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Coping with Root Maggots in Prairie Canola Crops

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Summary
Crucifer root-feeding maggots occur in field *Brassica* crops across the prairies, causing the greatest damage to canola fields in central and northern Alberta. No chemical options are available for their control in canola. Seed treatments currently utilized for flea beetle control are not efficacious against root maggots, and flies emerge over extended periods, making application of insecticide sprays impractical. Biological and cultural practices are the primary methods of root maggot management in canola. Fall cultivation, the use of vigorous canola cultivars, increased seeding rates, wider row spacings, and suitable fertilization regimes will aid in diminishing root maggot damage. Because natural enemies are an important means of root maggot control, research is needed into co-ordinating cultural management practices with biological control strategies for maximum effectiveness of both strategies and a truly integrated crop management approach to maggot control.

Species Composition and Host Range
The crucifer-feeding *Delia* root maggot complex that attacks canola on the prairies comprises five species. Cabbage maggot *D. radicum* (L.), turnip maggot *D. floralis* (Fall.), and seedcorn maggot *D. platura* (Meig.), are frequently encountered, while bean seed maggot *D. florilega* (Zett.) and *D. planipalpis* (Stein) occur in fewer numbers. *D. floralis* is prevalent in northern areas of Alberta and Saskatchewan, with *D. radicum* more southerly in distribution[1,2,3]. Mixtures of the two species occur in canola, depending on location and year (Table 1), although in Scandinavia co-occurrence is rare[4]. In Manitoba, *D. radicum* is the principal root-feeding *Delia* species in canola[5].

Delia radicum, *D. floralis*, and *D. planipalpis* are primary pests feeding on a wide range of crucifers[3]. *D. radicum* prefers cabbage as a principal host, while *D. floralis* prefers swede turnips, preferences that reflect their common names, although both species readily attack canola and other field *Brassica* crops as well as a variety of vegetable crucifers. As their common names suggest, seed corn maggot *D. platura* and bean seed maggot *D. florilega* are primary pests of seedlings of many crops, including legumes, cereals, cucurbits, lettuce and carrot[6], but not canola seedlings. They often occur together, laying their eggs near rotting vegetative material[7]. They are usually secondary invaders of developing canola, attacking roots previously damaged by primary pests[8,6], although primary infestation of these two species has been recorded on radish (*Raphanus sativus* L.) roots[9]. *D. platura* feeds on the roots of a broad range of hosts, including crucifers, onions and leeks, solanacious crops, cucurbits and cereal crops such as corn[6]. *D. florilega* maggots feed on potato, spinach, and other garden crops as well as crucifers[6]. Cabbage maggot flies are nectar feeders on a variety of plants[10].

Table 1. Crucifer-feeding root maggot species composition in different years, locations, and host plants in western Canada as collected in yellow water pan traps.

				% *Delia* species[1]				
Year	Location	Duration	Host	*rad*	*flora*	*plan*	*plat*	*flor*
1997	Creston, BC	season	canola fields	100				
1997	Saskatoon, SK	season	vegetable plots	84		12	3	
1998	Melfort, SK	July	canola plots	7	3		86	1
1999	Lethbridge, AB	July	canola plots		3		91	6
1999	Melfort, SK	Aug 4-11	canola plots	74			26	
1999	Saskatoon, SK	Aug 4-11	vegetable plots	88			12	
1999	Saskatoon, SK	Aug 4-11	canola plots	68			23	9

[1]*rad= Delia radicum* (L.), *flora= D. floralis* (Fall.), *plan= D. planipalpis* (Stein), *plat= D. platura* (Meig.), and *flor= D. florilega* (Zett.)

