.*, 1994; Ulmer and Dosdall, 2006). The hibernating adults begin to emerge from their overwintering sites in early spring as the mean ground temperature rises to 10–12°C and emergence peaks when ground temperatures reach 14–15°C (Ulmer and Dosdall, 2006). Depending on the fluctuations in spring temperature, it may take up to 3 weeks or more for the adults to leave the overwintering sites (Westdal and Romanow, 1972; Burgess, 1977a; Wylie, 1979). Beetles typically feed on volunteer canola, mustard and weeds of Brassicaceae before moving to spring-planted canola

*E-mail: janet.knodel@ndsu.edu

(Westdal and Romanow, 1972; Burgess, 1977a, 1981; Wylie, 1979). *Phyllotreta* flea beetles are strong flyers and can easily disperse to find spring-planted canola fields, regardless of the proximity of fields to their overwintering sites (Lamb, 1983; Burgess and Spurr, 1984; Ulmer and Dossdall, 2006).

Adults of *Phyllotreta* species feed and reproduce for about 10–12 weeks (Burgess, 1977a; Wylie,



Fig. 1.1. Adult crucifer flea beetle (*Phyllotreta cruciferae* (Goeze)). Photograph by P. Beauzay, NDSU.



Fig. 1.2. Adult striped flea beetle (*Phyllotreta striolata* (Fabricius)). Photograph by P. Beauzay, NDSU.

1979; Ulmer and Dossdall, 2006). Females oviposit in the soil during June and deposit up to 25 eggs per female; eggs are deposited singly or in groups of three or four on the roots of host plants (Westdal and Romanow, 1972). Eggs are oval, yellow and about 0.38–0.46 mm long by 0.18–0.25 mm wide. Larvae hatch from the eggs in about 12 days and feed on the secondary roots of the plant. Larvae are small (approximately 3 mm), whitish, slender, cylindrical worms with tiny legs and a brown head and anal plate. Larvae progress through three instars over a period of 25–34 days and then form an earthen puparium. Pupae are white except for the black eyes. The pupal stage lasts for about 7–9 days.

The new generation of adult *Phyllotreta* flea beetles emerges from puparia beginning in August and emergence continues through September in northern North America (Ulmer and Dossdall, 2006). Ulmer and Dossdall (2006) found that the sex ratio of *P. cruciferae* for the new generation was 1.2 females to one male. Beetles feed on the epidermis of green foliage and pods (Fig. 1.3); however,



Fig. 1.3. Feeding on seed pods of canola in late summer by new generation of *Phyllotreta* flea beetles. Photograph by P. Beauzay, NDSU.

due to the advanced stage of the crop, feeding injury is usually negligible (Knodel and Olson, 2002). In fall, adults move back to overwintering sites and repeat their life cycle (Burgess, 1977a, 1981; Wylie, 1979).

1.3 Hosts

Phyllotreta flea beetles are selective oligophagous herbivores that feed primarily on host plants in the family Brassicaceae (Feeny *et al.*, 1970). Many of the Brassicaceae plants produce a mustard oil called allyl isothiocyanate, a glucosinolate breakdown product, which is attractive to *Phyllotreta* flea beetles in the field (Vincent and Stewart, 1984; Chew, 1988; Pivnick *et al.*, 1992; Hopkins *et al.*, 2009). The most preferred agricultural hosts attacked by *Phyllotreta* species include oil rapeseed or Argentine canola (*Brassica napus* L.), Polish canola (*Brassica rapa* L.) and oriental or brown mustard (*Brassica juncea* L.) Czern.) (Palaniswamy and Lamb, 1992; Palaniswamy *et al.*, 1992; Soroka and Grenkow, 2013). Mustard species (*Sinapis alba* L. and *B. juncea*) typically have less damage from feeding *Phyllotreta* flea beetles and higher yield compared with canola *Brassica* species (Brandt and Lamb, 1991, 1993; Hopkins *et al.*, 1998; Brown *et al.*, 2004). Henderson *et al.* (2004) found that *S. alba* has a volatile deterrent phytochemical that inhibits feeding by *Phyllotreta* flea beetles. Crambe (*Crambe abyssinica* Hochst. and *Crambe hispanica* L.) also had lower feeding injury by *Phyllotreta* flea beetles compared with canola *Brassica* species due to a non-volatile deterrent phytochemical (Chengwang *et al.*, 1992; Henderson *et al.*, 2004; Soroka and Grenkow, 2013). False flax (*Camelina sativa* L.) Crantz was found to act as a non-host of *Phyllotreta* flea beetles since it lacked the cues to initiate feeding (Pachagounder *et al.*, 1998; Henderson *et al.*, 2004; Soroka and Grenkow, 2013). In the garden, *Phyllotreta* flea beetles will feed on other *Brassica* species, such as broccoli (*Brassica oleracea* var. *italica*), cabbage (*B. oleracea* var. *capitata*), cauliflower (*B. oleracea* var. *botrytis*), kale (*B. oleracea* var. *acephala*), Brussels sprouts (*B. oleracea* var. *gemmifera*), turnip (*Brassica rapa* subsp. *rapifera*), horseradish (*Armoracia rusticana* Gaertn., Mey. and Scherb.) and radish (*Raphanus sativus* L.) (Westdal and Romanow, 1972). Weeds infested by *Phyllotreta* species include flixweed (*Descurainia sophia* L.), field pennycress/stinkweed (*Thlaspi arvense* L.), peppergrass (*Lepidium virginicum* L.)

and wild mustard (*Sinapis arvensis arvensis* L.) (Westdal and Romanow, 1972). Laboratory feeding studies showed that *P. cruciferae* also fed on plants in the caper family (Capparidaceae), the nasturtium family (Tropaeolaceae) and the marshflower family (Limnanthaceae) (Feeny *et al.*, 1970).

