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- A signed electronic copy of this report must be forwarded to the funders' representative on or before the due date, as per the investment agreement.
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Section A: Project overview

1. Project number: 2013F060R
2. Project title: Improving lygus management for current canola and faba bean cultivars
3. Abbreviations: Define ALL abbreviations used. AAFC: Agriculture and Agri-Food Canada; AAF: Alberta Agriculture and Forestry; CSW: cabbage seedpod weevil; CARP : Canola Agronomic Research Program; ET: Economic Threshold; EIL: Economic Injury Level; IPM: Integrated Pest Management; LRDC: Lethbridge Research and Development Centre
4. Project start date: (2013/04/01)
5. Project completion date: (2016/11/30)
6. Final report submission date: (2016/10/12)

7. **Research and development team data**	
a) Principal Investigator: (Requires personal data sheet (refer to Section 14) only if Principal Investigator has changed since last report.)	
Name	**Institution**
Hector Carcamo	AAFC
b) Research team members (List all team members. For each new team member, *i.e*., joined since the last report, include a personal data sheet. Additional rows may be added if necessary.)	
Name	**Institution**
Jennifer Otani	AAFC
Neil Harker	AAFC
Jim Broatch	AAF
Darren Bruhjell	AAFC

Section B: Non-technical summary (max 1 page)

Lygus bugs are native insect pests with general feeding habits and can damage a variety of important crops including seed alfalfa, canola and faba beans. Current thresholds for lygus in canola were developed in conventional cultivars such as Westar with much lower yield potential than current hybrid cultivars. Different regions of Alberta have unique environmental conditions including distinct climate, different lygus species and number of generations, and different other co-occurring pests. For example in southern Alberta, the cabbage seedpod weevil is a chronic pest. Faba beans are an expanding crop in the Prairies and as with other crops, as acreages expand the insects find them and can cause damage. In the case of faba bean there are concerns that lygus feeding can increase necrotic spots that reduce quality and marketability in addition to potential yield. The objectives of this study were to validate economic thresholds for lygus in southern and central Alberta using a hybrid cultivar, compare the impact of lygus feeding on current hybrids of canola and a conventional cultivar, and obtain baseline information about lygus in faba beans to improve their management.

A multi-year and multi-site cage study was completed near Lethbridge, Lacombe and Beaverlodge to update our knowledge on how lygus affects yield in canola for current cultivars and refine thresholds. The outcome of the studies suggests that the current economic threshold of 1 lygus per sweep at the early pod stage is too low. For Lethbridge, the data (converted from density to sweeps) suggested that canola yield losses to warrant control did not occur till lygus reached around 3 lygus per sweep. For the Lacombe region, the threshold was around 2 per sweep. The results for Beaverlodge were less conclusive but a similar impact of lygus on canola was observed and a similar threshold could be applied. Across all regions the average yield losses that could be attributed to lygus in cages (relative to cages without lygus) was around 15-25%. More site-years are needed to relate weather to yield losses, but for Lethbridge the highest number of lygus per cage (+1000) and extreme yield loss (40%) occurred when July temperatures were hot (mean of 20°C) and lowest rainfall relative to 2013 and 2014). Near Lethbridge, the study included cabbage seedpod weevil and these data will be integrated with past field studies to refine a threshold for this pest as well.

Current analysis suggest that the threshold of 2-3 weevils per sweep in use is likely correct.

Using a higher threshold, even though only slightly higher, may result in a large reduction in pesticide use in canola crops. Such a reduction may have other positive repercussions such as increased activity by pollinators and other natural enemies which provide beneficial ecosystem services. Information on economic thresholds for insect pests such as lygus and cabbage seedpod weevils has a high potential to reduce production costs. Currently, in Alberta it is recommended to spray when lygus reach 1 per sweep at the early pod. The results from this study showed that in a normal year with sufficient rain (>120 mm in June and July, normal mean temperature under 20°C in July) lygus bugs at such low abundances (1/sweep) do not pose a yield risk. Therefore, there are significant savings in production costs ($22/ha to spray insecticide by plane) when growers do not take action when not required. On the other hand, if lygus reach or surpass 3 per sweep in the south, there are significant economic returns to be realized by spraying because our results, despite high local variability, showed that lygus can reduce damage by about 15% in most years in southern Alberta and up to 20% in central Alberta. The higher yield loss reduction for central Alberta agrees with the recommendation based on regression analysis to use a lower threshold of 2 per sweep for that area. In a field situation the yield loss should be lower because lygus in open field are likely subjected to higher predation by natural enemies and also suffer more disturbance from rain and wind, unlike the situation in a cage. In a previous field study for cabbage seedpod weevils the average yield saved by spraying insecticide at early flower was around 2 bushels per acre, which is far less than 15% for most crops. This agrees with the idea that cages may overestimate the yield losses from insect feeding. An ongoing 4 year CARP-funded study will validate the lygus threshold at the farm level.

For faba beans, no cage studies were conducted, but field and plot studies showed a similar species composition of lygus and activity pattern as with canola. In most fields lygus were less than 1 per sweep and rarely 2 or more per sweep at any crop stage. Further studies are needed to make management recommendations but as a guideline farmers may take control action if there are more than 2 lygus per sweep, but should attempt to mitigate impacts on pollinators and natural enemies. Faba bean requires pollinators to improve yield, hence it is crucial to mitigate insecticide impacts on them or the action could also affect yields negatively. Planting early is recommended to avoid the peak of damaging lygus populations that occur late in the growing season.

Section C: Project details

1. Background (max 1 page)

Lygus bugs (Miridae) are native polyphagous pests of several crops in North America (Otani & Carcamo 2011, Carcamo & Blackshaw 2007). In the Canadian prairies they have been a historical pest of seed alfalfa, but with increasing areas planted to canola (15 M tonnes targeted by 2015), they are becoming a more perennial pest in this crop.

