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Managing the Pea Leaf Weevil in Field Peas

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Summary
The pea leaf weevil is one of the few insect pests of field peas in southern Alberta and southwest Saskatchewan. Adults cause distinctive notching on seedlings which generally does not affect yield. Larval feeding on nitrogen-fixing root nodules may reduce yield if soil is nitrogen deficient. Only field peas and faba beans are at risk of damage. Other crops in the bean family may be fed on by adults but do not suffer significant damage from larvae. The economic threshold during the second to fifth node stages in field peas is 30% of seedlings with damage to the terminal (clam) leaf. Seed treated with thiamethoxam has produced more consistent yield responses than application of foliar insecticides but additional farm-level trials are required. Trap cropping the pea leaf weevil can be done by planting a border in the fall with winter peas or adjacent, earlier planting of a spring cultivar. Close monitoring of the trap crop is needed to control the weevils in the trap crop area before they move to the rest of the field. Fields under no tillage regimes suffer less damage than those under conventional tillage. Biological control is a research area that should be pursued for sustainable management of this pest.

Background
The pea leaf weevil, *Sitona lineatus* L. (Fig. 1), belongs to the most speciose insect order, the Coleoptera, and the most speciose beetle family, the Curculionidae. Although over 100 *Sitona* species occur worldwide, only 11 are found in North America and five of these were introduced[1]. The pea leaf weevil is a common pest of field peas, *Pisum sativum* L. and faba beans, *Vicia faba* L. (Fabales: Fabaceae) in its native Europe[2]. It was first collected on Vancouver Island in 1936[3]. Since then it has been reported in several states on both the east and west coast of the USA[1,4], southern Alberta in 1997 (R. J. Byers, personal communication) and Saskatchewan in 2007[5]. A detailed review of its history, biology and management has been described by Vankosky et al.[6]. In this review we focus on its local biology, summarize research on chemical and cultural management in the southern Canadian prairies and provide a short summary of key recent publications.

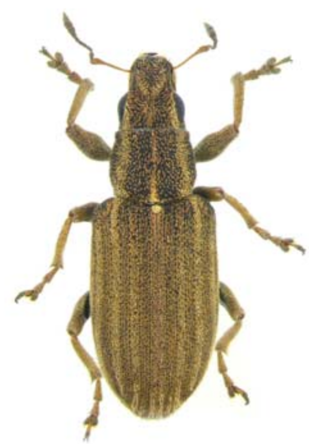

Figure 1: Adult pea leaf weevil showing alternating light and dark brown stripes extending from the thorax to the abdomen (H. Goulet, AAFC-Ottawa).

Morphology and Seasonal Biology

The morphology of all stages of the pea leaf weevil was described in detail by Jackson[7]. Further morphological details and development time of each stage in Europe and North America are summarized by Hoebeke and Wheeler[8]. In the Canadian prairies, pre-overwintering adults can be distinguished from related *Sitona*, such as the sweet clover weevil, by light and dark brown alternating stripes extending along the pronotum onto the base of the elytra (Fig. 1). Older adults which have lost the scales that form the stripes require examination under a microscope to confirm that the anterior procoxal cavities touch the narrow groove in front[1].

The following summary is based upon field and laboratory studies conducted in the Lethbridge area from 2007 to 2009[9]. Adults were collected in pea fields using pitfall traps or pan traps as early as mid-May in warm years such as 2007 and 2 to 3 wk later in cool years such as 2008 and 2009. Adults immediately fed on pea foliage (Fig. 2), mated and started laying eggs within a week. Peak egg densities occurred 2 to 3 wk after arrival and ranged from about 2000-20,000 eggs per square meter. Under laboratory conditions (16/20°C), eggs took 12 to 14 d to hatch. Larval densities peaked from late June to early July at 2000-5000 larvae per m^2 and declined each year by mid July. Pupal densities peaked from mid July to early August. Adults lay eggs over 3 months so all stages can be found simultaneously even though there is only one generation per year. New generation adults start emerging from the soil in late July, with peak emergence occurring in mid-August. Emergence continues until the host plant senesces. New generation adults do not mate but do feed on any green legume foliage before seeking sheltered leaf litter habitats for overwintering.