1.4 Crop Damage

The greatest crop loss from this pest occurs in the seedling stage within the first 2 weeks after plant emergence (Turnock and Lamb, 1982; Lamb, 1984; Bracken and Bucher, 1986). Adult feeding on cotyledons causes the tissue to die around the feeding sites, creating a shot-hole appearance and necrosis on seedlings (Fig. 1.4). Feeding injury is often concentrated on one cotyledon only, since *P. cruciferae* tend to aggregate during feeding (Anderson *et al.*, 1992). As a result of herbivory by *Phyllotreta*, the plant's ability to conduct photosynthesis is negatively affected, often causing wilting and seedling death (Westdal and Romanow, 1972). Damage from *Phyllotreta* herbivory on seedlings results in reduced crop stands, causing lower seed yield and quality, and uneven plant growth, causing delayed maturity (Putnam, 1977; Lamb and Turnock, 1982; Lamb, 1984; Weiss *et al.*, 1991). Fields may need to be reseeded when canola stands are below 43 plants/m² (Kandel and Knodel, 2011). Gavloski and Lamb (2000) found that compensation by canola seedlings from



Fig. 1.4. Canola seedling damaged by *Phyllotreta* flea beetles feeding on cotyledons (note pitting and shot holing). Photograph by P. Beauzay, NDSU.

flea beetle herbivory was a function of whether the insects destroyed the apical meristem and the degree of defoliation. *Phyllotreta* flea beetles have been recorded attacking the growing point (meristem tissue) of four- to six-leaf seedlings, killing the plant when populations are significant and environmental conditions are hot and dry (Burgess, 1977a; Lamb, 1984; Knodel and Olson, 2002). Warm, dry weather promotes flea beetle flight and increases feeding activity (Burgess, 1977a; Turnock and Lamb, 1982; Lamb, 1984). In contrast, cool, wet and windy conditions cause flea beetles to creep slowly just into field edges, where feeding damage is often lower (Westdal and Romanow, 1972).

During the summer, larval feeding injury on the secondary root hairs causes only a negligible effect on canola yield. Bracken and Bucher (1986) reported a yield loss of 5% from larval densities of 0.16/cm² in Manitoba, Canada. In the summer, a new generation of *Phyllotreta* flea beetles feeds on the epidermis of green foliage and pods of mature canola (Feeny *et al.*, 1970). This feeding damage results in poor seed fill, premature pod drying, shrivelled seeds or pod shattering, and provides an entry point for fungal growth within pods in damp weather (Knodel and Olson, 2002). When populations of the new generation are significant, reduced seed production and quality can occur, especially on the upper or younger pods or late-seeded crop (Knodel and Olson, 2002).

1.5 Integrated Pest Management

Implementing an integrated pest management (IPM) programme provides the best pest management strategies for *Phyllotreta* flea beetles in canola. IPM uses pest monitoring in conjunction with economic thresholds and multiple strategies to promote the judicious use of insecticides and conservation of natural enemies of pests (Pedigo and Rice, 2009).

1.6 Monitoring

The most critical time to monitor for *Phyllotreta* species is when spring-planted canola is emerging and ground temperatures are above 14–15°C (Knodel and Olson, 2002; Ulmer and Dosdall, 2006). Canola fields should be scouted by walking a ‘W’ pattern in the field and inspecting ten plants randomly at five sites per field for a total of 50 plants/field. The amount of defoliation is used as a

guide to determine the need for management action (Knodel and Olson, 2002). The percentage defoliation is estimated for each plant selected. Scouting should continue until plants have reached the four- to six-leaf stage (Knodel and Olson, 2002).

Traps also are used for monitoring populations of *Phyllotreta* flea beetles in canola. Yellow and white are preferred by *Phyllotreta* species over other colours, such as red or blue (Vincent and Stewart, 1985; Adams and Los, 1986; Láska *et al.*, 1986). Yellow sticky traps (Fig. 1.5) are available commercially from insect trap suppliers and can be used to detect first emergence and population peaks (Knodel

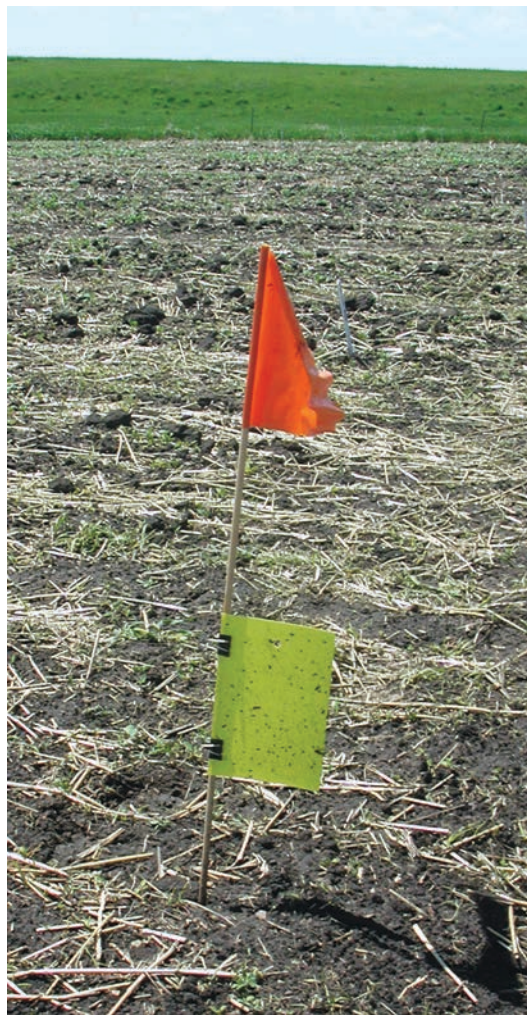


Fig. 1.5. Yellow sticky trap used for monitoring *Phyllotreta* flea beetles. Photograph by J. Knodel, NDSU.

and Olson, 2002). Lamb (1983) reported that neither sticky traps nor suction traps (baited or unbaited) are a reliable system for predicting densities of *Phyllotreta* flea beetles. However, Andersen *et al.* (2005) found that adult *P. cruciferae* catch on yellow sticky card was highly correlated with subsequent feeding injury on *Brassica* plants.

Male *Phyllotreta* flea beetles produce an aggregation pheromone, sesquiterpenes, which attracts both sexes (Chengwang and Weiss, 1992; Chengwang *et al.*, 1999; Toth *et al.*, 2005; Bartelt *et al.*, 2011). Using modified yellow plastic boll weevil traps, Soroka *et al.* (2005) found that combinations of the aggregation pheromone and allyl isothiocyanate (a crucifer-specific volatile) generally attracted higher numbers of flea beetles than either component by itself in the field. Vincent and Stewart (1984) reported that *P. cruciferae* was more attracted to allyl isothiocyanate than *P. striolata*; however, *Psylliodes punctulata* Melsheimer was not affected by the presence of allyl isothiocyanate. Gruber *et al.* (2009) found that allyl isothiocyanate was attractive to *Phyllotreta* flea beetles only in the spring and early fall, but it was inhibitory in the late fall. Currently, no aggregation pheromone is sold commercially by insect trap suppliers for monitoring *Phyllotreta* flea beetles.

The narrow time frame between spring emergence of *Phyllotreta* flea beetles and crop infestation limits the use of traps as a decision-making tool for scouts, crop consultants and producers (Ulmer and Dossall, 2006).