According to research conducted on open pollinated cultivars, they may cause yield losses to this crop that have been estimated around 10-20% during outbreak years (Wise & Lamb 1998a,b). Every year some spraying occurs, often with an organophosphate or pyrethroid insecticide, because of real outbreaks or as a standard prophylactic measure. In the North, growers are concerned about lygus damage at the bud stage and may add insecticide to their last herbicide spray; this practice is more rare in the south but may be increasing. In the south, some growers are spraying at the pod stage, in some cases very close to swathing, close to the pre-harvest interval. Economic thresholds for early pod stage were developed in Manitoba (Wise & Lamb 1998) using conventional varieties prior to the widespread adoption of hybrid, herbicide-tolerant cultivars with superior agronomic traits. Managing lygus across regions is complicated by the distinct climatic conditions in the northern Peace Region compared to southern Alberta, and the differences in Lygus species composition (Carcamo et al 2002) and life cycles relative to crop growth (Carcamo et al. 2006).

Lygus bugs are known pests of certain pulse crops worldwide. In Turkey, they reduce marketability of red lentils (Stoltz & McNeal 1982). In Quebec they damage green beans (Stewart & Khattat 1980), whereas in southern Manitoba they are intermittent pests of navy beans (Nagalingam, T. and N.J. Holliday 2012). In Alberta, lygus can damage faba bean cultivars of the zero tannin classes but apparently not those with tannins. The basic biology such as their seasonal activity, species responsible and the nature and timing of the damage is unknown; it may be possible that they move from surrounding canola crops or hay crops after harvest or they may immigrate early and produce a generation in the crop. In Alberta the species composition of lygus in alfalfa is distinctive from canola and at least in the more humid regions, there was no evidence of significant movement of lygus from alfalfa to canola crops (Carcamo et al. 2003).

2. Objectives and deliverables (max 1 page)

State what the original objective(s) and expected deliverable(s) of the project were. Also describe any modifications to the objective(s) and deliverable(s) which occurred over the course of the project.

Objectives:

1) Validate thresholds by assessing effects of lygus bug feeding on current hybrid herbicide-tolerant cultivars using cage studies in southern and central Alberta (Lethbridge and Lacombe)
2) Compare responses of key canola cultivars (LL, RR, Westar) to lygus feeding starting at the bud stage in northern and southern Alberta(Lethbridge and Beaverlodge)
3) Document phenology and species composition of lygus bugs in faba bean crops with and without tannins and relate abundance to damage

Deliverables:
1) Validated threshold for Lygus control in a hybrid canola cultivar
2) Interim and final reports with executive summaries with recommendations to manage

lygus bugs in canola and species activity and damage to faba beans
3) Summary of extension activities for presentations at grower meetings and other events
4) Summary chart in final report documenting seasonal activity and species composition of lygus in faba bean
5) Copies of scientific publications as they become available

This project will aid the Canola and faba bean industry to reduce costs of production and maintain high yields. By improving our understanding of lygus bug feeding on current canola cultivars, growers will be better informed to know when it is economical to spray them and what crop stage the plants are vulnerable in each region. This will save production costs by avoiding spraying when densities are too low and also increase profit margins by maintaining high yields by controlling these pests when they surpass damaging densities that can reduce yield.
This project will aid to increase the environmental sustainability of the canola and faba bean industry. Excessive insecticide spraying can result in well documented environmental issues such as reduction in populations of beneficial insects including natural enemies and honey bees. Decreases in natural enemies may further exacerbate secondary pest problems such as diamond back moth larva or bertha armyworms or even aphids that are normally maintained in check by predators like lady bird beetles. The project will also have a significant scientific contribution. The data generated will contribute to improve our understanding of plant compensation to insect feeding. The cage studies also provide valuable data on insect development rates in relation to crop stages. This information is also required to forecast lygus damaging stages in the field. The faba bean component will lay the foundations to undertake future more detailed studies to develop comprehensive IPM packages for this crop that can have applications to other bean classes in Alberta.

3. Research design and methodology (max 4 pages)

Describe and summarise the project design, methodology and methods of laboratory/field and statistical analysis that were actually used to carry out the project. Please provide sufficient detail to determine the experimental and statistical validity of the work and give reference to relevant literature where appropriate. For ease of evaluation, please structure this section according to the objectives cited above.

I) Cage study to validate economic thresholds (ET) for lygus in canola in southern and central Alberta. (Carcamo, Broatch, Harker)

Study site, years and agronomic activities
The study was conducted from 2012 - 2015 at the experimental farms of the Lethbridge and Lacombe Research Centres. The Liberty Link hybrid cultivar L120 was seeding at a rate of around 5-6 lb/ac in early to mid-May. A fertilizer plan to maximize yield was followed based on soil fertility analysis at each site. Weed control included Edge soil incorporation and manual pulling inside each cage. No foliar insecticides were used at

the seedling stage but the seed was coated with a neonicotinoid and fungicides, required for flea beetle and disease control. For completion we include data from a similar study started in 2012 using funds from the Pest Management Centre of AAFC (2012-2013) for the same objective, but only conducted near Lethbridge.

Lygus densities per cage

Field cages (1m x 1m x 1m at Lethbridge and 1.5 m tall at Lacombe) were used to confine canola at the early flower stage. The range of densities of lygus added included some of those used by Wise and Lamb (1998a) to derive current economic thresholds. The lygus density treatments per cage were the following: (1) Uncaged control, (2)Caged control without any insectes added, (3) 4 lygus, (4)10 lygus,(5) 20 lygus, (6) 50 lygus, (7) 80 lygus, (8) 10 lygus and 10 weevils (Lethbridge only). At Lacombe, in 2013, one additional treatment was included to compare the effect of a single species (L. lineolaris) on canola yield but only in L150. This pure species treatment with either of the two dominant species (L. lineolaris or L. keltoni) was repeated in the two cultivars (Westar and L150) in the last two years of the study. From 2013 till 2015 at Lethbridge, 3 additional treatments were included to validate the ET for cabbage seedpod weevils as part of an internally funded project, which will be reported elsewhere. These included cages with only 10, 20 and 40 CSW.