Figure 2: Damage to pea foliage by pea leaf weevil (Photo credit: H. Goulet, AAFC-Ottawa).

Host Damage and Nitrogen

Although pea leaf weevil adults have several legume hosts, reproductive potential and larval fitness are maximized on faba bean and field pea. An adult weevil consumes about 6 mm^2 of pea seedling foliage per day[10] (Landon et al., 1995). Feeding results in a characteristic scalloping on the leaf margins (Fig. 2)[7,11]. Under high infestations at the early seedling stage, feeding damage can severely reduce stand density[7]. However, plants can usually compensate for this damage so yield losses are minimal[12]. Larvae feed on root nodules that contain *Rhizobium leguminosarum* bacteria that fix atmospheric nitrogen (Fig. 3)[13].

Figure 3: Larva of pea leaf weevil on a *Rhizobium* root nodule of field peas (C. Herle, AAFC-Lethbridge).

The impact of pea leaf weevil on nitrogen fixation and uptake by field pea accounts for its pest status. Under controlled conditions, up to 98% of nodules were excavated[14]. In plots near Lethbridge in 2007 under extremely high weevil pressure (>100 notches/plant), over 90% of the nodules were damaged regardless of the crop stage when an insecticide was applied (Fig. 4). Depending on soil nitrogen levels, larval feeding had a greater impact on yield than adult feeding[15,16]. In faba beans, yield loss was due to fewer pods rather than fewer or lighter seeds per pod.

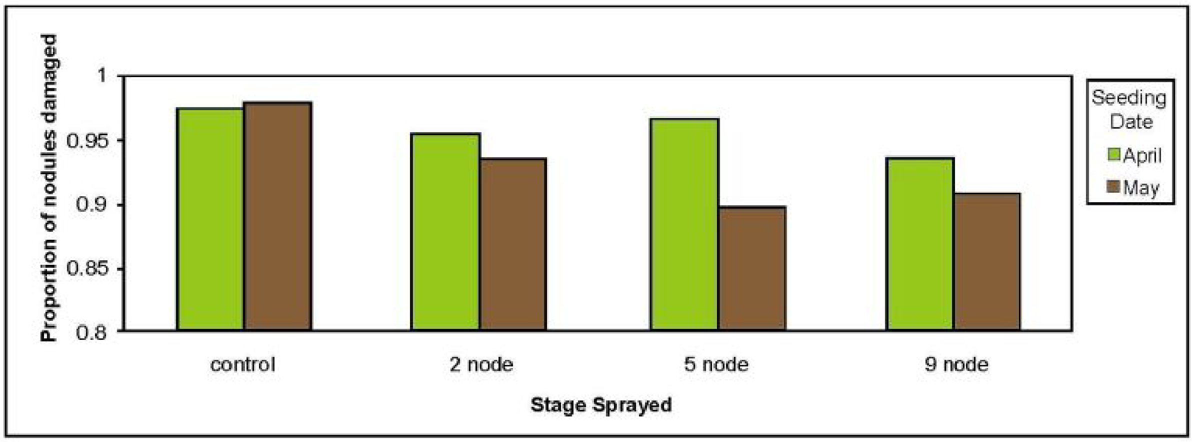

Figure 4: Proportion of field pea nodules destroyed by pea leaf weevil larvae near Lethbridge in early- and late-seeded plots in 2007.

Field plot and cage studies were conducted near Lethbridge and Vauxhall from 2007 to 2009 to validate economic thresholds and assess pea leaf weevil - field pea interactions with soil nitrogen[9,17]. El-Lafi[18] observed significant yield reductions when field pea stands had more than 30% of seedlings with terminal leaf damage. This threshold was validated in Alberta using field pea plots planted with or without thiamethoxam insecticide seed treatment. Plots that had less than 30% seedling damage before the 5th node stage, yielded at least 155 kg/ha more than those with 40% or more damage (Figure 5). Removing the insecticide-treated plots from the analysis did not affect results.