1.7 Chemical Control

Systemic insecticides in the neonicotinoid group of insecticides (IRAC 4A) that are applied as a seed treatment to canola seeds are the primary means of *Phyllotreta* pest management (Lamb and Turnock, 1982; Weiss *et al.*, 1991, 1994; Knodel *et al.*, 2008). Active ingredients in registered neonicotinoid insecticides for flea beetle control in canola in the USA include imidacloprid, thiamethoxam and clothianidin (Knodel *et al.*, 2015). Neonicotinoid seed treatments are the most widely used management strategy for control of *Phyllotreta* flea beetles. More than 90% of canola acreage in Canada and 95% in the USA are planted with neonicotinoid-treated seed (Soroka *et al.*, 2008). Cyantraniliprole (IRAC 28), a newer active ingredient, is also available as an insecticide seed treatment in canola for flea beetle control. Insecticide seed treatments generally

have an advantage over foliar spray applications of insecticides, because of their convenience during planting and extended protection against flea beetles when producers are busy planting other crops. Research has shown that neonicotinoid seed treatments are effective for reducing flea beetle damage to seedling canola, and seedling protection typically lasts for about 21 days (Antwi *et al.*, 2007a, b; Knodel *et al.*, 2008). Soroka *et al.* (2008) found that decreasing the ratio of neonicotinoid (acetamiprid or clothianidin) treated seed to two-thirds of the seed coated with insecticide was comparable to those in 1× treatments for flea beetle feeding injury, plant stands and seed yield except when feeding pressure was significant; however, there was no cost advantage to decreasing the volume of insecticide-treated seed. As result of this study, canola producers are discouraged from mixing untreated seed with insecticide-coated seed to reduce costs or insecticide use, or to use up stock of on-farm bin-run seed (Soroka *et al.*, 2008). The prophylactic use of insecticide seed treatments may be unnecessary in some situations where *Phyllotreta* populations are below economically damaging populations. However, producers must decide before planting whether an insecticide seed treatment will be used and before the population levels of *Phyllotreta* spp. are known. Currently, there is no forecasting model that predicts outbreaks of *Phyllotreta* flea beetles in the spring and their potential for damage to the canola crop (Thomas, 2003).

Since canola is a preferred crop for honey production by honey bees, *Apis mellifera* (L.), there are many concerns about the adverse risks of systemic neonicotinoid seed treatments in canola to bee health. Although systemic insecticide seed treatments are generally considered more ecologically sound than foliar-applied insecticides, systemic insecticides may translocate toxins to pollen or nectar during crop development, which could negatively impact foraging pollinators and cause pesticide poisoning. However, several studies indicate that long-term exposure of honey bees to neonicotinoid insecticide seed treatments in canola poses a minor risk to bee health (Schmuck *et al.*, 2001; Maus *et al.*, 2003; Schmuck, 2004; Faucon *et al.*, 2005; Cutler and Scott-Dupree, 2007; Nguyen *et al.*, 2009). Cutler and Scott-Dupree (2007) placed bee hives in the middle of 1 ha clothianidin-treated canola and untreated control fields during bloom for 3 weeks and found no differences in bee mortality, worker longevity or brood development between control

and clothianidin-treated canola. Maus *et al.* (2003) reviewed the safety of imidacloprid to honey bees and reported that the majority of studies found no acute or chronic toxicity of imidacloprid at ≤ 20 ppb. However, honey bees rejected imidacloprid-contaminated food at 20 ppb in the laboratory (Kirchner, 1999). Decourtye *et al.* (2001) reported compromised learning in honey bees after exposure to low rates of imidacloprid-contaminated food at 12–48 ppb in the laboratory. Suchail *et al.* (2001) observed honey bees fed low concentrations of imidacloprid had high chronic toxicity. Additional research is needed to improve knowledge on the interactions of pollinators and pesticides; both are key components of modern agriculture.

Foliar-applied insecticides are often necessary when the peak emergence of *Phyllotreta* flea beetles is delayed beyond the 21-day window of protection from insecticide seed treatments due to cool temperature (Weiss *et al.*, 1991; Ulmer and Dosdall, 2006; Knodel *et al.*, 2008). In addition, foliar-applied insecticidal sprays are often necessary to protect the canola crop when cool, wet weather slows the growth and uptake of insecticide seed treatment in the canola plant and *Phyllotreta* populations are significant (Knodel *et al.*, 2008). Some active ingredients of pyrethroid (IRAC 3A) insecticides registered for flea beetle control in canola include bifenthrin, deltamethrin, gamma-cyhalothrin, lambda-cyhalothrin and zeta-cypermethrin (Knodel *et al.*, 2015).

Reduced-risk insecticides have been tested for efficacy against *Phyllotreta* flea beetles. Elliott *et al.* (2007) found that spinosad was more toxic by ingestion than topical contact and that flea beetle mortality was increased with longer exposure times (more than 120 h) and toxicity was increased when an ionic surfactant was added. For *P. cruciferae* management in canola, spinosad was found to be the most effective ecorational insecticide compared with neem (azadirachtin), pyrethrin, kaolin (a clay) and the fungal entomopathogen *Beauveria bassiana* (Andersen *et al.*, 2006; Antwi *et al.*, 2007a, b). Reddy *et al.* (2014) reported that the combination of two entomopathogenic fungi, *Metarhizium brunneum* and *B. bassiana*, applied twice were as effective as conventional insecticides and presented a more ecologically sound alternative to conventional insecticide applications.

To protect canola from yield loss, foliar insecticides are often applied at a nominal threshold level of 25% defoliation to cotyledon and true leaves (Weiss *et al.*, 1991; Anon., 1997; Knodel and Olson,

2002). Most recently, research by Tangtrakulwanich *et al.* (2014) found that foliar treatments must be made quickly if damage exceeds a lower action threshold of 15–20% defoliation. Knodel and Olson (2002) recommended applying insecticides during the sunny, warm part of the day when flea beetles are actively feeding on the plants. Canola plants that have reached the four- to six-leaf vegetative growth stage or beyond can tolerate more feeding damage, unless flea beetles are damaging the growing point (Knodel and Olson, 2002).

