FINAL PROJECT REPORT
Canola Agronomic Research Program (CARP)

The Final Report should fully describe the work completed for the year and note the personnel involved. It should also note any deviations from the original plan and next and/or corrective steps as may be required if deviations are noted. The report should also provide an update on the status of the Project including forecasted date of completion. A complete statement of expenses should be included. In the event major changes are anticipated within the budget supporting notes along with a proposed budget should also be included. The report should also capture a complete summary of activity for the year.

Project Title: Getting more bang for your buzz: Does pollination compensate for canola yield lost under sub-optimal soil moisture, nitrogen fertilization and/or seeding rates?

Research Team Information

Lead Researchers:		
Name	**Institution**	**Expertise Added**
Ralph Cartar	University of Calgary	Bee foraging & pollination ecology
Research Team Members		
Name	**Institution**	**Expertise Added**
Shelley Hoover	Alberta Agriculture & Forestry - Lethbridge	Managed bees & plant-bee interactions; Location in Lethbridge.
Steve Pernal	AAFC Beaverlodge	Honey bee management; canola nectar & pollen production, Location in Peace River region.
Neil Harker (now Breanne Tidemann)	AAFC Lacombe	Canola agronomy

Project Start Date: **1 April 2016** **Project Completion Date:** **31 March 2019**

Reporting Period: **April 1, 2018** **to March 31, 2019**

CARP Project Number: 2016-20

This research involved important contributions from **many** people. Andony Melathopoulos largely conceived of this research, and, while employed as a postdoc with the project, got the work under way. George Adamidis, a postdoc with the project for 1.5 years, carried out field work, analyzed data, wrote manuscripts, and continues to be intimately involved with the research. Greg Semach organized and orchestrated 2 summers of field experiments, and their associated lab work in the fall. Four undergraduate Co-op students performed the bulk of the data collection: Ashley Londeau and Joseph Demarais (lab experiments), and Blake Temboline and Marie McCallum (field experiments). The following students and technicians helped in significant ways with the field experiment: Brett Campbell, Megan McElhinny, Rebecca Philip, Emily Melville, Irene Murray, Abdullah Ibrahim. Jeff Kearns and Lynae Ovinge helped with the lab experiments, and David Pearson, Tamar Messer, and Robert Prysiazny provided greenhouse help. Murray Hartman provided advice for setting up the lab experiments.

Detailed results

Experiment 1: Varietal specificity of pollinator benefits on canola seed yield

This project has been split into 2 manuscripts, one in revision, and one almost ready for submission. The first is a comprehensive paper that examines how presence of pollinators changes the traits of 23 canola varieties (9 open-pollinated and 14 hybrid), and the second is a more modest examination of floral traits in the same 23 varieties, and how these traits have changed with year of variety introduction. We excerpt blocks of the first manuscript in Subtopic 1, below.

Throughout this section of the report, when colour figures appear, yellow indicates presence of pollinators, and blue indicates absence of pollinators.

Subtopic 1: How do canola varieties, both past and present, differ in their pollinator dependency, and what traits explain any detected differences?

This greenhouse experiment compared traits of the 23 varieties grown in the presence or absence of pollinators.

The plants we used in this experiment were harvested in late December 2016, and early January 2017. From January to March, and continuing for a month thereafter, the harvested plants were bagged, dried, and measured for their traits. The traits we measured included: the number of flowers per plant, the amount of side-branching, length of the bloom period, harvest index (vegetative plant weight vs. seed weight), nectar sugar production (rate and concentration), yield on main and side branches and in total, 1000 seed weight (main and side branches), number of pods per plant, number of flowers per plant (estimated from pods and bud scars), weight of seeds per plant, green seed rate, oil content of seeds, branches per plant, root dry weight, proportion of flowers on the main vs. branch stems).