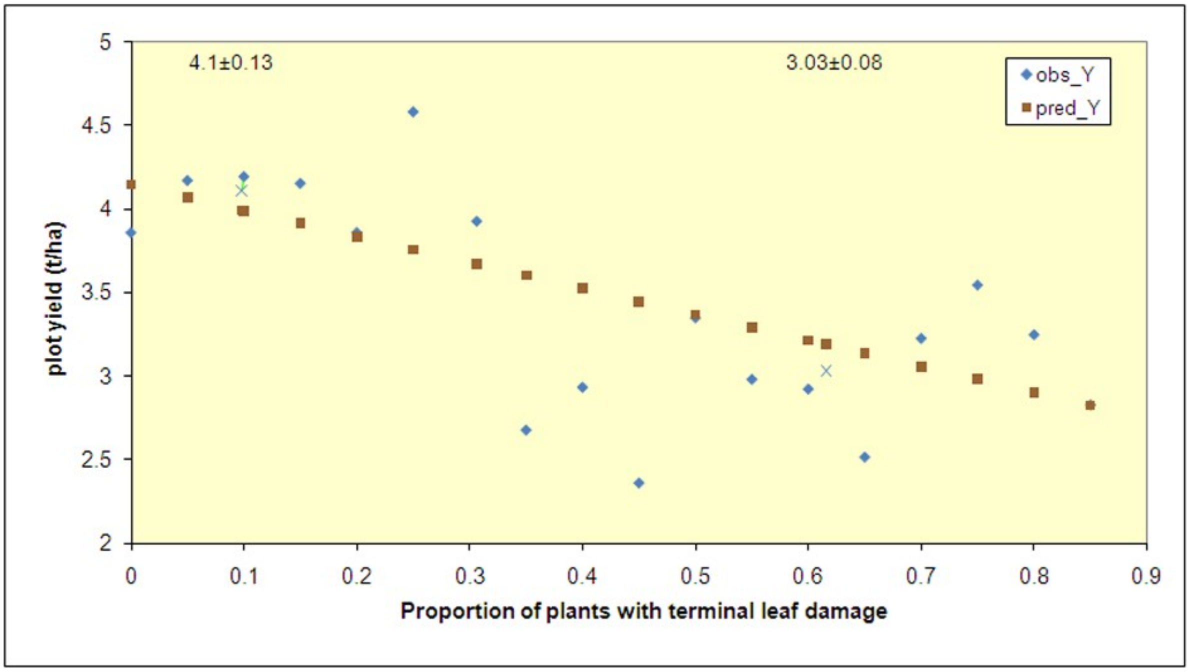

Figure 5: Observed mean pea yield in relation to proportion of plants with damage on terminal leaf (0.05 intervals). Predicted line from regression with plots with more than 1.2 t/ha or less than 6.9t/ha. Y = 4.145 – 1.553 (x). R^2 = 0.16, DF = 1, 140, p = 0.000. "X" symbol denotes average for all plots under or over economic threshold of 0.301, values and standard errors given above Xs. Mean yields difference between 0.30 and 0.40 damaged plots represents 155 kg/ha. There are no significant differences in yield among plots with proportion of seedlings with terminal leaf damage between 5 – 30 % (ANOVA, p>0.05) or those with damage between 30 – 85% (ANOVA, p>0.05).

Interactions with nitrogen were more subtle and no significant effects were observed in the field[19]. However, at the Lethbridge cage study site, plants growing in nitrogen-depleted soil experienced a greater yield loss (17%) than plants that were amended with urea (3% yield loss) (Fig. 6). A greenhouse study to further investigate the effects of larval feeding on plant and soil nitrogen also suggested that soil amendment with urea can buffer the negative effects of *S. lineatus* on plant nitrogen content and soil nitrogen (Cárcamo, Herle, and Lupwayi., unpublished data). Therefore, if soil nitrogen is sufficient, the pea leaf weevil poses less of a risk and control measures are not required.