Phyllotreta flea beetles have been effectively controlled by neonicotinoid-treated canola seed for more than a decade. Insecticide resistance occurs more rapidly when there is widespread adoption of one insecticide or insecticide class used year after year against an abundant pest. In Canada, Tansey *et al.* (2008, 2009) found that the two species, *P. cruciferae* and *P. striolata*, had different susceptibilities when exposed to canola neonicotinoid seed treatment with active ingredients clothianidin, imidacloprid and thiamethoxam. *P. cruciferae* had a higher mortality and exhibited less feeding when exposed to thiamethoxam and clothianidin compared with *P. striolata* (Tansey *et al.*, 2008, 2009). These effects were even more apparent when the two species were subjected to intraspecific crowding and stresses from overwintering, such as depletion of lipid and glycogen reserves (Tansey *et al.*, 2008). Differences in efficacy could cause a shift in the prevalence of flea beetle species from *P. cruciferae* to *P. striolata* where these species occur sympatrically and where seed-treated canola is grown in large acreage.

Pesticide resistance has costly consequences. Pimentel (2005) estimated that US\$1.5 billion of agronomic losses occurred each year in the USA due to the development of pesticide resistance in insect pests. Alternative IPM strategies for *Phyllotreta* flea beetle control are needed in canola. For example, Zhao *et al.* (2008) cloned and characterized the arginine kinase (AK) gene from *P. striolata* and constructed dsRNA to impair the beetle's development and to enhance mortality of adults. In addition, RNAi targeting the AK gene reduced fecundity and fertility of *P. striolata*, suggesting that this is a potential new strategy to help delay insecticide resistance (Zhao *et al.*, 2008).

1.8 Cultural Control

Cultural control studies have demonstrated that different cropping systems (described below) have

the ability to decrease the extent of feeding injury by *Phyllotreta* flea beetles in canola. Although the use of cultural strategies may not completely eliminate the need for insecticidal control, they offer the possibility for managing *Phyllotreta* flea beetles and reducing insecticide use in canola production.

1.8.1 Seeding dates

Peak flea beetle emergence often coincides with the germination of early-seeded canola in April or early May resulting in higher flea beetle feeding injury due to most of the canola being in the susceptible seedling stage (Ulmer and Dossdall, 2006; Knodel *et al.*, 2008). In contrast, less flea beetle feeding injury was observed on late-seeded canola from late May to early June (Lamb, 1984, 1988; Knodel *et al.*, 2008). However, yield of late-seeded canola is often lower than early-seeded canola, due to heat stress during flowering (Angadi *et al.*, 2000; Knodel *et al.*, 2008). As a result, agronomists recommend seeding canola early for optimal yields due to heat sensitivity during flowering, in spite of the higher risks of flea beetle damage (Angadi *et al.*, 2000). Another seeding date strategy is dormant seeded canola in the fall. Dossdall and Stevenson (2005) found that fall-seeded canola emerged and developed past the susceptible seedling stage before significant numbers of spring *Phyllotreta* flea beetles emerged from overwintering sites. However, fall-seeded canola is considered a high-risk practice by producers, especially in growing areas with extreme temperatures and dry soils in the winter (Kandel and Knodel, 2011).

1.8.2 Seed size, seeding rates and row spacing

Increased seeding rates have been shown to reduce the mean flea beetle damage per plant because there are more plants per unit area (Dossdall and Stevenson, 2005). Dossdall *et al.* (1999) found that increasing the seeding rate also reduced flea beetle injury to canola, since leaf biomass was greater at high seeding rates. Planting large-seeded rather than small-seeded varieties of canola has been shown to lower flea beetle damage and result in higher plant establishment, shoot weight and yield (Bodnaryk and Lamb, 1991; Elliott *et al.*, 2008). Canola planted in wider row spacing of 20–30 cm resulted in decreased feeding injury per plant than narrower row spacing of 10 cm (Dossdall *et al.*, 1999).

1.8.3 Tillage systems

Lower population densities of flea beetles have been observed in no-till fields compared with conventionally tilled fields, probably due to the cooler microenvironment which is less preferred by flea beetles (Dossdall *et al.*, 1999; Milbrath *et al.*, 1995).

1.9 Plant Resistance

Research has found that species and cultivars of Brassicaceae can vary in their levels of resistance to feeding injury by *Phyllotreta* flea beetles (Lamb, 1980, 1984, 1988; Lamb and Palaniswamy, 1990; Bodnaryk and Lamb, 1991; Palaniswamy *et al.*, 1992; Pachagounder and Lamb, 1998; Gavloski *et al.*, 2000). Bodnaryk and Lamb (1991) found that larger seed size in *B. napus* and *S. alba* increased seedling survival due to a lower proportion of cotyledon area damaged compared with smaller seeds, and that this could be a ‘desirable’ trait for host plant resistance against *Phyllotreta* flea beetles. Gavloski *et al.* (2000) found resistance to *Phyllotreta* flea beetles in yellow mustard (*S. alba* and some *S. alba* × *B. napus* crosses), which was due to the deterrent effect of p-hydroxybenzyl glucosinolate (HOBE or glucosinalbin) (Bodnaryk, 1991). Other researchers found that yellow mustard also has tolerance to flea beetle feeding injury (Bodnaryk and Lamb, 1991; Elliott and Rakow, 1999).

Trichomes on plant leaves, stems and pods in some species of Brassicaceae reduce feeding injury of *Phyllotreta* flea beetles and could be used for a host plant resistance trait in canola breeding. For example, the pods of white mustard, *S. alba*, are covered with large numbers of trichomes and these trichomes reduce feeding by *Phyllotreta* flea beetles compared with the glabrous pods of *B. napus* (Lamb, 1980). Leaves of a wild species, *Brassica villosa* Biv., are hirsute and were resistant to *P. cruciferae* feeding compared with the glabrous leaves of *B. rupestris* Raf., *B. macrocarpa* Guss. and *B. napus* (Palaniswamy and Bodnaryk, 1994). Soroka *et al.* (2011) found that the dense pubescence of leaves deterred feeding of *P. cruciferae* and doubled the time to reach satiation compared with glabrous leaves of *B. napus*. Henderson *et al.* (2004) found that the pre-feeding behaviour of *P. cruciferae* involved use of the antennae, tarsi and mouthparts to determine the suitability of a potential host. Any interruptions, such as dense pubescence preventing the pre-feeding behaviour, could negatively impact

feeding time and the amount of feeding, or both (Henderson *et al.*, 2004).