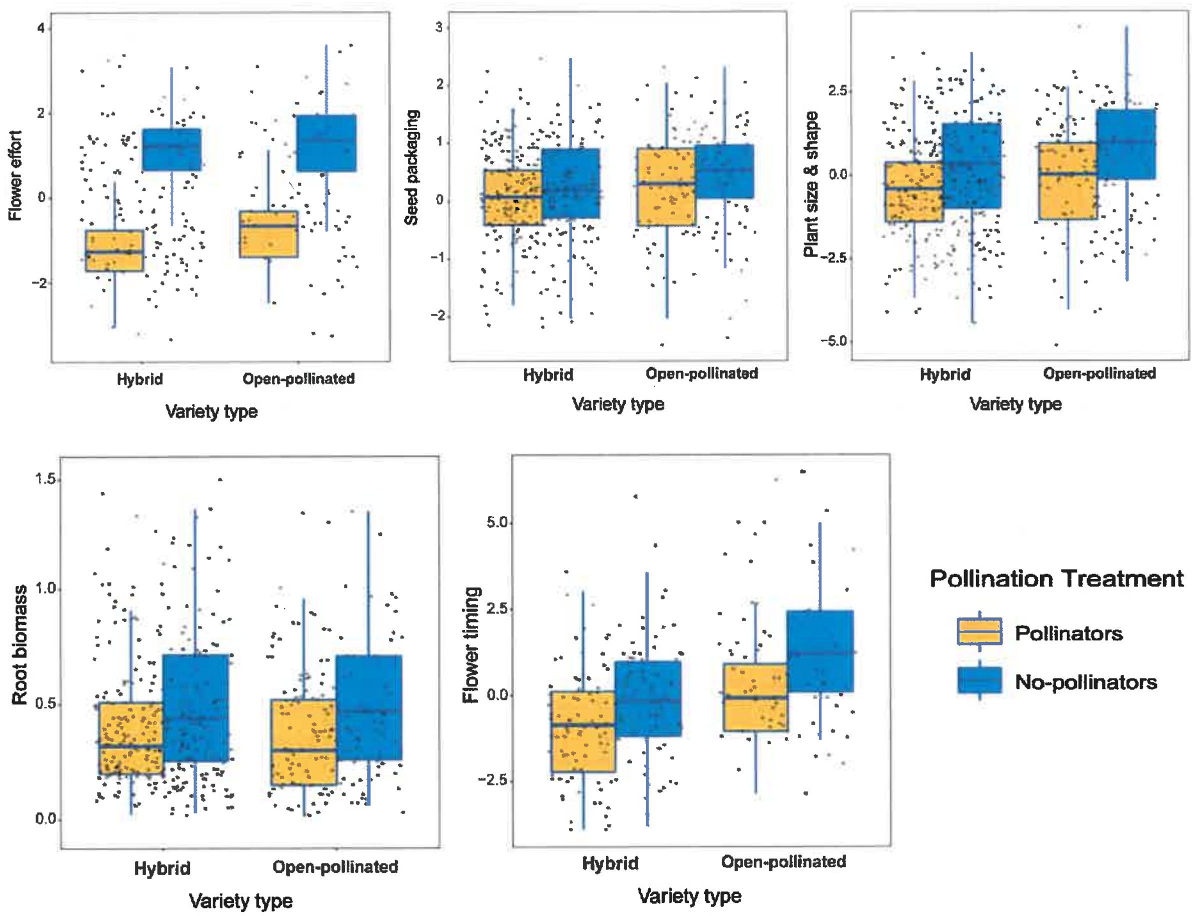
We obtained untreated seeds of 23 varieties of canola, and planted them in mid-September 2016 in greenhouses at the Agriculture and Agri-Food Canada (AAFC) Research Station in Lethbridge. The varieties were: 8 historic open-pollinated varieties, obtained from the Plant Gene Resources of Canada group at AAFC (ac excel, c1918, golden, midas, nugget, regent, tower, westar), and a range of hybrid seeds: 6 varieties from Bayer CropScience, 6 varieties from Monsanto, 2 varieties from Canterra Seeds, and 1 variety from Crop Production Services (Canada). Varieties were randomly assigned within 12 spatial blocks in a greenhouse, with one plant of each variety per block. These planting schemes were replicated in 2 greenhouses: one with pollinators (a single colony of captive commercial bumble bees), and one without pollinators. We used a bagged treatment of one variety (Westar) in both greenhouses to evaluate greenhouse effects that are independent of pollinators. The spatial blocks were implemented in consultation with Murray Hartman of Alberta Agriculture & Forestry (AAF). The spatial details of these blocks, and photographs of the experimental setup, were included in a previous progress report (Dec. 2016).