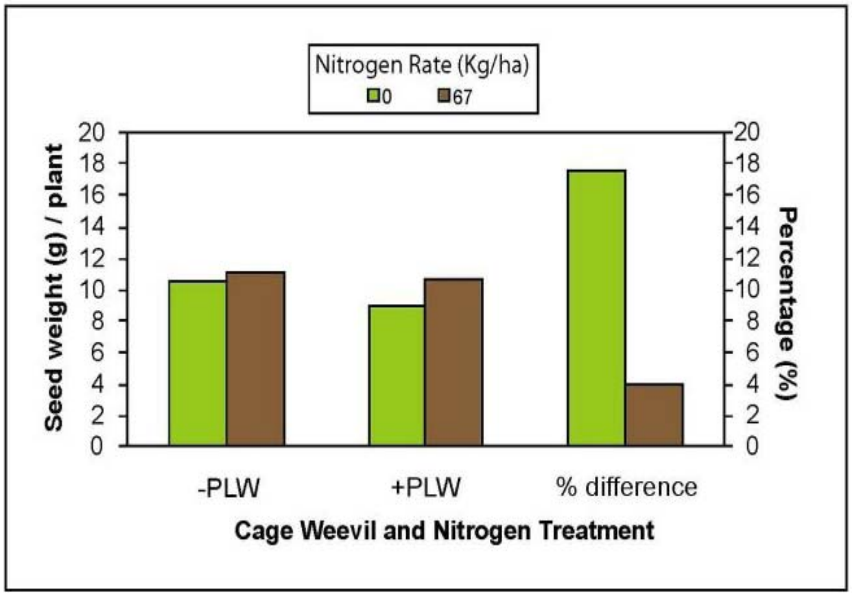

Figure 6: Effect of soil amendment with urea at 67 kg/ha on the ability of caged pea plants to tolerate feeding damage by pea leaf weevil. Entries are averages of cages 1 m^2 with 32 plants with 0.25. 0.50, or 1 pea leaf weevil (+PLW treatment, densities pooled) per plant or zero weevils (-PLW treatment).

Monitoring and Chemical Management

Adult pea leaf weevils are difficult to monitor because they drop to the ground when approached and their cryptic color makes them difficult to see against the soil. Despite these challenges a nominal threshold of 0.3 to 1 adult weevils per seedling has been recommended[20]. To count adults, the observer should sit quietly and still for a short time until weevils resume moving. During the warmest hours of the day, usually late morning to mid-afternoon, weevils are easily observed walking from plant to plant over the soil surface (Cárcamo, field observation). Species confirmation requires adult collection but threshold determination can be easily assessed by counting seedlings with terminal leaf feeding. At least 5 locations along the field margin and 5 locations approximately 100 m into the field should be selected to assess pea leaf weevil damage for threshold determination. At each location, a row of 10-20 seedlings should be selected and the terminal leaf on each seedling examined. If the average proportion of seedlings with terminal leaf damage at all spots exceeds 30% (i.e., more than 3 of 10 seedlings, or 6 out of 20), then the weevil poses a yield risk and warrants control. Field peas should be monitored from the second to fifth node growth stages. After the sixth node, plants are less vulnerable to both larval damage as shown in a greenhouse study (Cárcamo and Herle, unpublished data) and defoliation in a field study[12]. An aggregation pheromone has been used to monitor dispersal of pea leaf weevil, but trapped numbers could not be related to yield losses[21]. The pheromone monitoring system could be used to detect adult weevils in regions where it is expected to invade.

Managing the pea leaf weevil after damage reaches the economic thresholds is a challenge. Several foliar insecticides were tested in southern Alberta (Meers, unpublished data) from 2007 to 2010 but no yield benefits were observed. The same result was observed in plots near Lethbridge (Fig. 4) where a pyrethroid insecticide was applied at various crop stages to early- and late-seeded field peas[9]. Historically, products including permethrin, cypermethrin, carbosulfan, imidacloprid and cyhalothrin lambda have been tested against pea leaf weevil, with variable results when applied to the foliage (reviewed in [6]). An insecticide with a longer residual period is likely to be more effective given the protracted spring migration and invasion time of this pest over several weeks in the spring[22]. However, these products also pose a high risk to the environment and non-target natural enemies, hence, most have been de-registered.