1.10 Biological Control

Most biological control with predators and parasitoids has not been successful in reducing populations of *Phyllotreta* flea beetles in canola. Parasitic wasps, such as *Microtonus* species (Hymenoptera: Braconidae), are known to attack both *P. cruciferae* and *P. striolata*; however, the rate of parasitization is low and/or establishment of introduced parasitoids is unsuccessful (Wylie, 1982, 1983, 1984, 1988; Wylie and Loan, 1984). Only a few predators have been recorded as predaceous on *Phyllotreta* flea beetles: field crickets (Orthoptera: Gryllidae: *Gryllus pennsylvanicus* Burmeister), big-eyed bugs (Hemiptera: Geocoridae: *Geocoris bullatus* (Say)), damsel bugs (Hemiptera: Nabidae: *Nabis alternatus* Parshley and *Nabicula americolimbata* Carayon), lacewing larvae (Neuroptera: Chrysopidae: *Chrysopa* spp.) and two-lined collops (Coleoptera: Melyridae: *Collops vittatus* (Say)) (Burgess, 1977b; Thomas, 1986; Burgess and Hinks, 1987). Since adult beetles emerge during a narrow period in the spring, this makes it difficult for natural enemies to have a negative impact on populations of *Phyllotreta* species; and other life stages (egg, larva and pupa) are protected in the soil.

Entomopathogenic nematodes (Rahbditida: Steinernematidae and Heterorhabditidae) have been evaluated for management of *Phyllotreta* species on crucifer vegetables and canola in the laboratory and field (Xu *et al.*, 2010; Yan *et al.*, 2013; Antwi and Reddy, 2016). Yan *et al.* (2013) found that *Steinernema carpocapsae* All and *Heterorhabditis indica* LN2 controlled the soil-dwelling life stages of *P. striolata* in the field and resulted in lower adult populations and subsequent leaf shot-hole damage and higher yields in cabbage grown in China. Xu *et al.* (2010) discovered that nematodes with higher pathogenicity, greater heat tolerance and reproduction potential increased the potential for biological control of *P. striolata*. Reddy *et al.* (2014) also found that foliar applications of the entomopathogenic nematode *S. carpocapsae* reduced feeding injury and provided control of *P. cruciferae* in canola. Antwi and Reddy (2016) tested a sprayable polymer gel formulation of two entomopathogenic nematodes, *Steinernema* spp. and *Heterorhabditis* spp., and found that these formulations had the highest yield under significant

P. cruciferae densities and higher yield than conventional neonicotinoid seed treatments. Nematodes offer a viable alternative to conventional insecticides for pest management of *Phyllotreta* flea beetles.

References

- Adams, R.G. and Los, L. (1986) Monitoring adult corn flea beetles (Coleoptera: Chrysomelidae) in sweet corn fields with color sticky traps. *Environmental Entomology* 15, 867–873.
- Andersen, C.L., Hazzard, R., Van Driesche, R. and Mangan, F.X. (2005) Overwintering and seasonal patterns of feeding and reproduction in *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) in the Northeast United States. *Environmental Entomology* 34, 749–800.
- Andersen, C.L., Hazzard, R., Van Driesche, R. and Mangan, F.X. (2006) Alternative management tactics for control of *Phyllotreta cruciferae* and *Phyllotreta striolata* (Coleoptera: Chrysomelidae) on *Brassica rapa* in Massachusetts. *Journal of Economic Entomology* 99, 803–810.
- Anderson, M.D., Peng, C. and Weiss, M.J. (1992) Crambe, *Crambe abyssinica* Hochst., as a flea beetle resistant crop (Coleoptera: Chrysomelidae). *Journal of Economic Entomology* 85, 594–600.
- Angadi, S.V., Cutforth, H.W., Miller, P.R., McConkey, B.G., Entz, M.H., Brandt, S.A. and Volkmar, K.M. (2000) Response of three *Brassica* species to high temperature stress during reproductive growth. *Canadian Journal of Plant Science* 80, 693–701.
- Anon. (1997) *Flea beetle management for canola, rape-seed and mustard in the northern Great Plains. Sustainable Agriculture Facts. Growing for Tomorrow*. Agriculture and Agri-Food Canada, Ottawa, Canada. Available at: <http://www.saskatchewan.ca/>
- Antwi, F.B. and Reddy, G.V.P. (2016) Efficacy of entomopathogenic nematodes and sprayable polymer gel against crucifer flea beetle (Coleoptera: Chrysomelidae) on canola. *Journal of Economic Entomology* 109, 1706–1712. doi: 10.1093/jee/tow140.
- Antwi, F.B., Knodel, J.J. and Olson, D.L. (2007a) Comparative evaluation and economic potential of ecorational versus chemical insecticides for crucifer flea beetle (Coleoptera: Chrysomelidae) management in canola. *Journal of Economic Entomology* 100, 710–716.
- Antwi, F.B., Olson, D.L. and Carey, D.R. (2007b) Comparative of ecorational and chemical insecticides against crucifer flea beetle (Coleoptera: Chrysomelidae) on canola. *Journal of Economic Entomology* 100, 1201–1209.
- Bartelt, R.J., Zilkowski, B.W., Cossé, A.A., Schnupf, U., Vermillion, K. and Momany, F.A. (2011) Male-specific sesquiterpenes from *Phyllotreta* flea beetles. *Journal of Natural Products* 74, 585–595.