Experimental design and procedures

The design was a fully randomized block with 4 replicates. Each block contained the 8 experimental units of 1m x 1m where the above treatments were randomly allocated. Cages were set up with at least 2 m space among them and at least 1m away from field edges. The uncaged treatment was staked at each corner and its borders were delineated with a colored ribbon. At flower, in late June to early July, lygus adults of the summer generation were collected from canola fields and added to the experimental cages. Prior to stocking, weeds were removed as well as all insects, including lygus and predators. From 2013 to 2015 at all sites, plants were thoroughly sprayed with a can of Raid insecticide when the crop was at the vegetative stage to attempt to remove unwanted seedpod weevils and lygus from all cages to improve our ability to manipulate their densities.

Measurements and analysis

At early flower, immediately before caging each experimental unit, plant density was measured and the crop stages of all plants along the middle row were recorded. At the same time, the area was “cleaned” of all arthropods. Prior to harvesting plants, around the time when the crop would be swathed (5.3 stage), all lygus on the plant and the ground were vacuumed and preserved for identification to species and counting all nymphs by stage.

Plants were clipped about 5 cm above ground, counted and placed in a harvest sac and hung to dry for several days until threshed to collect yield. To assess seedpod weevil damage before threshing the plants, 100 pods were collected from the plants and 100 from shelled pods from the bottom of the sac. Ideally pods should be collected before clipping plants in the field but this was not possible as insects would escape and plants were too entangled inside the cages. Seeds samples were cleaned, weighed and subsamples used to obtain protein and oil content and determine test volumes and 1000-kernel weights.

Plant and insect response variables were studied using the Systat statistical package which has a mix model anova to determine treatment effects. Insect densities inoculated at flower were used as the fixed factor and replicate as the random factor. Regression analysis of the total lygus collected at harvest per cage was used to determine its effect on yield (and other seed quality parameters) and validate thresholds.

II) Damage and yield comparisons in relation to lygus feeding during bolting to maturity in 3 canola varieties at Beaverlodge and Lethbridge (J. Otani & H. Carcamo)

This study was conducted at Beaverlodge from 2013 to 2015. Three Brassica napus varieties (Westar, InVigor, RR) were seeded on plots, each 3.6 m x 8 m, at a seeding rate of 6 lb/ac in early or the middle of May. The experimental design was a full two factorial with cultivar (L150, RR, Westar) and a cage treatment (0 or 20 lygus); Agronomic treatments to grow canola were similar to those described in the above cage study. Plant growth ratings were performed weekly for 10 plants per plot (cotyledon stage until harvest). Cages were set over 4 rows of canola per plot at the late rosette stage (2.5-2.6 using Harper and Berkenkamp 1975).

Lygus adults were sweep-net collected from local fields of alfalfa, sorted to species, then the dominant species of Lygus was used to stock cages at the late rosette stage with 20 adults (1:1 sex ratio) per cage for ONLY Treated plots. At crop maturity, cages were removed, and all enclosed Lygus adults + nymphs were vacuumed and preserved by freezing for later processing (density by species and stage per cage). All enclosed plants were hand-harvested at ground level and bagged in cotton for drying (above-ground biomass, g/m2) and yield (g/m2) data was recorded. Quality (1000-seed weights, percent oil, green-seed counts) were determined from the yield samples threshed from each plot. Data analysis was done using the SYSTAT proc mixed for a two factorial anova with cultivar, lygus and the interaction of lygus*cultivars as main effect.

Variance: this study was conducted only at Beaverlodge. The comparison of the three cultivars was integrated into the study of lygus density effects on canola yield at Lacombe. It could not be conducted in Lethbridge because the presence of cabbage seedpod weevil required manipulation of its densities and would have made the study of cultivars overly complex and beyond the resources available to complete such study.

III) Lygus in faba bean: species, phenology and damage

This study was intended as a first step to develop a management strategy for lygus in faba beans. First, a survey of faba bean fields and plots was conducted in the Lacombe region and Vauxhall, respectively. In Lacombe 2-10 fields of tannin cultivars and 6-11 fields of zero tannin faba beans were surveyed in 2013-2015 (43 fields total over 3 years) with sweep nets at the bud, flower and pod stages. Lygus were identified to species and nymphal stage and their numbers were recorded. Pearson correlations were done each year to explore relationships with seed quality.

An experimental plot study was conducted at Vauxhall on irrigated land to document lygus phenology, species composition in faba bean adjacent to canola. This study also assessed potential insecticide effects on lygus and bean quality in zero tannin and tannin faba beans. A 40 m x 40 m block of canola was planted in early May each year and four blocks of faba bean were planted around the inside perimeter of the canola crop. Each faba bean block consisted of a current variety with tannins (SSNS-1, 8 plots) and a corresponding zero tannin variety (Snowbird, 16 plots). For the Snowbird, the two factors tested were seed treatment insecticide for pea leaf weevil (with or without cruiser) and foliar insecticide (Decis or Matador) at early pod or not sprayed. For the tannin variety only the foliar insecticide factor was manipulated. Each faba bean plot was 10m x 9 m. These plot sizes allowed sweeping the crop at the key crop stages (pre-flower, flower and pod) and to obtain seed yield and quality data. The analysis took the form of a randomized block two way anova.

Results, discussion and conclusions (max 8 pages)

Present the project results and discuss their implications. Discuss any variance between expected targets and those achieved. Highlight the innovative, unique nature of the new knowledge generated. Describe implications of this knowledge for the advancement of agricultural science. For ease of evaluation, please structure this section according to the objectives cited above.

NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

(1)Threshold validation study. This study was conducted at Lethbridge and Lacombe. The cultivar L150 was planted at both locations. One meter square cages (1.2 and 1.5 m tall, at Lethbridge and Lacombe, respectively) were used to confine 75 plants and the area was manually cleaned of all insects and also sprayed with insecticide. The treatments included an uncaged area, and caged densities of 0, 4, 10, 20, 50 (40 in Lacombe) and 80 lygus. In year 2 in Lacombe, an extra treatment was added in each cultivar to compare two lygus species (*L. keltoni* and *L. lineolaris*) at a density of 20 bugs per cage. At Lethbridge the treatments included additional treatments with seedpod weevils at 10, 20 and 40 per cage as well as a combination of 10 lygus and 10 weevils per cage to assess the joint effects of these two insects at moderate densities below threshold. At Lacombe, the study included Westar as one of the cultivars in a two factorial design to allow fulfilling the second objective simultaneously (see section below on comparison of cultivars).

In general the insect manipulations were successful in establishing a gradient of cages with different lygus densities. At both sites, the number of insects sampled twice during the growing season and at harvest reflected the densities of the treatments; i.e. our manipulations of densities were successful as illustrated in Figure 1, with data pooled over years and two cultivars.

At Lethbridge, insect pest densities (lygus or weevils) had a statistically significant effect on canola yield only in 2015 (Figure 2, Systat, mixed models anova, $p=0.05$) when densities of 20 or 40 weevils per cage reduced yield relative to control cages. However, a summary of the percent differences in yield between cages with and without lygus for all the study sites (Fig. 14), showed that at Lethbridge the differences ranged from a very large yield loss of 40% in 2012 to a consistent and still large loss of 15% from 2013 to 2015. It appears that variability was too high among cages within treatments and a much larger level of replication (10 or more cages!) would be needed to detect significant overall treatment effects. Pairwise comparisons using Fisher's Protected Least Significant Differences after the mixed model anova were performed because of the obvious yield losses that could be attributed to the insects in the cages. For 2012, all treatments with 20 or more lygus per cage had significantly lower yield than the control cages ($p<0.05$) and the differences were highly significant ($p<0.01$) for the treatment with 80 lygus per cage. A similar pattern of significant differences occurred in 2013 but not in 2014 and 2015 where treatments differences, though large (15%) for the cages with high lygus numbers, were not statistically significant (FPLSD, $p > 0.05$).

At Lacombe, there were more significant and larger effects of lygus densities on canola yield compared to Lethbridge during 2013 and 2014 (Fig. 3). On average the cages with lygus had from 14-28% less yield for L150 than those cages where no lygus were added (Fig. 14b). These percentages of yield reductions are within the range or higher than those observed by Wise and Lamb in Manitoba.

A regression analysis pooling the data across all years at each site suggested a significant, though still weak, regression and a slope coefficient that differed from zero at each site (Table 1, slide 5 of power point attached and Figure 4). Using these coefficients, an Economic Threshold (= Economic Injury Level) was calculated for each cultivar in Lacombe and for Lethbridge using the following formula used by Wise and Lamb (1998) which they took from Stone and Pedigo (1972).

$$EIL = g/b$$

In the above equation, the Economic Injury Level (EIL) equals the Gain Threshold (g) divided by the slope coefficient (b) of the regression of yield on lygus bugs, which quantifies the yield losses per insect sampled. The Gain Threshold was calculated using a recent canola price of $427.71/ton and a cost of aerial insecticide spraying of $22.24 per ha (22.24/427.71 = 0.05199, this is the amount of canola seed yield/ha (5.199 g/m^2) needed to be saved by spraying for lygus to cover the cost of the control action). As shown in table 1 (slide 6) the ET for lygus bugs in Lethbridge is around 3 per sweep and 2 per sweep for Lacombe for L150. These numbers are slightly higher than those reported by Wise and Lamb (1998). The main explanation for the higher threshold is the much lower slope coefficient (b) which ranged from -0.10 to -0.15 for L150 compared to -0.51 to -0.79 for southern Manitoba. This suggests that under these environments, growing condition and for this cultivar, lygus bugs are less damaging to canola than under the conditions experienced in southern Manitoba for the study by Wise and Lamb (1998). Site, must play an important role in addition to cultivar because in our study the old cultivar Westar in fact had a lower slope coefficient than L150. Another potential explanation is that *L. keltoni* (not found in Manitoba) is less pesky than *L. lineolaris*.

Damage by seedpod weevils to canola pods was high in some of the cages where only lygus were added in 2012 and 2015 (Fig. 5). However, there was no correlation of yield with the average number of exit holes per pod in each cage in any year. Average yields also were not consistently related to weevil densities per cage, although there was a trend towards lower yields in the cages with weevils added compared to the control plants caged without any insects added at the flower stage; the exception was the year 2014 when yield was similar in cages with weevils and the control cages (Fig. 3). An ET cannot be calculated for the weevil because of the lack of significant regressions ($R^2 < 0.1$) between yield and damage or adults collected from the cages. However, data from a large scale field study completed from 2010-2013 suggests that the current ET of 2-3 weevils per sweep is correct.

A partial validation of the nominal threshold used for weevils can be attempted using the cage data summarized in Figure 6. This figure shows the damage to the pods in terms of the number of cabbage seedpod weevil exit holes caused by the larvae when they exit the pods in relation to the adult weevils added at early flower. The number of exit holes per 100 pods (or per pod) is a better indication of damage and potential yield loss than the more commonly used measure of percentage of pods with any exit holes (damage) because some pods have 2 or more holes. Each larvae damages from 3 to 5 seeds and also allows fungi to enter the pod and cause further damage in addition to the increased risk of pod shattering. Based on figure 6, it can be suggested that only the addition of 40 weevils per cage resulted in damages to the pods that surpassed 25 exit holes per 100 pods. In a number of studies (e.g. Lerin 1984), it has been shown that when damage is below this level (25% of pod damage) there is no impact on yield. Therefore, we can suggest that for our study if there are fewer than 40 weevils per square meter at early flower, then there is only a minor risk of yield loss and growers should not take a control action. Converting this value to number of weevils per square meter is difficult due to the lack of a conversion factor similar to the one used for lygus (0.526). A conservative method is to double the conversion factor used for lygus because weevils are easier to sample with a sweep net at the flower stage compared to lygus at the pod stage. Then, using a conversion factor of 1.05, the expected number of weevils per sweep would be around 4. This is the same threshold that we suggested with the late Dr. Dosdall in the early 2000's before canola prices were high. We reduced the threshold to 2-3 as a request from agronomists who noted that canola prices were much higher recently. In summary, it appears that the nominal threshold of 2-3 weevils should be a correct guideline for growers to make a spray decision for cabbage seedpod weevil.