Insecticides applied in-furrow at planting or seed coatings are generally more efficacious than foliar treatments[6,9] (Meers, unpublished data). Carbamates such as furathiocarb reduced larval damage and increased yield relative to untreated plots in Europe[23,24], but have been deregistered due to environmental concerns[6]. Imidacloprid, a neonicotinoid applied as a seed coating, reduced adult feeding by 50%[23]. In Alberta, another neonicotinoid seed treatment Cruiser® (thiamethoxam) was registered on an emergency basis and later received full registration against pea leaf weevil based on reduced foliar feeding by adults. A series of controlled studies[9] showed that thiamethoxam killed less than 30% of adults. Weevils that appeared to be dead recovered and resumed feeding within a few days, and foliar damage was reduced by about 50%. Furthermore thiamethoxam delayed oviposition by about one week, reduced oviposition during the critical crop stages (second to fifth node) by about 90% and killed approximately half of the larvae feeding on the nodules of treated plants. Field plot studies to assess yield responses to thiamethoxam, however, have produced inconsistent results[19] (Meers, unpublished data). As noted for other seed treatments, thiamethoxam may be effective at moderate weevil densities but further research at the commercial scale is needed.

In summary, to manage pea leaf weevil in the Canadian prairies, farmers should determine their relative risk from the distribution map (available at: http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/prm12934/$FILE/plw2009.pdf), and use local information on weevil abundance. In regions of high risk, producers may consider using a seed treatment (consult provincial crop protection guide for latest registered products) when soil nitrogen levels are low. Otherwise, growers can monitor their fields and if damage exceeds the economic threshold, they may apply a foliar insecticide between the third and fifth nodes to reduce weevil populations. If spring conditions are warmer than average, control action should be taken earlier, but if conditions are cool, control may not be needed as weevils will emerge and infest plants that are more advanced. If infestation occurs after the sixth node, plants are less vulnerable to foliar damage[12] or larval feeding on root nodules.

Alternative Agronomic Management Strategies

Alternative pea leaf weevil management strategies, suitable for use in an Integrated Pest Management program, have also been studied on the Canadian prairies. In Europe, trap crops have been investigated as a management strategy[25]. In Alberta, a two-year trap crop study was conducted near Lethbridge using winter peas as the trap crop (K. Coles, unpublished data, summarized in [9]). Austrian winter peas (Fig. 7) were planted in autumn around the perimeter of fields that were seeded with spring pea (main crop) the following spring. In 2007, weevil damage to pea seedlings was very high in the trap crop and was negligible in the spring peas before mid May. Delays in insecticide application to the trap crop, or extended weevil migration, led to significant damage in the main crop and the entire field had to be sprayed. Less damage was observed in winter pea (Whistler variety) trap crops in 2008, as was damage in the main crop. This was probably because cool, wet spring conditions delayed weevil emergence. These are only preliminary results; however, trap cropping has potential to manage the pea leaf weevil and merits further investigation.

Figure 7: Trap cropping pea leaf weevil, near Nobleford in southern Alberta, using Austrian winter peas along the perimeter and spring peas planted in the rest of the field. Photo credit: Héctor A. Cárcamo, AAFC, Lethbridge.

In addition to trap cropping, the impact of tillage regime on pea leaf weevil has recently been investigated in the United States. Evidence from several research projects indicate that migrating pea leaf weevil are more attracted to conventionally tilled plots relative to no-till plots and feeding damage by pea leaf weevil was significantly greater in conventional till than in no-till plots[26,27,28]. In conventional till plots, larvae developed faster and new generation adult emergence occurred earlier than in no-till plots, where larval development was delayed and larval survival to the adult stage was reduced[27]. The impact of tillage regime on the yield of field pea attacked by the pea leaf weevil has yet to be investigated. In addition to reducing pea leaf weevil density, no-till is expected to positively impact the natural enemies of the pea leaf weevil such as carabid beetles[29], which would add to the value of this cultural control tactic.