- Bodnaryk, R.P. (1991) Developmental profile of sinalbin (p-hydroxybenzylglucosinolate) in mustard seedlings, *Sinapis alba* L., and its relationship to insect resistance. *Journal of Chemical Ecology* 17, 1543–1556.
- Bodnaryk, R.P. and Lamb, R.J. (1991) Influence of seed size in canola, *Brassica napus* L., and mustard, *Sinapis alba* L., on seedling resistance against flea beetles, *Phyllotreta cruciferae* (Goeze). *Canadian Journal of Plant Science* 71, 397–404.
- Bracken, G.K. and Bucher, G.E. (1986) Yield losses in canola caused by adult and larval flea beetles, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 118, 319–324.
- Brandt, R.N. and Lamb, R.J. (1991) Mechanisms of resistance to the flea beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae), in mustard seedlings, *Sinapis alba* L. *Canadian Journal of Plant Science* 71, 13–20.
- Brandt, R.N. and Lamb, R.J. (1993) Distribution of feeding damage by *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae), on oilseed rape and mustard seedlings in relation to crop resistance. *The Canadian Entomologist* 125, 1011–1021.
- Brown, W.J. (1967) Notes on the extralimital distribution of some species of Coleoptera. *The Canadian Entomologist* 99, 85–93.
- Brown, J., McCaffrey, J.P., Brown, D.A., Harmon, B.L. and Davis, J.B. (2004) Yield reduction in *Brassica napus*, *B. rapa*, *B. juncea*, and *Sinapis alba* caused by flea beetle (*Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae)) infestation in northern Idaho. *Journal of Economic Entomology* 97, 1642–1647.
- Burgess, L. (1977a) Flea beetles (Coleoptera: Chrysomelidae) attacking rape crop in the Canadian Prairie Provinces. *The Canadian Entomologist* 109, 21–32.
- Burgess, L. (1977b) *Geocoris bullatus*, an occasional predator on flea beetles (Hemiptera: Lygaeidae). *The Canadian Entomologist* 109, 1519–1520.
- Burgess, L. (1981) Winter sampling to determine overwintering sites and estimate density of adult flea beetles of rape (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 113, 441–447.
- Burgess, L. and Hinks, C.F. (1987) Predation on adult of the crucifer flea beetle by the northern fall field cricket. *The Canadian Entomologist* 119, 495–496.
- Burgess, L. and Spurr, D.T. (1984) Distribution and abundance of overwintering flea beetles (Coleoptera: Chrysomelidae) in a grove of trees. *Environmental Entomology* 13, 941–944.
- Chengwang, P. and Weiss, M.J. (1992) Evidence of an aggregation pheromone in the flea beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae). *Journal of Chemical Ecology* 18, 875–884.
- Chengwang, P., Weiss, M.J. and Anderson, M.D. (1992) Flea beetle (Coleoptera: Chrysomelidae) response, feeding, and longevity on oilseed rape and crambe. *Environmental Entomology* 32, 604–609.
- Chengwang, P., Bartelt, R.J. and Weiss, M.J. (1999) Male crucifer flea beetle produces an aggregation pheromone. *Physiological Entomology* 24, 98–99.
- Chew, F.S. (1988) Biological effects of glucosinolates. In: Cutler, H.G. (ed.) *Biologically Active Natural Products: Potential Uses in Agriculture*. American Chemical Society, Washington, DC, pp. 155–181.
- Chittenden, F.H. (1923) Notes on the distribution and habits of North American *Phyllotreta* (Coleop.). *Proceedings of the Entomological Society of Washington* 25, 131–139.
- Cutler, G. and Scott-Dupree, C.D. (2007) Exposure to clothianidin seed-treated canola has no long-term impact on honey bees. *Journal of Economic Entomology* 100, 765–772.
- Decourtye, A., Le Matayer, M., Pottiau, H., Tisseur, M., Odoux, J.F. and Pham-Delegue, M.H. (2001) Impairment of olfactory learning performances in the honey bee after long term ingestion of imidacloprid. In: Belzunces, L.P., Pelissier, C. and Lewis, G.B. (eds) *Hazard of Pesticides to Bees*. Institut National de la Recherche Agronomique, Paris, pp. 113–117.
- Dosdall, L.M. and Stevenson, F.C. (2005) Managing flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae) in canola with seeding date, planting density, and seed treatment. *Agronomy Journal* 97, 1570–1578.
- Dosdall, L.M., Dolinski, M.G., Cowle, N.T. and Conway, P.M. (1999) The effect of tillage regime, row spacing, and seeding rate of feeding injury by flea beetles, *Phyllotreta* spp. (Coleoptera: Chrysomelidae) in canola in central Alberta, Canada. *Crop Protection* 18, 217–224.
- Elliott, R.H. and Rakow, G.F.W. (1999) Resistance of *Brassica* and *Sinapis* species to flea beetles, *Phyllotreta cruciferae*. In: Wratten, N. and Salisbury, P.A. (eds) *New Horizons for an Old Crop: Proceedings of 10th International Rapeseed Congress, Canberra, Australia, 26–29 September 1999*. Canberra GCIRC, Canberra, Australia.
- Elliott, R.H., Benjamin, M.C. and Gillott, G. (2007) Laboratory studies on the toxicity of spinosad and deltamethrin to *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 139, 534–544.
- Elliott, R.H., Franke, C. and Rakow, G.F.W. (2008) Effects of seed size and seed weight on seedling establishment, vigour and tolerance of Argentine canola (*Brassica napus*) to flea beetles, *Phyllotreta* spp. *Canadian Journal of Plant Science* 88, 207–217.
- Faucon, J.P., Aurieres, C., Drajnudel, P., Ribiere, M., Martel, A.C., Zeggane, S., Chauzat, M.P. and Aubert, M.F.A. (2005) Experimental study on the toxicity of imidacloprid given in syrup to honey bee (*Apis mellifera*). *Pest Management Science* 61, 111–125.
- Feeny, P., Paauwe, K. and Demong, N. (1970) Flea beetles and mustard oils: host plant specificity of *Phyllotreta cruciferae* and *P. striolata* adults (Coleoptera:

- Chrysomelidae). *Annals of the Entomological Society of America* 63, 832–841.
- Gavloski, J.E. and Lamb, R.J. (2000) Compensation by cruciferous plants is specific to the type of simulated herbivory. *Environmental Entomology* 29, 1273–1282.
- Gavloski, J.E., Ekuere, U., Keddie, A., Dossdall, L., Kott, L. and Good, A.G. (2000) Identification and evaluation of flea beetle, *Phyllotreta cruciferae*, resistance within Brassicaceae. *Canadian Journal of Plant Science* 80, 881–887.
- Gruber, M.Y., Xu, N., Grenkow, L., Li, X., Onyilagha, J., Soroka, J.J., Westcott, N.D. and Hegedus, D.D. (2009) Responses of the crucifer flea beetle to *Brassica* volatiles in an olfactometer. *Environmental Entomology* 38, 1467–1479.
- Henderson, A.E., Hallett, R.H. and Soroka, J.J. (2004) Prefeeding behavior of the crucifer flea beetle, *Phyllotreta cruciferae*, on host and nonhost crucifers. *The Journal of Insect Behavior* 17, 17–39.
- Hopkins, R.J., Ekbom, B. and Henkow, L. (1998) Glucosinolate content and susceptibility for insect attack of three populations of *Sinapis alba*. *Journal of Chemical Ecology* 24, 1203–1216.
- Hopkins, R.J., van Dam, N.M. and van Loon, J.J.A. (2009) Role of glucosinolate in insect-plant relationships and multitrophic interactions. *Annual Review of Entomology* 54, 57–83.
- Kandel, H. and Knodel, J.J. (eds) (2011) *Canola Production Field Guide*. North Dakota State University Cooperative Extension Service Publication A1280, Fargo, North Dakota.
- Kirchner, W.H. (1999) Mad-bee disease? Sublethal effects of imidacloprid (Gaucho) on the behavior of honey bees. *Apidologie* 30, 422–423.
- Knodel, J.J. and Olson, D.L. (2002) *Biology and Integrated Pest Management of the Crucifer Flea Beetle in Canola*. North Dakota State University Cooperative Extension Service Publication E-1234, Fargo, North Dakota.
- Knodel, J.J., Olson, D.L., Hanson, B.K. and Henson, R.A. (2008) Impact of planting dates and insecticide strategies for managing crucifer flea beetle (Coleoptera: Chrysomelidae) in spring-planted canola. *Journal of Economic Entomology* 101, 810–821.
- Knodel, J.J., Beauzay, P. and Boetel, M. (2015) *2016 North Dakota Field Crop Insect Management Guide*. North Dakota State University Cooperative Extension Service Publication E-1143, Fargo, North Dakota.
- Lamb, R.J. (1980) Hairs protect pods of mustard (*Brassica hirta* 'Gisilba') from flea beetle feeding damage. *Canadian Journal of Plant Science* 60, 1439–1440.
- Lamb, R.J. (1983) Phenology of flea beetle (Coleoptera: Chrysomelidae) flight in relation to their invasion of canola fields in Manitoba. *The Canadian Entomologist* 115, 1493–1502.
- Lamb, R.J. (1984) Effects of flea beetle *Phyllotreta* spp. (Coleoptera: Chrysomelidae) on survival, growth, seed yield and quality of canola, rape and yellow mustard. *The Canadian Entomologist* 116, 269–280.
- Lamb, R.J. (1988) Assessing the susceptibility of crucifer seedlings to flea beetle (*Phyllotreta* spp.) damage. *Canadian Journal of Plant Science* 68, 85–93.
- Lamb, R.J. and Palaniswamy, P. (1990) Host discrimination by a crucifer-feeding flea beetle, *Phyllotreta striolata* (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 122, 817–824.
- Lamb, R.J. and Turnock, W.J. (1982) Economics of insecticidal control of flea beetles (Coleoptera: Chrysomelidae) attacking rape in Canada. *The Canadian Entomologist* 114, 827–840.
- Láska, P., Zelenkova, I. and Bičík, V. (1986) Colour attraction in species of the genera: *Delia* (Diptera: Anthomyiidae), *Ceutorhynchus*, *Meligethes*, and *Phyllotreta* (Coleoptera: Curculionidae, Nitidulidae, and Chrysomelidae). *Acta Entomologica Bohemoslovaca* 83, 418–424.
- Madder, D.J. and Stemeroff, M. (1988) The economics of insect control on wheat, corn, and canola, 1980–1985. *Bulletin of Entomological Society of Canada Supplement* 2.
- Maus, C., Cure, G. and Schmuck, R. (2003) Safety of imidacloprid seed dressings to honey bees: a comprehensive overview and compilation of the current state of knowledge. *Bulletin of Insectology* 56, 51–57.
- Milbrath, L.R., Weiss, M.J. and Schatz, B.G. (1995) Influence of tillage strategies, planting dates, and oil-seed crucifers on flea beetle populations (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 127, 289–293.
- Nguyen, B.K., Saegerman, C., Pirard, C., Mignon, J., Widart, J., Thirionet, B., Verheggen, F.J., Berkvens, D., De Pauw, E. and Haubruge, E. (2009) Does imidacloprid seed-treated maize have an impact on honey bee mortality? *Journal of Economic Entomology* 102, 616–623.
- Pachagounder, P. and Lamb, R.J. (1998) Feeding preference of a flea beetle, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) among wild crucifers. *The Canadian Entomologist* 130, 241–242.
- Pachagounder, P., Lamb, R.J. and Bodnaryk, R.P. (1998) Resistance to the flea beetle, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae), in false flax *Camelina sativa* (Brassicaceae). *The Canadian Entomologist* 130, 235–240.
- Palaniswamy, P. and Bodnaryk, R.P. (1994) A wild *Brassica* from Italy provides trichome resistance against flea beetles. *The Canadian Entomologist* 126, 1119–1120.
- Palaniswamy, P. and Lamb, R.J. (1992) Host preference of the flea beetles, *Phyllotreta cruciferae* and *P. striolata* (Coleoptera: Chrysomelidae), for crucifer seedlings. *Journal of Economic Entomology* 85, 743–752.