Biology and Damage

Delia spp. overwinter in cigar-shaped tobacco-coloured puparia five to 20 cm below the soil surface[10]. Adults emerge from mid-May to mid-July[12]; shortly after emergence flies mate and females lay eggs, singly or in batches of up to 25-30, near the base of host plants (Figure 1), usually in cracks or under a thin layer of soil[3]. Each female can lay 50-200 oval white eggs during a 5-6 week oviposition period[13]. The eggs hatch in 3-10 days and the white legless maggots burrow into the soil to feed on root hairs and on secondary roots. Developing through three instars, older maggots tunnel into the taproot of the plant (Figure 1). Maggots feed for 3-4 weeks and pupariate in the taproot or in the soil nearby. Pupation lasts 2-3 weeks or the winter, depending on voltinism[14,2]. Root maggots have one or two complete generations per year in canola, depending on species, geographic latitude and local conditions[2,15]. *D. radicum* and *D. floralis* are univoltine and *D. platura* is bivoltine in canola in central Alberta[2,12], but there are two peak periods of activity by *D. radicum* in canola in Manitoba[5]. When multiple generations occur they usually overlap, so that adult flies can be present in crucifer fields from late spring to October[16].

Figure 1. Eggs, adult, and larvae of cabbage root maggot, *Delia radicum* (L.). Photo credit:

Delia spp. maggots are principally root feeders, although they occasionally burrow into crucifer stems (JJS, pers. obs.) In canola, severe maggot infestations can cause plant wilting, stunting, and reduced flowering, decreased seed weight and lower seed yields[17,18]. If feeding tunnels are extensive and girdle the root, plant lodging and death can occur. Roots damaged by *Delia* spp. are more susceptible to invasion by root pathogens such as *Fusarium* than intact roots[17]. Yield reductions from root maggot damage of 50 and 19% for crops of *Brassica rapa* L. and *B. napus* L., respectively, have been reported[17].

In a four year survey of nearly 3000 canola fields across western Canada, the greatest degree of damage over the largest area was found in central, western and north western Alberta, although localized areas with severely damaged roots occurred along the northern edge of the entire Parkland ecoregion[19] (Figure 2). As well as ecoregion, soil type can play a part in degree of root maggot infestation of canola. Dosdall et al. (1998b) [20] found that the highest infestation rates in canola roots by maggots in Alberta occur in areas of black chernozemic soils, with plants in lighter soils receiving less root damage. On the other hand, Philip and Mengerson (1989)[16] suggest that, in general, maggot damage is more severe to plants grown in light soils than in heavy soils, and Turnock et al. (1992)[5] found that soil texture is not a significant factor in canola root damage levels in Manitoba.

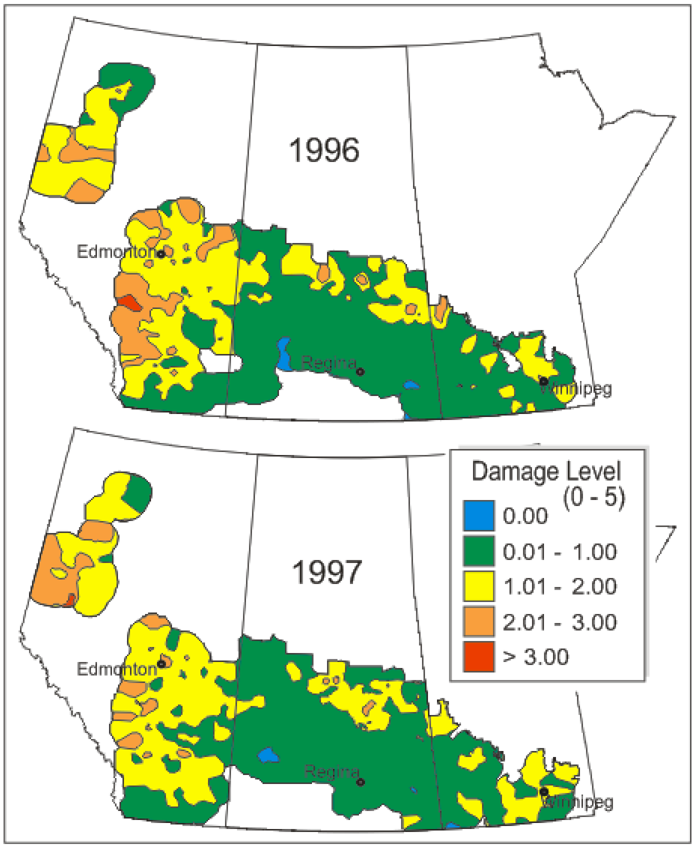

Figure 2. Damage level on a scale of 0 (no damage) to 5 (root completely severed) for canola, *Brassica rapa* and *B. napus* roots infested with root maggots, *Delia* spp., across the prairies 1996-97. (There were no fields with average damage at levels 4 or 5). (modified from Soroka et al. 2004. Can. J. Plant Sci. 84:1176).