Biological Control

Biological control of pea leaf weevil has been more thoroughly investigated in Europe than in North America; a number of potential natural enemies have been identified (reviewed by[6]). Aeschlimann[2] reported that the parasitoid, *Microctonus aethiopoides* (Loan) (Hymenoptera: Braconidae) was an important natural enemy of *Sitona* weevils in the Mediterranean, and this species is being considered for the control of *S. lepidus* Gyllenhal (Coleoptera: Curculionidae) in New Zealand[30]. A similar parasitoid, *M. aethiops* Nees and two other braconid wasps, *Perilitus rutilus* (Nees) and *Pygostolus falcatus* (Nees) (Hymenoptera: Braconidae) and the fly, *Campogaster exigua* (Diptera: Tachinidae) were released in an attempt to control *S. cylindricollis* (Fahr), the sweet clover weevil, in Manitoba in the 1950s, but apparently did not become established[31]. The only other stage vulnerable to parasitoid attack is the egg stage. The mymarid wasp, *Patasson lameerei* Debauche may be a *Sitona* specialist[32] and was responsible for 95% of all attacks of eggs observed throughout southern Europe but the overall mortality from egg parasitism was generally low and rarely exceeded 20% in France[2]. Pea leaf weevil larvae are sheltered in root nodules, but may be preyed upon by several nematode species with variable effects on mortality[33,6]. Generalists predators such as ground beetles (Coleoptera: Carabidae) attack adult weevils, especially as they emerge from the soil[34]. Small carabid beetles in the genus *Bembidion* (e.g., *B. quadrimaculatum* L.) are well known predators of insect eggs and this species was a voracious predator of pea leaf weevil eggs under laboratory conditions[35]. *Bembidion quadrimaculatum* and other small ground beetle species are common in agroecosystems[36,35]. To better promote carabid beetle populations in field pea crops, the application of foliar insecticides should be avoided as much as possible. Alternatively, systemic insecticides employed as seed treatments are more compatible with biological control programs[37,38,39], although further investigation regarding the efficacy of systemic insecticides against pea leaf weevil is required.

Conclusions

The pea leaf weevil is well established in the southern prairies but it is unclear if it can expand northward where peas are grown extensively. Damage to field pea is more likely to occur in early planted fields if spring conditions are warmer than average and weevil arrival coincides with the vulnerable crop stages. A key area of research for the pea leaf weevil is population forecasting to assess damage risk at the local level. Currently, risk maps indicate the general region of potential damage based on spring counts of plant damage. However, it is difficult to determine if a seed treatment will be cost-effective. At this point Growers need to rely on both the regional map and their local observations of weevil abundance at the end of the summer. A quantitative predictive model to estimate weevil populations in the spring and the need to plant seed treated with an insecticide, will require more research on overwintering survivorship and local sampling of populations at the end of the summer that could be highly laborious._Over the long term, a biological control program may provide sustainable management if exotic parasitoids of the egg and the adult stage could be introduced from the native range of this insect.