- Palaniswamy, P., Lamb, R.J. and McVetty, P.B.E. (1992) Screening for antixenosis resistance to flea beetles, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae), in rapeseed and related crucifers. *The Canadian Entomologist* 124, 895–906.
- Pedigo, L.P. and Rice, M.E. (2009) *Entomology and Pest Management*, 6th edn. Waveland Press, Inc., Long Grove, Illinois.
- Pimentel, D. (2005) Environmental and economic costs of the application of pesticides primarily in the United States. *Environment, Development and Sustainability* 7, 229–252.
- Pivnick, K.A., Lamb, R.J. and Reed, D. (1992) Response of flea beetles, *Phyllotreta* spp., to mustard oils and nitriles in field trapping experiments. *Journal of Chemical Ecology* 18, 863–873.
- Putnam, L.G. (1977) Response of four *Brassica* seed crop species to attack by the crucifer flea beetle, *Phyllotreta cruciferae*. *Canadian Journal of Plant Science* 57, 987–989.
- Reddy, G.V.P., Tangtrakulwanich, K., Wu, S., Miller, J.H., Ophus, V.L. and Prewett, J. (2014) Sustainable management tactics for control of *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) on canola in Montana. *Journal of Economic Entomology* 107, 661–666.
- Rousseau, M. and LeSage, L. (2016) Earliest North American occurrence of *Phyllotreta striolata* (Coleoptera: Chrysomelidae) from Québec, Canada. *The Canadian Entomologist* 148, 476–478.
- Schmuck, R.O. (2004) Effects of a chronic dietary exposure of the honey bees *Apis mellifera* (Hymenoptera: Apidae) to imidacloprid. *Archives of Environmental Contamination and Toxicology* 47, 471–478.
- Schmuck, R., Schoening, R., Stork, A. and Schramel, O. (2001) Risk posed to honey bees *Apis mellifera* (Hymenoptera: Apidae) by an imidacloprid seed dressing of sunflowers. *Pest Management Science* 57, 225–238.
- Soroka, J. and Grenkow, L. (2013) Susceptibility of brassicaceous plants to feeding by flea beetles, *Phyllotreta* spp. (Coleoptera: Chrysomelidae). *Journal of Economic Entomology* 106, 2557–2567.
- Soroka, J.J., Bartelt, R.J., Zilkowski, B.W. and Cossé, A.A. (2005) Response of flea beetles, *Phyllotreta cruciferae* in the field to synthetic aggregation pheromone components and plant host volatiles. *Journal of Chemical Ecology* 31, 1829–1843.
- Soroka, J.J., Grenkow, L.F. and Irvine, R.B. (2008) Impact of decreasing ratios of insecticide-treated seed on flea beetle (Coleoptera: Chrysomelidae, *Phyllotreta* spp.) feeding levels and canola seed yields. *Journal of Economic Entomology* 101, 1811–1820.
- Soroka, J.J., Holowachuk, J.M., Gruber, M.Y. and Grenkow, L.F. (2011) Feeding by flea beetles (Coleoptera: Chrysomelidae, *Phyllotreta* spp.) is decreased on canola (*Brassica napus*) seedlings with increased trichome density. *Journal of Economic Entomology* 104, 125–136.
- Suchail, S., Guez, D. and Belzunces, L.P. (2001) Discrepancy between acute and chronic toxicity induced by imidacloprid and its metabolites in *Apis mellifera*. *Environmental Toxicology and Chemistry* 20, 2482–2486.
- Tangtrakulwanich, K., Reddy, G.V.P., Wu, S., Miller, J.H., Ophus, V.L. and Prewett, J. (2014) Developing nominal threshold for *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) damage on canola in Montana, USA. *Crop Protection* 66, 8–13.
- Tansey, J.A., Dossdall, L.M., Keddie, B.A. and Sarfraz, R.M. (2008) Differences in *Phyllotreta cruciferae* and *Phyllotreta striolata* (Coleoptera: Chrysomelidae) response to neonicotinoid seed treatments. *Journal of Economic Entomology* 10, 159–167.
- Tansey, J.A., Dossdall, L.M. and Keddie, B.A. (2009) *Phyllotreta cruciferae* and *Phyllotreta striolata* response to insecticidal seed treatments with different modes of action. *Journal of Applied Entomology* 133, 201–209.
- Toth, M., Csonka, E., Bartelt, R.J., Cosse, A.A., Zilkowski, B.W., Muto, S.-E. and Mori, K. (2005) Pheromonal activity of compounds identified from male *Phyllotreta cruciferae*: field tests of racemic mixtures, pure enantiomers, and combination with allyl isothiocyanate. *Journal of Chemical Ecology* 31, 2705–2720.
- Thomas, P. (2003) *Canola Growers Manual*. Canola Council of Canada, Winnipeg, Manitoba, Canada.
- Thomas, W.C. (1986) Predation on adult *Phyllotreta striolata* (F.) flea beetles by *Podisus maculiventris* (Heteroptera: Pentatomidae) and *Nabicula americalimbata* (Hemiptera: Nabidae). *The Canadian Entomologist* 118, 731–732.
- Turnock, W.J. and Lamb, R.J. (1982) Protecting canola from flea beetle injury. *Canadian Agriculture* 27, 4–8.
- Turnock, W.J., Lamb, R.J. and Bilodeau, R.J. (1987) Abundance, winter survival, and spring emergence of flea beetles (Coleoptera: Chrysomelidae) in a Manitoba grove. *The Canadian Entomologist* 119, 419–426.
- Ulmer, B.J. and Dossdall, L.M. (2006) Emergence of overwintered and new generation adults of the crucifer flea beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae). *Crop Protection* 25, 23–30.
- Vincent, C. and Stewart, R.K. (1984) Effect of allyl isothiocyanate on field behavior of crucifer-feeding flea beetles (Coleoptera: Chrysomelidae). *Journal of Chemical Ecology* 10, 33–39.
- Vincent, C. and Stewart, R.K. (1985) Influence of trap color on captures of adult crucifer-feeding flea beetles. *Journal of Agricultural Entomology* 3, 120–124.
- Weiss, M.J., McLeod, P., Schatz, B.G. and Hanson, B.K. (1991) Potential for insecticidal management of flea beetle (Coleoptera: Chrysomelidae) on canola. *Journal of Economic Entomology* 84, 1597–1603.

- Weiss, M.J., Schatz, B.G., Gardner, J.C. and Nead, B.A. (1994) Flea beetle (Coleoptera: Chrysomelidae) populations and crop yield in field pea and oilseed rape intercrops. *Environmental Entomology* 23, 654–658.
- Westdal, P.H. and Romanow, W. (1972) Observation on distribution, seasonal life history, and abundance of flea beetles (Coleoptera: Chrysomelidae). *Manitoba Entomologist* 6, 35–45.
- Wylie, H.G. (1979) Observations on distribution, seasonal life history, and abundance of flea beetles (Coleoptera: Chrysomelidae) that infest rape crops in Manitoba. *The Canadian Entomologist* 111, 1345–1353.
- Wylie, H.G. (1982) An effect of parasitism by *Microctonus vittatae* (Hymenoptera: Braconidae) on emergence of *Phyllotreta cruciferae* and *Phyllotreta striolata* (Coleoptera: Chrysomelidae) from overwintering sites. *The Canadian Entomologist* 114, 727–732.
- Wylie, H.G. (1983) Oviposition and survival of the European parasite *Microctonus bicolor* (Hymenoptera: Braconidae) in crucifer-infesting flea beetles (Coleoptera: Chrysomelidae) in Manitoba. *The Canadian Entomologist* 115, 55–58.
- Wylie, H.G. (1984) Oviposition and survival of three Nearctic euphorine braconids in crucifer-infesting flea beetle (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 116, 1–4.
- Wylie, H.G. (1988) Release in Manitoba, Canada of *Townesilitus bicolor* [Hym.: Braconidae], an European parasite of *Phyllotreta* spp. [Col.: Chrysomelidae]. *Entomophaga* 33, 25–32.
- Wylie, H.G. and Loan, C. (1984) Five Nearctic and one introduced euphorine species (Hymenoptera: Braconidae) that parasitize adults of crucifer-infesting flea beetles (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 116, 235–246.
- Xu, C., de Clercq, P., Moens, M., Chen, S. and Han, R. (2010) Efficacy of entomopathogenic nematodes (Rhabditida: Steinernematidae and Heterorhabditidae) against striped flea beetle, *Phyllotreta striolata* (Coleoptera: Chrysomelidae). *BioControl* 55, 789–797.
- Yan, X., Han, R., Moens, M., Chen, S. and de Clercq, P. (2013) Field evaluation of entomopathogenic nematodes for biological control of striped flea beetle, *Phyllotreta striolata* (Coleoptera: Chrysomelidae). *BioControl* 58, 247–256.
- Zhao, Y., Yang, G., Wang-Pruski, G. and You, M. (2008) Arginine kinase cloning and RNAi-based pest control. *European Journal of Entomology* 105, 815–822.