Seasonal weather affects *Delia* population densities. In Alberta canola root damage from root maggots is positively correlated with rainfall received during the growing season[1,17,20]. Similarly, infestation rates in Manitoba have been correlated with average daily air temperature and total precipitation for June and July[5]. Soroka et al. (2004)[19] found that the severity of maggot infestation is decreased if the previous summer was warm and dry.

Control

Biological – Natural enemies arguably provide the greatest control of root maggot populations in prairie canola. Predators attack all stages of *Delia* spp. development. Carabid beetles prey upon *Delia* eggs, maggots, and puparia[21]. Nematodes in the genera *Heterorhabdites* and *Steinernema* prey upon *Delia* spp. Larvae[22]. The staphylinid beetle *Aleochara bilineata* Gyll. is both a predator and parasitoid, and may be the most important natural enemy of root maggots in Canada. Adults prey upon *Delia* spp. eggs and larvae; Read (1962)[23] recorded that more than 1200 *Delia* eggs and 120 larvae were consumed over the life of a pair of these staphylinid beetles. Larval *A. bilineata* invade *Delia* puparia, parasitizing and eventually consuming the pupae within. When the life cycle of *Aleochara* is in synchrony with its *Delia* hosts, rates of parasitism of *Delia* puparia of up to 95% have been recorded in the field[23,24,26,25]. The figitid wasp *Tribliographa rapae* Westwood parasitizes *Delia* spp. larvae at rates of up to 30% [26]. In a two year field study Hummel et al. (2010)[27] found that average parasitism by all parasitoids of *D. radicum* puparia collected from canola field plots near Edmonton, AB, ranged from 61-87%. *A. bilineata* larval parasitism is not totally synchronized with *D. radicum* maggot populations later in the season at all prairie locations [26]. Studies are underway to examine the feasibility of introduction of a European staphylinid species, *A. bipustulata* L., as an additional mortality factor to enhance the effectiveness of *Aleochara* control of root maggot populations throughout the summer[28,26,29,30].

Several species of entomopathogens, including the fungi *Entomophthora muscae* (Cohn) Fesenius and *Strongwellsea castrans* Batko and Weiser[31,32] and the bacterium *Bacillus thuringiensis* Berliner[33] exert some control of *Delia* spp. populations. A commercial formulation of *Metarhizium anisopliae* (Metsch.) Sorokin, a soil-dwelling fungus that is pathogenic to specific host insects, recently received Canadian registration for control of root weevil species[34]. The fungus holds promise for control of *D. radicum* and other soil-dwelling pest insects (T. Kabaluk, pers. comm.). However, because the reproduction of *Metarhizium* conidiospores is reliant upon infection of a suitable host under conditions of high humidity, use of the pathogen for root maggot control in prairie canola fields will depend on discovery of the most efficacious fungal strain and appropriate application techniques.

Chemical – At present there are no insecticides registered for root maggot control in canola in Canada. Seed treatments currently used for flea beetle control do not appear to last long enough for effective control of maggots[35]. In cruciferous vegetable crops repeated applications of insecticidal drenches provide some control, but the protracted emergence of the fly makes season-long control difficult. In Germany producers are utilizing a new seed treatment from Bayer CropScience containing the insecticides clothianidin and betacyfluthrin as a means of managing *Delia* spp. during oilseed rape establishment in the fall[36].