References

1. Bright, D. E. 1994. Revision of the Genus *Sitona* (Coleoptera: Curculionidae) of North America. Ann. Entomol. Soc. Am. 87:277-306.
2. Aeschlimann, J.-P. 1980. The *Sitona* (Col.: Curculionidae) species occurring on *Medicago* and their natural enemies in the Mediterranean region. Entomophaga 25:139-153.
3. Downes, W. 1938. The occurrence of *Sitona lineatus* in British Columbia. Can. Entomol. 70:22.
4. Bloem, S., R. F. Mizell, and C. W. O'Brien. 2002. Old traps for new weevils: new records for curculionids (Coleoptera: Curculionidae), brentids (Coleoptera: Brentidae) and anthribids (Coleoptera: Anthribidae) from Jefferson Co., Florida. Fla. Entomol. 85:632-644.
5. Hartley, S. 2007. Saskatchewan insect pest report. Minutes of the 2007 Western Committee on Crop Pests, Penticton, British Columbia, 18 Oct. 2007. Online: http://www.westernforum.org/WCCP%20Minutes.html. Accessed : 25 Nov. 2010
6. Vankosky, M., L. M. Dosdall, and H. A. Cárcamo. 2009. Distribution, biology and integrated management of the pea leaf weevil, *Sitona lineatus* L. (Coleoptera: Curculionidae), with an analysis of research needs. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. Doi: 10.1079/PAVSNNR20094007.
7. Jackson, D. J. 1920. Bionomics of weevils of the genus *Sitones* injurious to leguminous crops in Britain. Ann. Biol. 7:269-298.
8. Hoebeke, E. R., and A. G. Wheeler, Jr. 1985. *Sitona lineatus* (L.), The pea leaf weevil: first records in eastern North America (Coleoptera: Curculinoidae). Proc. Entomol. Soc. Wash. 87:216-220.
9. Cárcamo, H., M. Vankosky, C. Herle, S. Meers, K. Coles, R. McKenzie, and O. Olfert. 2010. Integrated pest management of the pea leaf weevil in field peas: Final report for ACIDF, Alberta and Saskatchewan Pulse Growers Commission and MII (AAFC).
10. Landon F, J. Levieux, J. Huignard, D. Rougon and P. Taupin. 1995. Feeding activity of *Sitona lineatus* L. (Col., Curculionidae) on *Pisum sativum* L. (Leguminosae) during its imaginal life. J. Appl. Entomol. 119: 515-522.
11. Nielsen, B. S. 1990. Yield responses of *Vicia faba* in relation to infestation levels of *Sitona lineatus* L. (Col. Curculionidae). J. Appl. Entomol. 110:398-407.
12. Williams, L., D. J. Schotzko, and L. E. O'Keeffe. 1995. Pea leaf weevil herbivory on pea seedlings: effects on growth response and yield. Entomol. Exp. Appl. 76:255-269.
13. Johnson, M. P., and L. E. O'Keeffe. 1981. Presence and possible assimilation of *Rhizobium leguminosarum* in the gut of pea leaf weevil, *Sitona lineatus*, larvae. Entomol. Exp. Appl. 29:103-108.
14. El-Dessouki, S.A. 1971. The effect of some *Sitona* spp. larvae on leguminous plants. Z. Angew. Entomol. 67:411-431.
15. Doré, T., and J. M. Meynard. 1995. On-farm analysis of attacks by the pea weevil (*Sitona lineatus* L.; Col. Curculionidae)and the resulting damage to pea (*Pisum sativum* L.) crops. J. Appl. Entomol. 119:49-54.
16. Corre-Hellou, G., and Y. Crozat. 2005. N_2 fixation and N supply in organic pea (*Pisum sativum* L.) cropping systems as affected by weeds and peaweevil (*Sitona lineatus* L.). Eur. J. Agron. 22:449-458.