We measured details of the floral display (flower size, nectar standing crop, nectar volume) from single-aged flowers (2 days old) on non-focal plants (i.e., one of 3 pot-mates). We measured floral morphology and nectar only in the non-bee greenhouse, to allow easy measurement of nectar standing crop and flower dimensions without the influence of sometimes heavy floral visitation. Among varieties, we found a broad range of plant-level investment in flowers, as shown here using 2 traits: floral size, and nectar secretion. In the tables and figures below, we do not identify the corporate source of each variety.

We begin with results from Manuscript 1: "Pollinators enhance the yield and shorten the season of canola crops by modulating their functional characteristics".

(1) Do different canola varieties and variety types (OP & H) alter their functional character in response to insect pollination?

In a word: yes. Grouping traits into syndromes using Principal Components Analysis, and analysing these using ANOVA, we found that canola plants exposed to pollinators allocated fewer resources to flower production (i.e., flowering effort), to the production of pods (i.e., seed packaging) and to both above- and below-ground plant growth (plant size & shape, and root biomass, respectively), while flowering earlier than plants in the "no-pollinators" treatment. The figures appearing next show these pollinator-induced reductions, further broken out by variety type (which itself differed in 2 of the figures, see text below).



In the figures above, the "syndrome" variables are: Flowering Effort (# flowers at peak flowering, total flowers over phenology, duration of phenology); Seed Packaging (number of abscissed flower scars, number of main stem pods, number of branch pods); Plant Size & Shape (above-ground biomass, plant height, number of primary branches, number of secondary branches); Flower Timing (dates of: onset of flowering, peaking of flowering, median of flowering). Root biomass is just that.

We find strong effects of presence of pollinators on plant traits. Do these differences change according to variety or variety type? Variety type mattered for two of the syndromes: open-pollinated varieties allocated more resources to above ground plant growth, and flowered later

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relative to hybrid varieties. But at the varietal level, varieties didn't differ across pollination treatment in a way that differed from the overall effects shown in the figures above.

Take home message: presence of pollinators reduces plant size. What are the consequences for seed yield?

(2) Does insect pollination increase seed yield and quality across canola varieties and variety types, and if so, through which specific vegetative and phenological trait alterations is this being achieved?

Total canola yield (measured as total seed biomass, ln-transformed) was, on average, higher in canola plants exposed to insect pollination than those not exposed to pollinators, with canola varieties differing in their seed biomass, and with hybrid variety types producing the greatest yields.

On average, canola seed biomass decreased with a later peak of flowering, and increased with increasing root biomass, plant height, number of primary branches, and number of main stem pods. These relationships are in the following figure.