Objective 2) Damage and yield comparisons in relation to lygus feeding during bolting to maturity in 3 canola varieties

This study was conducted only at Beaverlodge from bolting to maturity from 2012 to 2015. Similar to the Lethbridge study, it was supported in part by the Pest Management Centre starting in 2012-2103 and all years are reported here for completion. Two cultivars were compared in Lacombe from early flower to maturity as part of the study to investigate the impact of lygus densities on canola yield. As expected, at all sites and years, Westar canola had much lower yield (15-50% lower, e.g. 30 vs 60 bu) than the modern hybrid cultivars.

At Lacombe, where only Westar and L150 were compared, Westar appeared to be less vulnerable to lygus damage compared to L150. There were no consistent differences in yields in cages with lygus and those without lygus but on average cages with lygus had about 9% lower yield than those with no lygus added at early flower. This was in contrast to L150, which had an average of 21% more yield in the control cages without lygus than in those with lygus added at early flower. The highest inoculation of 80 lygus per cage significantly reduced yields (by 20%) relative to the control cages in 2014 and 2105 for L150 but for Westar the yields were never significantly different, although the differences were also around 15 % lower in cages with lygus than without lygus (Fig. 3).

Regression analysis also suggested that at Lacombe the Westar cultivar was less vulnerable to lygus feeding damage than L150 (Fig. 4). An overall regression analysis was conducted for all years, removing yield outliers for each cultivar as identified by the Systat program. The slope coefficient of the regression for L150 was -0.15 and only -0.07 for Westar(Table 1). This means that for every increment of 1 lygus found in a cage at harvest there was twice as much yield loss in L150 than in Westar and these values correspond well to the average overall mean losses observed in cages with lygus relative to those with lygus for the two cultivars: 21% vs 9%, respectively for L150 and Westar.

At Beaverlodge in 2012, the cages had high levels of lygus contamination so that those that received 20 lygus per cage had similar numbers to those that did not (Fig. 7). Also, there were very large numbers of diamond back moth (Fig. 8) and flea beetles in all the cages. The densities of these pests as expected from the small variability at harvest time were not related to yield of canola (Fig. 8). These results were excluded from analyses where years were pooled.

In 2013 at this site, in contrast to 2012, no lygus emerged from the control cages, only from those that received them at bolting (Fig. 9). The numbers produced per cage, however, were about half of those observed in 2012 and 2014 at this site and also about half of those observed in Lacombe and Lethbridge. For example, in Lacombe in 2013, the two treatments with 20 Lygus of either *L. lineolaris* or *L. keltoni* produced around 140 lygus at harvest time, more than double the number found at Beaverlodge that year (40-65 per cage, Fig. 9). Similar to 2012, there was no apparent effect of lygus on canola yield as revealed by regression analysis with all cultivars combined (Fig. 10). However, the mean yields were slightly and consistently lower in the cages that had lygus added than the control cages without lygus (about 7% lower, Figs. 11, 15). The differences were only marginally statistically significant (p = 0.09, mixed anova in systat).

In 2014, a similar pattern was observed, but the yield difference between the cages with and without lygus was around 28% on average (Fig. 12). There was a significant cultivar and lygus effect (p<0.05) but no interaction between cultivar and lygus treatment. In 2015, there were no differences in yield between cages with lygus or without lygus for the RR cultivar; in fact the cages with lygus had 3% more yield than those without lygus. For L150 and Westar, however, there were significant and large differences in yield and higher in the cages without lygus than those with lygus: 27 and 44 %, respectively, for L150 and Westar (Fig 13).

Regression analysis for the hybrid canolas combined over the 3 years suggested a marginally significant effect (p= 0.06) of lygus on canola yield (Fig. 14) and non-significant for Westar (p=0.11). Regression analysis by year, suggested a strong effect only in 2014 for L150, but with only 4 cages with lygus and 4 without lygus (near 0 bugs), the results cannot be conclusive, plus the significance of the regressions were not consistent every year. With a larger sample size, it is likely that the negative effects would be confirmed. In summary for Beaverlodge, as in Lacombe, Westar had much lower yield. It appears that in some years, 20 lygus per square meter at the bolting stage have the potential to reduce yields. Plot studies and past cage studies, however, does not support the notion of early control at the bud or bolting stage and this needs validation using commercial fields. Further migration may negate the impact of early insecticide spray. Furthermore, sufficient rainfall after spraying during the flower and pod stage may have made such action unnecessary because it may reduce pest populations and increase plant tolerance to lygus feeding.

An important consideration when assessing lygus (or any insect pest) effect on plant yield is the abiotic environment in terms of precipitation, temperature and soil fertility. According to Wise and Lamb (1998), if there is over 100 mm of rainfall from bud to the end of flower (early pod) then the crop may compensate for lygus feeding. For Lethbridge, during June and July, rainfall was only 51 mm during this period; however the crop was irrigated (38 mm) up to the time when the cages were set up in June. For the other years, rainfall was 148, 175 and 164 mm for 2012, 2013, and 2014, respectively. Rainfall alone does not explain the yield differences observed and potential effect of lygus. According to figure 2, the lowest yields and larger overall differences between cages with lygus and those without it occurred in 2012 when yields were about 130 g/m2 in the control cages without lygus added and around 60-90 g/m2 in those where lygus were added at early flower (i.e. 30-54% lower). If temperature was the overriding factor determining lygus damage then the worst yield losses should have occurred in 2015 when there were only 51 mm of rainfall in June and July. Temperature may combine with rainfall because it has a positive effect on lygus development and negative on canola if it peaks at flowering. Ideal conditions to avoid lygus and maximize canola yields could be a wet June/July (may also drown/dislodge small nymphs) and cool conditions in July during flowering for yield set and also to slow down lygus nymphs development. Based on the temperatures and rainfall combinations, 2013 was an ideal year with the highest rainfall of 175 mm and a cool July of 18.4°C and agrees with our yield measurements and low lygus impact. Weather could explain the patterns observed for other years except 2015 when drought conditions and warm temperatures should have resulted in more significant yield losses from lygus bugs. It is likely that cabbage seedpod weevils, which are probably a more serious pest than lygus are obscuring the picture at Lethbridge.