17. Vankosky, M. A. 2010. Integrated pest management of *Sitona lineatus* L. (Coleoptera: Curculionidae) in crops of *Pisum sativum* L. (Fabales: Fabaceae) in western Canada. Masters Thesis, University of Alberta, Edmonton, Alberta, Canada.
18. El-Lafi, A. M. 1977. The economic injury level of the pea leaf weevil, *Sitona lineatus* (L.) in northern Idaho and eastern Washington. Ph.D. dissertation, University of Idaho, Moscow.
19. Vankosky, M. A., H. A. Cárcamo, R. H. McKenzie, and L. M. Dosdall. 2011. Integrated management of *Sitona lineatus* L. (Coleoptera: Curculionidae) with nitrogen fertilizer, *Rhizobium* inoculation and thiamethoxam insecticide. Agron. J. (in press).
20. Antonelli, A., A. Retan, L. E. O'Keeffe, and C. Johansen. 1985. Pea leaf weevil: its biology and control. Extension Bulletin, Washington State University [0903], 3 pp.
21. Nielsen, B. S., and T. S. Jensen. 1993. Spring dispersal of *Sitona lineatus*: the use of aggregation pheromone traps for monitoring. Entomol. Exp. Appl. 66:21-30.
22. Hamon, N., R. Bardner, L. Allen-Williams, and J. B. Lee. 1987. Flight periodicity and infestation size of *Sitona lineatus*. Ann. Appl. Biol. 111:271-284.
23. Steene, F., G. Vulsteke, M. de Proft, and D. Callewaert. 1999. Seed coating to control the pea leaf weevil, *Sitona lineatus* (L.) in pea crops. Z. Pflanzenk. Pflanzen. 106:633-637.
24. Taupin, P. 1994. Protection insecticide – La précision génère la marge. Perspectives Agricoles 187:3 pp.
25. Smart, R. R., M. M. Blight, J. A. Pickett, and B. J. Pye. 1994. Development of field strategies incorporating semiochemicals for the control of pea and bean weevil, *Sitona lineatus* L. Crop Prot. 13:127-135.
26. Hanavan, R. P., N. A. Bosque-Perez, D. J. Schotzko, S. O. Guy, and S. D. Eigenbrode. 2008. Early season aerial adult colonization and ground activity of pea leaf weevil (Coleoptera: Curculionidae) in pea as influenced by tillage system. J. Econ. Entomol. 101:1606-1613.
27. Hanavan, R. P., N. A. Bosque-Perez, D. J. Schotzko, and S. D. Eigenbrode. 2010. Influence of tillage on adult and immature pea leaf weevil (Coleoptera: Curculionidae) densities in pea. J. Econ. Entomol. 103:691-697.
28. Hatten, T. D., R. M. Dahlquist, S. D. Eigenbrode, and N. A. Bosque-Perez. 2010. Tillage affects the activity-density, absolute density, and feeding damage of the pea leaf weevil in spring pea. Entomol. Exp. Appl. 136:235-242.
29. Eilenberg, J., A. Hajek, and C. Lomer. 2001. Suggestions for unifying the terminology in biological control. Biocontrol 46:387-400.
30. Goldson, S. L., M. R. McNeill, J. R. Proffitt, and B. I. P. Barratt. 2005. Host specificity testing and suitability of a European biotype of the braconid parasitoid *Microctonus aethiopoides* as a biological control agent against *Sitona lepidus* (Coleoptera: Curculionidae) in New Zealand Biocont. Sci. Technol. 15:791-813.
31. De Clerk-Floate, R., and H. Cárcamo. 2011. Biocontrol arthropods: new denizens of Canada's grassland agro-ecosystems. *In:* K. Floate (ed.) Vol. II – Arthropods of Canadian Grasslands (in press).
32. Aeschlimann, J.-P. 1977. Notes on *Patasson lameerei* (Hym.: Mymaridae) an egg parasitoid of *Sitona* spp (Col.: Curculionidae) in the Mediterranean region. Entomophaga 22:111-114.
33. Jaworska, M. 1998. Laboratory preference of annual legumes by pea weevil *Sitona lineatus* L. (Col. Curculionidae) and their effect on susceptibility of weevils to entomogenous nematodes. J. Invertebr. Pathol. 71:248-250.
34. Hamon, N., R. Bardner, L. Allen-Williams, and J. B. Lee. 1990. Carabid populations in field beans and their effect on the population dynamics of *Sitona lineatus* (L.) Ann. Appl. Biol. 117:51-62.
35. Vankosky, M. A., H. A. Cárcamo, and L. M. Dosdall. 2010. Identification of potential natural enemies of the pea leaf weevil, *Sitona lineatus* L. in western Canada. J. Appl. Entomol. doi: 10.1111/j.1439-0418.2010.01542.x.
36. Floate, K. D., H. A. Cárcamo, R. E. Blackshaw, B. Postman, and S. Bourassa. 2007. Response of ground beetle (Coleoptera: Carabidae) field populations to four years of Lepidoptera-specific *Bt* corn production. Environ. Entomol. 36:1269-1274.
37. Ripper, W. E., R. M. Greenslade, and L. A. Lickerish. 1949. Combined chemical and biological control of insects by means of a systemic insecticide. Nature 163:787-789.
38. Maienfisch, P., M. Angst, F. Brandl, W. Fischer, D. Hofer, H. Kayser, W. Kobel, A. Rindlisbacher, R. Senn, A. Steinemann, and H. Widmer. 2001. Chemistry and biology of thiamethoxam: a second generation neonicotinoid. Pest Manage. Sci. 57:906-913.
39. Elbert, A., M. Haas, B. Springer, W. Thielert, and R. Nauen. 2008. Applied aspects of neonicotinoid uses in crop protection. Pest Manage. Sci. 64:1099-1105.