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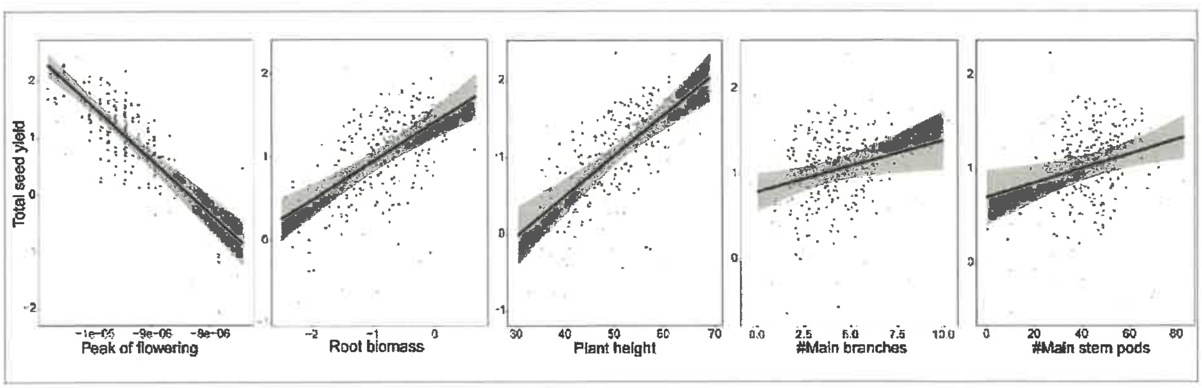
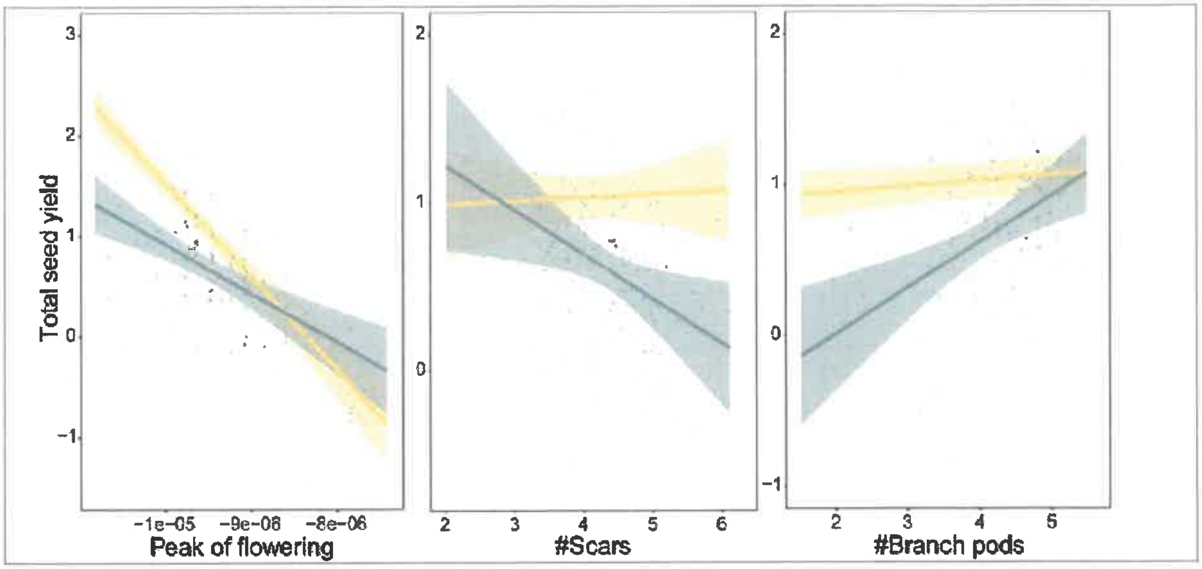


Pollinator visitation exacerbated the negative relationship between seed yield and time of peak flowering, resulting in higher yields in canola plants with an earlier peak of flowering. The presence of pollinators removed both the negative effect of number of scars, and the positive effect of number of branch pods on total seed yield, always resulting in higher or equivalent yields in comparison to the plants grown in the absence of pollinators. See below.