Cultural – Because there are no registered insecticides for root maggot control in canola crops in Canada, cultural measures to decrease maggot damage are of primary importance. Cultivar selection is an important first step for root maggot management in districts prone to severe maggot infestations. *Brassica rapa* cultivars are more susceptible to root maggot injury than are *B. napus* and *B. juncea* (L.) Czern. (brown mustard) entries, with *Sinapis alba* L. (yellow mustard) cultivars least damaged in choice tests[37].

Increased seeding rates, with concomitant increases in plant density, reduce root maggot infestations[38] (Dosdall et al. 1996a). There is a negative correlation between canola plant density and basal stem diameter, and a positive one between root diameter and root maggot damage[39,38,40]. Plants with large basal stems are preferred for oviposition and larval feeding of root maggots[38,41]. Unlike the situation with flea beetles, where canola seed size has a direct impact on levels of seedling damage[42], planting large-sized seed does not affect the subsequent level of damage to canola roots by maggots[40]. By the time flies are actively seeking host plants other agronomic and environmental factors likely influence plant size more than the size of the sown seed.

Root maggot female flies prefer to oviposit near older, larger plants[14]. Therefore, delaying seeding may help in mitigating maggot damage. Root maggot infestation was decreased in Alberta canola fields seeded in late May compared to ones seeded in early or mid-May[38]. However, because of the detriment to seed yields, late seeding is not a recommended canola production practice.

Wider row spacings can decrease root maggot damage levels to canola. Dosdall et al. (1998a) [41] found that canola grown at spacings of 20 and 30 cm had less root damage and higher yields than canola grown at 10 cm row spacings.

Tillage, or the lack of it, can also influence root maggot damage to canola. Root maggot egg numbers and canola root injury are greater under zero-till systems than under conventional tillage[43,41], in part because the increased soil moisture levels in zero till fields are conducive to root maggot abundance. Cultivation prior to seeding may reduce emergence of adult flies from overwintering puparia[44,43]. Despite higher numbers of maggots under zero tillage, yields in zero till fields usually exceed those under conventional till, and benefits of practicing zero till usually outnumber the drawbacks. In regions of high root maggot populations, fall cultivation could be used to decrease subsequent root maggot damage without sacrificing all of the benefits of no tillage in the next spring. However, erosion concerns with fall tillage may not be compatible with optimal crop management.

Soil fertility can have varying effects on root maggots. Addition of sulphur alone in either elemental or ammonium sulphate form did not consistently decrease root maggot oviposition or root damage[45], and is not recommended as a maggot management method. Increasing levels of all four principal soil nutrients from 0.5 to 2.0 times the recommended rate had no effect on egg deposition but actually increased degree of root damage by the maggots[46], suggesting that the maggots performed better on plants growing vigorously than on stressed plants. However, vigorously growing plants were able to better compensate for maggot damage than were plants receiving less fertilizer, and seed yields also increased. Therefore, adequate fertilization for optimum crop health is important for many reasons, including increasing the ability of plants to compensate for damage by root maggots.

Female root maggot flies go through an elaborate sequence of behavioural activities in host selection prior to oviposition, and contact with a non-host plant causes the flies to restart the selection process from the beginning[47]. Therefore, increasing vegetation diversity by intercropping or delayed weed control could decrease the number of maggot eggs laid in a canola field. Hummel et al. (2009a, 2009b) [35,48] found that increased proportions of wheat in intercrops of wheat and canola reduced maggot damage to canola taproots, but did not reduce adult fly or egg abundance. Broatch et al. (2008a) [49] manipulated populations of monocotyledonous weeds in herbicide-tolerant canola and found that root maggot damage decreased with increases in weed dry weight. Delaying weed control from the two to the four leaf stage, if not agronomically detrimental to the crop, may minimize opportunities for females of *Delia* spp. to complete the behavioural sequence required for oviposition and result in fewer eggs laid[50].