Similar data was obtained from Environment Canada for Lacombe and Beaverlodge (http://climate.weather.gc.ca/historical_data/search_historic_data_e.html?Month=10&Day=7&Year=2016&timeframe=2&StartYear=1840&EndYear=2016) to relate them to yield as shown in Figure 15. A Pearson Correlation for the 10 site years showed that July temperature had the strongest correlation with yield loss (R = 0.44), but was not significant for this small sample size. The next strongest correlation was June rainfall (R = 0.38). Based on Figure 15, there is no pattern of yield loss and rainfall or temperature as speculated for Lethbridge. However, at both sites rainfall over the two months that would include the bud to flower periods was well over the threshold of 100 mm suggested by Wise and Lamb (1998).

In summary this multi-year and multi-site cage study completed near Lethbridge, Lacombe and Beaverlodge allowed us to update our knowledge on how lygus affects yield in canola for current cultivars and refine thresholds. The outcome of the studies suggests that the current economic threshold of 1 lygus per sweep at the early pod stage is too low. For Lethbridge, the data (converted from density to sweeps) suggested that canola yield losses to warrant control did not occur till lygus reached around 3 lygus per sweep. For the Lacombe region, the threshold was around 2 per sweep. The results for Beaverlodge were less conclusive but a similar impact of lygus on canola was observed and a similar threshold could be applied. Across all regions the average yield loss that could be attributed to lygus in cages (relative to cages without lygus) was around 15-25%. More site-year data are needed to relate weather to lygus damage, but for Lethbridge the highest number of lygus per cage (+1000) and extreme yield loss (40%) occurred when July temperatures in 2012 were hot (mean of 20°C and lowest rainfall relative to other years). Near Lethbridge, the study included cabbage seedpod weevil and these data will be integrated with past field studies to refine a threshold for this pest as well. Current analysis suggest that the threshold of 2-3 weevils per sweep in use is likely correct. Some of the limitations of cage experiments are the partial exclusion of natural enemies and protection from wind and hard rain, therefore, the estimates of damage could be exaggerated and the thresholds could be even higher. Another ongoing study funded by CARP (Canola Council of Canada) is underway across the 3 Prairie Provinces to attempt to validate these thresholds in actual canola commercial farms.

III) Lygus in faba bean: species, phenology and damage

All four lygus species reported from canola fields (Carcamo et al 2002) were found in faba beans in south central Alberta around the Lacombe region from 2013 to 2015 (Fig.

16 shows the map of the area surveyed). *Lygus lineolaris* and *L. keltoni* were dominant; *Lygus borealis* was less common and *L. elisus* was rare. There was no clear pattern of species preferences for either type of faba bean but there was a trend in 2014 towards higher abundance of lygus in the no tannin cultivar (Figure 17). There was a clear difference in lygus life stage depending on the crop stage: at the bud and late pod stage the majority were adults, whereas at the flower stage the majority of lygus were juveniles (Figure 18). In general during the 3 years, lygus abundances were low, under 0.5 per sweep during the bud and flower stage and on average about 1.5 per sweep at the late pod stage. At Vauxhall, the lygus species have not been identified but it appears that the dominant species is *L. keltoni*, with a few *L. borealis* and rarely any *L. lineolaris* – similar to canola.

Bean seed surface damage (Fig. 19) was assessed visually from 100 seeds per site and also by image analysis for a subsample in 2013 (see appendix 2 – word file with student's report). The image analysis method appears to be slightly more accurate than the visual method. However, the time and labour requirement, makes it impractical. Bean surface damage was higher for the zero tannin cultivars than for the tannin cultivar (Malik) all years and significantly so in 2014 and 2015 (Fig. 20, non parametric Kruskall Wallis test, $p < 0.05$). Regression analysis for the 21 sites, each with 10 subsamples, suggested no direct relationship of any lygus stage at any crop stage or other insect such as aphids with the level of necrotic damage. Further analysis using the level of damage by position of the bean pod will be done as part of a related ongoing study attempting to distinguish lygus and chocolate spot damage.

At the Vauxhall plot study site (Figure 21), similar to Lacombe, there were about 15-20 lygus per 10 sweeps at the pod stage and far fewer at the flower stage. There were more lygus in plots of the zero tannin cultivar only in 2014 and only at one sampling date on August 6th (early pod). Damage to bean seeds, however, was clearly lower in the plots planted to the tannin cultivar than the zero tannin cultivar in the two years of the study (Figures 22 and 23) and agreed with the commercial field data from the Lacombe region.

None of the insecticide treatments (seed or foliar applied) influenced faba bean yield in the plot study near Vauxhall (Figure 24). The numerical trends suggested higher yields in the plots of either cultivar that were not treated with foliar insecticide both years. This may result from potential physical trampling of the crop at the early pod stage while spraying. Also, faba bean rely on pollinators to set seed (Free and Williams 1976) and these are likely affected negatively by spraying insecticides while the crop is still in flower. This area requires further research. Other potential serious pests of faba bean at the late crop stage may include aphids. Spraying insecticides may reduce the population of generalist predators such as lady bird beetles that help to keep late invasions of aphids in check.

Correlation analysis of faba bean yield or surface damage with lygus at the plots suggested no significant consistent associations with various lygus life stages throughout the growing season in 2013 and 2014 (data not shown). On some dates the associations were negative or positive and rarely significant. In some cases it appeared that the more lygus adults were at the plots during the late stage, the higher the yield. Such a peculiar pattern may result from late migration to plots with more vigorous plants that would produce higher yield. One may also speculate that plots with more lygus (unsprayed) also had more pollinators that could have improved yield.