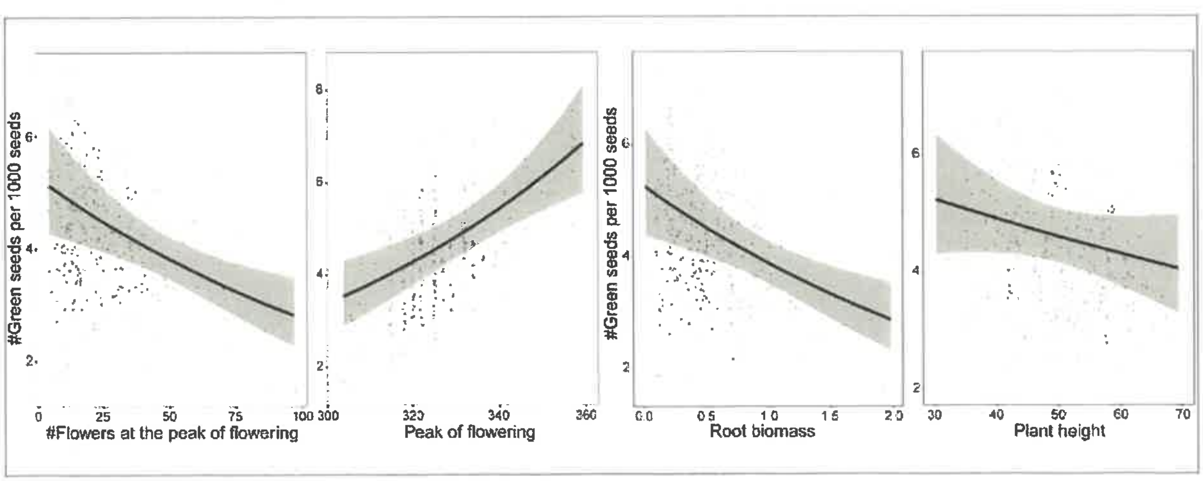
In the figures above, the "pollinators" treatment is shown in yellow, and "no pollinators" in blue-gray.

Overall, bigger, earlier-flowering plants with more investment in main stems (not secondary branches) produced the highest yield. But some of these simple responses depended on pollinator presence. Pollinators increased the value of earlier phenology, and removed the relationship between scars or branch pods and seed yield (in both cases keeping yield at its highest in the presence of pollinators).

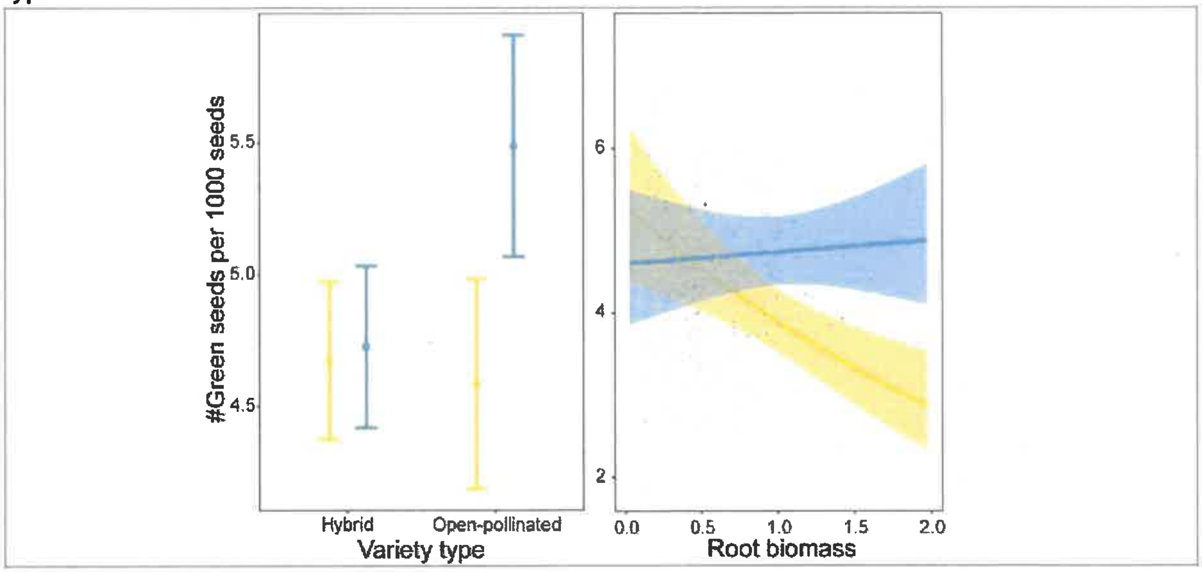
A second component of yield is the proportion of green seeds. Green seeds are undeveloped, and therefore represent a fitness and an economic cost.