Host Plant Resistance

Species and cultivars of canola and mustards vary in their susceptibility to root maggot infestation[37]. Intergeneric crosses between *S. alba*, which has a high degree of resistance to the maggot, and *B. napus* resulted in lines with heritable resistance at levels similar to those of *S. alba* [51,52]. Substantial progress has been made in developing *Brassica* germplasm resistant to root maggot injury[53], but it may be some time until canola cultivars with resistance to crucifer-feeding root maggots will be available commercially. Canola, especially *B. napus*, has a tremendous ability to compensate for root damage [46]. Producers can capture this ability by growing vigorous canola cultivars and implementing cultural practices that encourage healthy crops and that discourage root maggot infestation.

Increases in the area devoted to the production of canola in western Canada since the 1970s have been accompanied by increased abundance levels of several insect pests, including root maggots. The focus on increasing canola production in future years ensures that this insect pest complex will continue to pose a serious threat to sustainable production of the crop across the prairies, and especially in the Aspen Parkland and Peace River regions of western Canada. Over the past 20 years, research to identify strategies for minimizing root maggot damage has proceeded along several fronts, and has resulted in a number of recommendations that can be applied by canola producers. Among these, selecting the least susceptible canola varieties, seeding at recommended rates and with relatively wide row spacings, and applying recommended levels of fertilizer can combine to provide a competitive advantage to the crop and facilitate plant compensation for insect attack. Recent research investigating the influence of increases in crop diversity on root maggots and their natural enemies, and studies on the biology of *A. bilineata*, the most important natural enemy of these pests, has shown promise. Further research is needed to identify cropping practices that best enhance populations of *A. bilineata* and other natural enemies. If research to develop root maggot-resistant canola is successful, an additional new tool would be added to manage root maggot infestations.

References

1. Griffiths, G.C.D. 1986a. Relative abundance of *Delia floralis* (Fallén) and *D. radicum* (L.) (Diptera: Anthomyiidae) infesting canola in Alberta. Quaest. Entomol. 22:23-26.
2. Griffiths, G.C.D. 1986b. Phenology and dispersion of *Delia radicum* (L.) (Diptera: Anthomyiidae) in canola fields at Morinville, Alberta. Quaest. Entomol. 22:29-50.
3. Griffiths, G.C.D. 1991a. Cyclorrhapha II (Schizophora: Calyptratae) Part 2, Anthomyiidae. In Griffiths G. C. D., ed. Flies of the Nearctic Region. Volume VIII. Stuttgart, Germany: Schweizerbart'sche Verlagsbuchhandlung, 8(2/7):953-1048.
4. Darvas, B and Szappanos, A. 2003. Male and female morphology of some central European *Delia* (Anthomyiidae) pests. Acta Zool. Hung. 49:88-101.
5. Turnock, W.J., Timlick, B., Galka, B.E., and Palaniswamy, P. 1992. Root maggot damage to canola and the distribution of *Delia* spp. (Diptera: Anthomyiidae) in Manitoba. Can. Entomol. 124:49-58.
6. Griffiths, G.C.D. 1993. Cyclorrhapha II (Schizophora: Calyptratae). Part 2, Anthomyiidae. In Griffiths, G.C.D., ed. Flies of the Nearctic Region. Volume VIII. Stuttgart, Germany: Schweizerbart'sche Verlagsbuchhandlung, 8(2/10)1417-1632.
7. Hill, D. S. 1987. Agricultural Insect Pests of Temperate Regions and Their Control. Cambridge University Press, Cambridge, U.K. 659 pp.
8. Read, D.C. 1958. Factors influencing infestation and injury of rutabagas by root maggots (*Delia*: Anthomyiidae) in Prince Edward Island. I. Field studies. Can. J. Plant Sci. 38: 188-198.
9. Nair, K.S.S. and McEwen, F.L. 1973. The seed maggot complex, *Hylemya* (*Delia*) *platura* and *H.* (*D.*) *litura* (Diptera: Anthomyiidae), as primary pests of radish. Can. Entomol. 105:445-447.
10. Miles, M. 1952. Studies of British anthomyiid flies. III. Immature stages of *Delia cilicrura* (Rond.), *D. trichodactyla* (Rond.), *Erioishia brassicae* (Bouché), *E. floralis* (Fall.) and *Pegohylemyia fugax* (Mg.). Bull. Entomol. Res. 43:83-90.
11. Rännbäck, L-M. 2008. Flower attractiveness and nectar accessibility for *Delia radicum* (Diptera: Anthomyiidae) with implications for the control by *Trybliographa rapae* (Hymenoptera: Figitidae). Master of Science thesis, Swedish University of Agricultural Sciences, Alnarp, Sweden.
12. Broatch, J.S., Dosdall, L.M., Clayton, G.W., Harker, K.N., and Yang, R-C. 2006. Using degree-day and logistic models to predict emergence patterns and seasonal flights of the cabbage maggot and seed corn maggot (Diptera: Anthomyiidae). Env. Entomol. 35: 1166-1177.
13. Nair, K.S.S. and McEwen, F.L. 1975. Ecology of the cabbage maggot, *Hylemya brassicae* (Diptera: Anthomyiidae), in rutabaga in southwestern Ontario, with some observations on other root maggots. Can. Entomol. 107:343-354.
14. McDonald, R. S. and Sears, M.K. 1992. Assessment of larval feeding damage of the cabbage maggot (Diptera: Anthomyiidae) in relation to oviposition preference in canola. J. Econ. Entomol. 85:957-962.
15. Bracken, G. K., 1988. Seasonal occurrence and infestation potential of cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae), attacking rutabaga in Manitoba as determined by captures of females in water traps. Can. Entomol. 120:609-614.
16. Philip, H. and Mengerson, E.1989. Insect Pests of the Prairies. University of Alberta. Edmonton, Alberta. 122 pp.
17. Griffiths, G.C.D. 1991b. Economic assessment of cabbage maggot damage in canola in Alberta. pp 528-535 In McGregor, D.I., ed. Proceedings, GCIRC Eighth International Rapeseed Congress. Saskatoon, SK, Canada.