In summary, the survey of commercial fields near Lacombe and Vauxhall provided baseline information about lygus species, abundance and damage levels. In terms of the dynamics and species composition, the crop is similar to canola. Populations peak as the crop matures when abundance can reach on average around 2 per sweep at most sites, but occasionally 4-5 per sweep; at the bud and flower stage, abundances were less than 1 per sweep and mostly adults (many had zero). The species in the Lacombe area were the typical *L. lineolaris* (tarnished plant bug) and *L. keltoni*, with few *L. borealis* and *L. elisus*. The tarnished plant bug was rare in the south. Because of the low and variable numbers of lygus, there were poor correlations with damage levels or yield. It was clear that damage levels were much lower in the tannin cultivar than in the zero tannin cultivar. One strategy to avoid the potential insect problem is to plant tannin cultivars. For zero tannin production where damage is an issue, growers should plant the crop as early as possible and monitor with a sweep net once the crop starts to flower. From our study and past work (Dosdall 2003) it appears that spraying insecticide may not reduce damage and if the crop depends on pollinators to set yield, spraying may be counterproductive. If lygus are abundant (2 or more per sweep at the late flower stage?), they should do it when pollinators are not active, preferably at night.

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5. Project team (max ½ page)

Describe the contribution of each member of the R&D team to the functioning of the project. Also describe any changes to the team which occurred over the course of the project.

Hector Carcamo (AAFC); Principal Investigator. In collaboration with researchers and technical staff at the 3 sites, developed the protocols to execute the studies, collated, analyzed and summarized the data and prepared the final report. Presented results on behalf of the team and answered media questions. Allocated financial resources to the 3 sites.

Jennifer Otani (AAFC): contributed to the experimental design and protocols to collect data at all sites and was responsible for the execution and data collection at the Beaverlodge site to do the cage study with the 3 cultivars of canola from 2012 to 2015. She managed the budget allocated to her site.

Neil Harker: provided scientific leadership, mentorship and contributed to the experimental design for the team at Lacombe to complete the lygus cage study and provided the human resources (Patty Reid) to complete the survey of lygus bugs in commercial faba bean fields. He managed the budget allocated to his site.

Jim Broatch: contributed to the experimental design and execution of the lygus cage study. Worked diligently with Patty Reid to collect, identify lygus species and stock them to the cages. Provided mentorship and advice to the technical support staff at Lacombe to complete the entomological tasks for this project at Lacombe.

Darren Bruhjell will be involved in drafting related fact sheet and extension documents. The threshold for lygus bugs is being validated at the farm level scale as part of an ongoing study, therefore, this information is not ready for extension. Another study on faba bean assessing lygus impact on damage and yield as well as chocolate spot is wrapping up by next summer and the information could be dispersed at that time. The most likely related fact sheet to be developed in the near future will be on cabbage seedpod weevil in canola where a farm level validation was completed while the cage work was ongoing.

6. Benefits to the industry (max 1 page; respond to sections *a)* and *b)* separately)

a) Describe the impact of the project results on the Alberta or western Canadian agriculture and food industry (results achieved and potential short-term, medium-term and long-term outcomes).

The cage study data suggested that the economic threshold currently being recommended (1 per sweep) is too low. According to our results near Lethbridge and Lacombe, the threshold where lygus cause a large enough reduction in yield is around 3 and 2 per sweep, for south and central Alberta. The latter may apply to northern Alberta, as the regression results were similar. Using a higher threshold, even though only slightly higher, may result in a large reduction in pesticide use in canola crops. Such a reduction may have other positive repercussions such as increased activity by pollinators and other natural enemies which provide beneficial ecosystem services.
For faba beans, no cage studies were conducted, but field and plot studies showed a similar species composition of lygus and activity pattern as with canola. In most fields lygus were less than 1 per sweep and rarely 2 or more per sweep at any crop stage. Further studies are needed to make management recommendations but as a guideline farmers may take control action if there are more than 2 lygus per sweep but take care to mitigate impacts on pollinators and natural enemies. Faba bean, may rely on pollinators to improve yield, hence it is

crucial to mitigate insecticide impacts on them or the action could also affect yields negatively.

b) Quantify the potential economic impact of the project results (*e.g.,* cost-benefit analysis, potential size of market, improvement in efficiency, etc.).

Information on economic thresholds for insect pests such as lygus and cabbage seedpod weevils has a high potential to reduce production costs. Currently, in Alberta it is recommended to spray when lygus reach 1 per sweep at the early pod. The results from this study showed that in a normal year with sufficient rain (>120 mm in June and July, normal mean temperature under 20°C in July) lygus bugs at such low abundances (1/sweep) do not pose a major yield risk. Therefore, there are significant savings in production costs ($22/ha to spray insecticide by plane) when growers do not take action when not required. On the other hand, once lygus reach or surpass 3 per sweep in the south, there are significant economic returns to be realized by spraying because our results, despite high local variability, showed that lygus can reduce damage by about 15% in most years in southern Alberta and up to 20% in central Alberta. The higher yield loss reduction for central Alberta agrees with the recommendation based on regression analysis to use a lower threshold of 2 per sweep for that area. In a field situation the yield loss should be lower because lygus in open field are likely subjected to higher predation by natural enemies and also suffer more disturbance from rain and wind, unlike the situation in a cage. In a previous field study for cabbage seedpod weevils the average yield saved by spraying insecticide at early flower was around 2 bushels per acre, which is far less than 15% for most crops. This agrees with the idea that cages may overestimate the yield losses from insect feeding. An ongoing 4 year CARP-funded study will validate the lygus threshold at the farm level.

7. Contribution to training of highly qualified personnel (max ½ page)

Specify the number of highly qualified personnel (*e.g.*, students, post-doctoral fellows, technicians, research associates, etc.) who were trained over the course of the project.