There was a marginally significant tendency ($P = 0.071$) for canola plants not visited by pollinators to produce more green seeds, while variety type and variety, on average, did not differ in their green seed count.

After statistically controlling for presence of pollinators, green seeds were more common in canola plants with a later peak of flowering, but were reduced with increasing number of flowers at the peak of flowering. The number of green seeds was also lower for plants with high root biomass and plant height. On average, fast-growing and fast-maturing canola plants, with the ability to produce high numbers of flowers at the peak of flowering, produced less green seeds and thus higher quality yields.



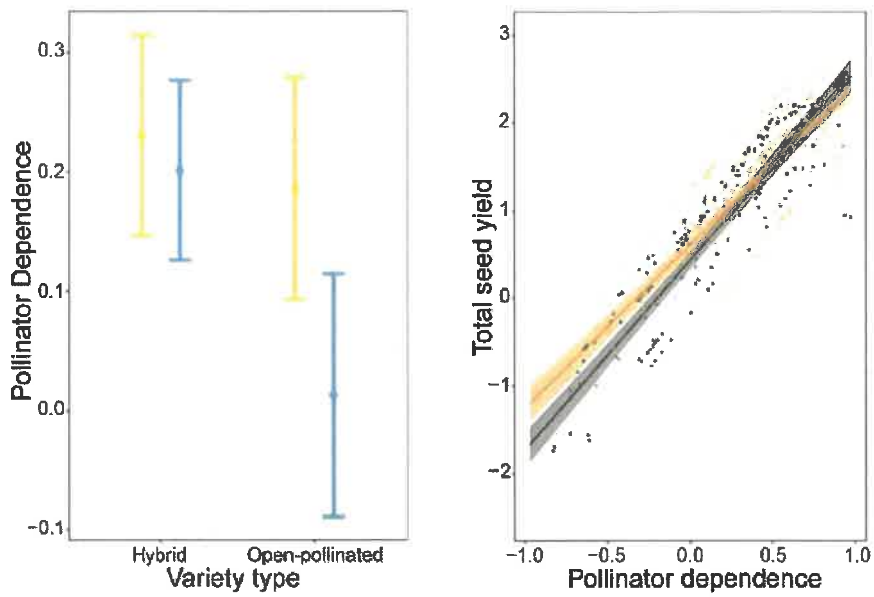
Bee pollination decreased the number of green seeds for open-pollinated canola varieties, but not for hybrid varieties, which had low numbers of green seeds in both pollination treatments. The presence of pollinators interacted with root biomass to affect the number of green seeds: in the presence of pollinators, plants with larger roots produced more green seeds but in the absence of pollinators, root biomass was unrelated to green seed production. See the figures below. Overall, green seeds increased with later peak flowering, and decreased with plant size (i.e., root biomass, plant height) and number of flowers, but lack of bees removed the effect of roots on green seeds. Pollinators reduced green seeds, but only in open pollinated variety types.



(3) Does pollinator dependence vary across canola varieties and variety types, and, if so, what traits characterize a 'pollinator-dependent' canola plant?

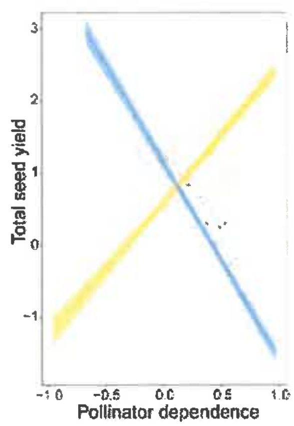
To characterize pollinator dependence, we introduce the notion of an individual-level of a measure of comparison commonly used to compare traits in a dimensionless common currency: the Relative Inequality Index, typically calculated as $(X_{pol} - X_{nopol}) / (X_{pol} + X_{nopol})$, where X_{pol} and X_{nopol} is the average total seed biomass in plants in the pollinator and no-pollinator treatments, respectively. We modified this formula to produce plant-level measurements, by comparing an individual plant's seed biomass to its varietal group mean in the other pollination treatment (either pollinator or no-pollinator). RII ranges from -1 to +1, is symmetrical around zero, has identical absolute values for dependence and non-dependence, and is continuous across its range. Positive values indicate a higher seed yield in the presence of pollinators (or a higher pollinator dependence), while negative values indicate the opposite.