18. McDonald, R. S. and Sears, M.K. 1991. Effects of root damage by cabbage maggot, *Delia radicum* (L.), (Diptera: Anthomyiidae), on yield of canola, *Brassica campestris* L., under laboratory conditions. Can. Entomol. 123:861-867.
19. Soroka, J.J., Dosdall, L.M., Olfert, O.O. and Seidle, E. 2004. Root maggots (*Delia* spp., Diptera: Anthomyiidae) in prairie canola (*Brassica napus* L. and *B. rapa* L.): spatial and temporal surveys of root damage and prediction of damage levels. Can. J. Plant Sci. 84:1171–1182.
20. Dosdall, L.M., Soroka, J. and O. Olfert. 1998b. Incidence and yield impact of root maggots in canola. Technical Report, Alberta Agricultural Research Institute, Project Number 96M980.
21. Wishart, G., J. F. Doane, and G. W. Maybee. 1956. Notes on beetles as predators of eggs of *Hylemya brassicae* (Bouche) (Diptera: Anthomyiidae). *Canadian Ent.* 88: 634-639.
22. Bracken, G. K. 1990. Susceptibility of first-instar cabbage maggot, *Delia radicum* (L.) (Anthomyiidae: Diptera), to strains of the entomogenous nematodes *Steinernema feltiae* Filipjev, *S. bibionis* (Bovien), *Heterorhabditis bacteriophora* Poinar, and *H. heliothidis* (Khan, Brooks and Hirschmann). Can. Entomol. 122:633-639.
23. Read, D.C. 1962. Notes on the life history of *Aleochara bilineata* (Gyll.) (Coleoptera: Staphylinidae), and on its potential value as a control agent for the cabbage maggot, *Hylemia brassicae* (Bouché) (Diptera: Anthomyiidae). Can. Entomol. 94:417-424.
24. Turnock, W.J., Boivin, G., and Whistlecraft, J.W. 1995. Parasitism of overwintering puparia of the cabbage maggot *Delia radicum* (L.) (Diptera: Anthomyiidae), in relation to host density and weather factors. Can. Entomol. 127:534-542.
25. Broatch, J.S., Dosdall, L.M., Yang, R.-C., Harker, K.N., and Clayton, G.W. 2008b. Emergence, and seasonal activity of the entomophagous rove beetle *Aleochara bilineata* (Coleoptera: Staphylinidae) in canola in western Canada. Environ. Entomol. 37:1451-1460.
26. Hemachandra, K.S., Holliday, N.J., Mason, P.G., Soroka, J.J., and Kuhlmann, U. 2007. Comparative assessment of the parasitoid community of *Delia radicum* in the Canadian prairies and Europe: a search for classical biological control agents. Biol. Control 43:85-94.
27. Hummel, J.D., Dosdall, L.M., Clayton, G.W., Harker, K.N., and O'Donavon, J.T. 2010. Responses of the parasitoids of *Delia radicum* (Diptera: Anthomyiidae) to the vegetational diversity of intercrops. Biol. Control 55:151-158.
28. Soroka, J.J., Kuhlmann, U., Floate, K.D., Whistlecraft, J., Holliday, N.J., and Boivin, G. 2002. *Delia radicum* (L.), Cabbage maggot (Diptera: Anthomyiidae). pp 99-104 In Mason, P.G. and Huber, J.T., eds. Biological Control Programmes in Canada 1981-2000. CABI Publishing.Wallingford, United Kingdom.