Around 10 undergraduate students, interns, including co-op and other university or college students received training in crop entomology research as part of this project. A new senior technician at Lethbridge was trained on this type of specialized insect-cage research at the Lethbridge Research and Development Centre. Four technicians with AAFC, one temporary technician with AAF and one senior employee of AAF also received training on how to identify local lygus bugs in field crops of Alberta.

8. Knowledge transfer/technology transfer/commercialisation (max 1 page)

Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Please ensure that you include descriptive information, such as the date, location, etc. Organise according to the following categories as applicable:

a) Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report. None.

b) Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.); attach copies of any publications as an appendix to this final report. None.

c) Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report.

   a. Updating economic thresholds for lygus bugs in canola in Alberta, Canada. Carcamo, H., J. Otani, S. Daniels, N. Harker, P. Reid, J. Broatch and R. Laird. Poster presented at the 25th International Congress of Entomology, Orlando, Florida, 25-30 Sept 2016.
   b. Carcamo, Hector A., Otani, J., Harker, N., Reid, P., Broatch, J., Meers, S., Barkley, S.,Daniels, S. Of lygus and canola: where is the threshold? Proceedings of the Entomological Society of Alberta 63rd Annual Meeting, 1-3 October, 2015.

d) Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report.

   a. Cárcamo, H. and Hervet, V. An overview of beneficial insects and spiders in agroecosystems - including a live display. (Field Day Oral Presentation at Farming Smarter Crop Walk, 7 Aug 2014)
   b. Teleconference with Canola Council Agronomist to advice them on current thresholds and management of lygus bugs and seedpod weevil (Jay Wetter, 20 Jan 2015)

e) Media activities (*e.g.*, radio, television, internet, etc.)

   a. Web article by Barb Glenn of Western Producer was based on above presentation: http://www.producer.com/2014/08/bugs-dont-get-recognition-they-deserve/
   b. Interviews for Top Crop Manager with D. Fleury on Lygus IPM, 15 Oct 2015, published in Feb 2016: http://www.topcropmanager.com/insect-pests/managing-cabbage-seed-pod-weevil-and-lygus-bug-16787)
   c. Lygus & seedpod weevils in Saskatchewan (N. Billinger, CJWW Radio, 19 Aug 2015).

f) Any commercialisation activities or patents - NONE

N.B.: Any publications and/or presentations should acknowledge the contribution of each of the funders of the project, as per the investment agreement.

Section D: Project resources

1. **Provide a detailed listing of all cash revenues to the project and expenditures of project cash funds in a separate document certified by the organisation's accountant or other senior executive officer, as per the investment agreement.** Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage (CDL); and overhead (if applicable).

2. **Provide a justification of project expenditures and discuss any major variance (*i.e.*, ± 10%) from the budget approved by the funder(s). None**
3. **Resources:**
   Provide a list of all external cash and in-kind resources which were contributed to the project.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Agriculture Funding Consortium	$192,000	40.76433
Other government sources: Cash	$86,000	18.25902
Other government sources: In-kind	$189,000	40.12739
Industry: Cash		0
Industry: In-kind	$4,000	0.849257
Total Project Cost	$471,000	**100%**

External resources (additional rows may be added if necessary)		
Government sources		
Name (no abbreviations unless stated in Section A3)	Amount cash	Amount in-kind
Industry sources		
Name (no abbreviations unless stated in Section A3)	Amount cash	Amount in-kind

Section E: Research Team Signatures and Authorised Representative’s Approval

The Principal Investigator and an authorised representative from the Principal Investigator’s organisation of employment MUST sign this form.

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

By signing as an authorised representative of the Principal Investigator’s employing organisation and/or the research team member’s(s’) employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this final report to the funder(s).

Principal Investigator

Principal Investigator	
Name: **Hector Carcamo**	**Title/Organisation:** **Research Scientist, AAFC**
Signature:	**Date:** **11 October 2016**
Principal Investigator’s Authorised Representative’s Approval	
Name: **Dr. François Eudes**	**Title/Organisation:**
Signature:	**Date:**

Research Team Members (add more tables as needed)

1. Team Member	
Name:	**Title/Organisation:**
Signature:	**Date:**
Team Member's Authorised Representative's Approval	
Name:	**Title/Organisation:**
Signature:	**Date:**

2. Team Member	
Name:	**Title/Organisation:**
Signature:	**Date:**
Team Member's Authorised Representative's Approval	
Name:	**Title/Organisation:**
Signature:	**Date:**

Section F: Suggested reviewers for the final report

Provide the names and contact information of four potential reviewers for this final report. The suggested reviewers should not be current collaborators. The Agriculture Funding Consortium reserves the right to choose other reviewers. Under *Section 34* of the *Freedom of Information and Protection Act (FOIP)* reviewers must be aware that their information is being collected and used for the purpose of the external review.

Reviewer #1
Name: John Gavloski
Position: Farm Production Extension - Entomologist
Institution: Manitoba Agriculture
Address:
Phone Number: (204) 745-5668
Fax Number:
Email Address: Gavloski, John (MAFRD) (John.Gavloski@gov.mb.ca)

Reviewer #2
Name: Gadi Reddy
Position: Professor
Institution: Montana State University
Address:
Phone Number: (406) 450 0365
Fax Number:
Email Address: Reddy, G.V.P. (gadi.reddy@montana.edu)

Reviewer #3
Name: Scott Hartley
Position: Provincial Specialist, Insect/Vertebrate Pest Management
Institution: Government of Saskatchewan
Address: 125 - 3085 Albert Street, Regina, SK, Canada, S4S 0B1
Phone Number: 306-787-4669
Fax Number:
Email Address: Hartley, Scott AG (Scott.Hartley@gov.sk.ca)

Reviewer #4
Name: Andrew Keddie
Position: Associate Professor
Institution: University of Alberta
Address: Department of Biological Sciences
Phone Number: 780-492-0455
Fax Number:
Email Address: andrew.keddie@ualberta.ca