Total seed yield was, on average, higher on pollinator dependent canola plants. Pollinator dependence had a stronger effect on yield than the effects of pollination treatment, variety type, and variety. The presence of pollinators significantly increased pollinator dependence of canola plants, especially for open-pollinated varieties. Open-pollinated varieties produced higher seed yields for the same amount of pollinator dependence. These last 2 sentences are visualized in the following figures, where error bars are 95% confidence intervals, and the black regression line shows the no-pollinator treatment (it's blue elsewhere).



(4) Are pollinator-dependent canola varieties/variety types more productive, or less so?

Pollinator dependence affected canola in a different way across the different pollination treatments. Pollinator dependence resulted into higher yields for canola plants visited by pollinators (e.g., at the edges of large canola fields), and to lower yields for plants that grew in the absence of pollinators (e.g., in the middle of large canola fields). See below.

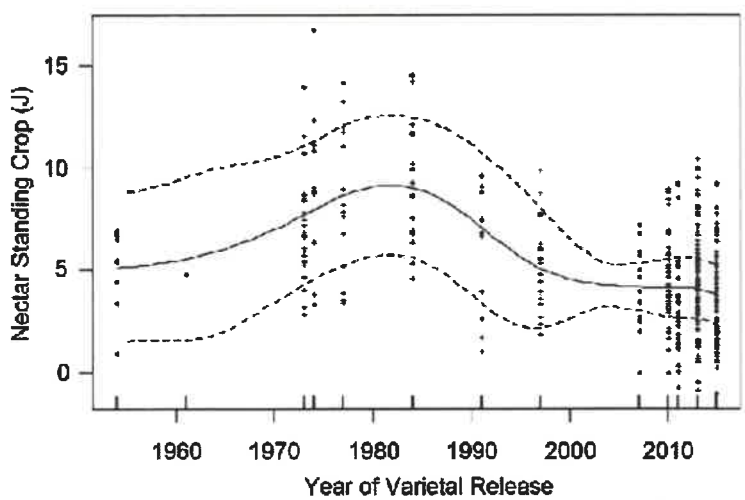


In sum, we detected trait responses to insect pollination across a wide range of commercially available canola varieties of two canola variety types (open-pollinated, 9 varieties; hybrid, 14 varieties), which represent a range from historic open-pollinated to contemporary hybrid canola varieties. Overall, we found that insect pollination modified the functional character of canola crops, increasing yield quantity and quality and pollinator dependence. Moreover, we show that, on average, canola yield and pollinator dependence are defined by strong trait trade-offs which range from more pollinator-dependent plants favouring rapid returns on investment (pollinator-dependent plants were larger, with earlier peak of flowering), to less pollinator-dependent canola plants favouring a more prolonged phenology with smaller plant size (and, as a consequence, lower seed quality caused by more undeveloped seeds). Finally, we find a negative relationship between canola yield and pollinator dependence in the absence of pollinators, and that hybrid varieties with lower values of pollinator dependence are more productive than the open-pollinated canola varieties. At a practical level, preferred use of hybrid varieties will decrease reliance on pollinators compared to open-pollenated varieties, but even among hybrid varieties in this class of canola, pollinators typically enhance yield. The sensitivity of plant traits to pollinators may have implications for plants, populations, communities, and ecosystems under climate change.