29. Andreassen, L., Kuhlmann, U., Mason, P.G. and Holliday, N.J. 2007. Classical biological control of the cabbage maggot, *Delia radicum* in Canadian canola: An analysis of research needs. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2:1-13.
30. Andreassen, L.D., Kuhlmann, U., Whistlecraft, J.W., Soroka, J.J., Mason, P.G., Akinremi, O.O., and Holliday, N.J. 2010. Spring emergence of Canadian *Delia radicum* (Diptera: Anthomyiidae) and synchronization with its natural enemy, *Aleochara bilineata* (Coleoptera: Staphylinidae). Can. Entomol. 142:234-249.
31. Griffiths, G.C.D. 1985. Field studies of *Delia radicum* (L.) as a pest of canola in northern Alberta. Farming for the Future Technical Report 82-0123 and 83-0150. Alberta Agriculture. Edmonton, Alberta. 48 pp.
32. Finch, S. 1989. Ecological considerations in the management of *Delia* pest species in vegetable crops. Ann. Rev. Ent. 34: 117-137.
33. Eilenberg, J., Damgaard, P.H., Hansen, B.M., Pedersen, J.C., Bresciani, J., and Larsson, R. 2000. Natural coprevalence of *Strongwellsea castrans*, *Cystosporogenes deliaradicae*, and *Bacillus thuringiensis* in the host *Delia radicum*. J. Invertebr. Pathol. 75:69–75.
34. Health Canada. 2010. Evaluation Report *Metarhizhium anisopliae* strain F52. ERC 2010-01. Heath Canada, Ottawa, On. 48 pp. http://dsp-psd.pwgsc.gc.ca/collection_2010/arla-pmra/H113-26-2010-1-eng.pdf accessed 09-12-2010
35. Hummel, J.D., Dosdall, L.M., Clayton, G.W., Turkington, Lupwayi, N.Z., Harker, K.N., and O'Donavon, J.T. 2009a. Canola – wheat intercrops for improved agronomic performance and integrated pest management. Agron. J. 101:1190-1197.
36. Parsons, C.K. 2006. Literature review and summary of personal communications. Cabbage maggot management and research around the world: a status report and development of IPM strategies for Canada. Project PRR06-690. Agriculture and Agri-Food Canada. Pest Management Centre. Pesticide Risk Reduction Strategies Initiative. Ottawa, Ontario. 52 pp.
37. Dosdall, L.M., Herbut, M. and Cowle, N.T. 1994. Susceptibilities of species and cultivars of canola and mustard to infestation by root maggots (*Delia* spp.) (Diptera: Anthomyiidae). Can. Entomol. 126:251-260.
38. Dosdall, L.M., Herbut, M.J., Cowle, N.T. and Micklich, T.M. 1996a.The effect of seeding date and plant density on infestations of root maggots, *Delia* spp. (Diptera: Anthomyiidae), in canola. Can. J. Plant Sci. 76:169–177.
39. Dosdall, LM., Herbut, M.J., Cowle, N.T. and Micklich, T.M. 1995. The effect of plant density on root maggot (*Delia* spp.) (Diptera: Anthomyiidae) infestations in canola. pp 1306–1308 in Proc. Ninth Int. Rapeseed Congr., 4–7 July 1995, Cambridge, United Kingdom. GCIRC. Paris, France.

40. Soroka, J.J. and Elliott, R.H. 2006. The effects of seed size and seeding rate on injury by root maggots (*Delia* spp., Diptera: Anthomyiidae) to canola (*Brassica rapa* L. and *B. napus* L.). Can J. Plant Sci. 86:907-909.
41. Dosdall, L.M., Florence, L.Z., Conway, P.M., and Cowle, N.T. 1998a. Tillage regime, row spacing, and seeding rate influence infestations of root maggots (*Delia* spp.) (Diptera: Anthomyiidae) in canola. Can. J. Plant Sci. 78:671-681.
42. 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. Can. J. Plant Sci. 88:207-217.
43. Dosdall, L.M., Herbut, M.J., Cowle, N.T. and Micklich, T.M. 1996b.The effect of tillage regime on emergence of root maggots (*Delia* spp.) (Diptera: Anthomyiidae) from canola. Can. Entomol. 128:1157–1165.
44. Finch, S. and Skinner, G. 1980. Mortality of overwintering pupae of the cabbage root fly (*Delia brassicae*). J. Appl. Ecol. 17:657-665.
45. Dosdall, L.M., Yang, R.C., and Conway, P.M. 2002. Do applications of sulfur or sulfate influence infestations of root maggots (*Delia* spp.) (Diptera: Anthomyiidae) in canola? Can. J. Plant Sci. 82:599-610.
46. Dosdall, L.M., Clayton, G.W., Harker, K.N., O'Donovan, J.T. and Stevenson, F. 2004. The effects of soil fertility and other agronomic factors on infestations of root maggots (*Delia* spp.) (Diptera: Anthomyiidae) in canola. Agron. J. 96:1306–1313.
47. Finch, S. and Collier, R.H. 2000. Host plant selection by insects – a theory based on 'appropriate/inappropriate landings' by pest insects of cruciferous plants. Entomol. Expl. Appl. 96:91-102.
48. Hummel, J.D., Dosdall, L.M., Clayton, G.W., Harker, K.N., and O'Donovan, J.T. 2009b. Effects of canola-wheat intercrops on *Delia* spp. (Diptera: Anthomyiidae) oviposition, larval feeding damage, and adult abundance. J. Econ. Entomol. 102:219-228.
49. Broatch, J.S., Dosdall, L.M., O'Donovan, J.T., Harker, K.N., and Clayton, G.W. 2008a. Herbicide rate effects on weed and root maggot dynamics in canola. Weed Sci.56: 477-483.
50. Dosdall, L.M., Clayton, G.W., Harker, K.N., O'Donovan, J.T. and Stevenson, F.C. 2003. Weed control and root maggots: making canola pest management strategies compatible. Weed Sci. 51:576–585.
51. Dosdall, L.M., Good, A., Keddie, B.A., Ekuere, U. and Stringam, G. 2000. Identification and evaluation of root maggot (*Delia* spp.) (Diptera: Anthomyiidae) resistance within Brassicaceae. Crop Prot. 19:247–253.
52. Ekuere, U.U., Dosdall, L.M., Hills, M., Keddie, B.A., Kott, L., and Good, A. 2005. Identification, mapping, and economic evaluation of QTLs encoding root maggot resistance in *Brassica*. Crop Sci. 43:371-378.
53. Kott, L.S. and Dosdall, L.M. 2004. Introgression of root maggot resistance (*Delia* spp.) derived from *Sinapis alba* L. into *Brassica napus* L. Brassica 6:55-62.