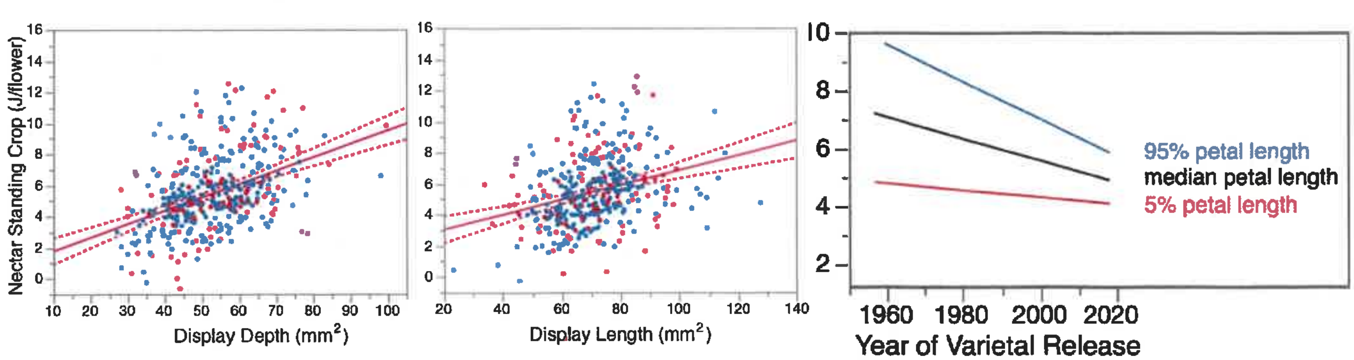
Subtopic 2: Floral traits of canola varieties: Decadal trends and size-nectar relationships.

Perhaps the most relevant canola trait for beekeepers is their rate of nectar secretion. We measured nectar standing crop in unvisited flowers of the no-bees treatment at a common developmental state (i.e., fully open corolla, with the style length ≤ the length of the stamens), and obtained a correlate of rate of nectar secretion (measured here as nectar standing crop).

Viewed across time, we see that open-pollinated canola varieties increased in their floral rewards between 1954 and 1984, and decreased thereafter (with the time series ending at 1997). Hybrid varieties, for which our earliest was developed in 2007, were relatively similar across years in nectar secretion, but at a mean level consistent with the lowest mean rewards offered by the open-pollenated varieties. Hybrid varieties, on average, secreted about 17% less nectar than did open-pollinated varieties. That is, beekeepers are expected to fare less well in current canola fields than they did in the 1980s, based on availability of nectar.



The overall effect of petal length and depth, a measure of the apparency and size of a flower, on nectar production was positive. Interestingly, floral length influenced the manner in which nectar secretion decreased with time of varietal release. The decrease was steepest for large floral displays (red line, below), and least important for flowers that were small (blue line, below). Points in red and blue represent open-pollinated and hybrid varieties, respectively.



In sum, floral size is positively associated with floral nectar rewards, suggesting a mechanism of choice for foraging bees. And with ongoing canola breeding, we see a world that is changing through the years in flower shape and reward: hybrid varieties offer visiting pollinators ~17% less reward than their open-pollinated cousins, and rewards have been on the decline since the mid-1980s, particularly for flowers with large petals.

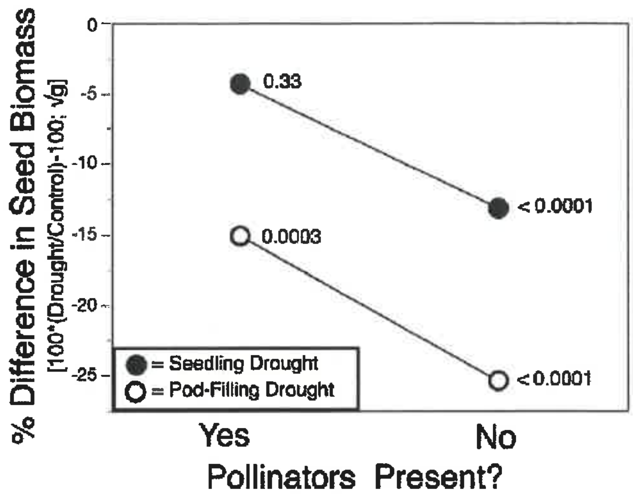
Experiment 2: Can pollinators reduce the negative impact of drought?

Stress during plant development is expected to decrease yields. In this greenhouse-based experiment, we tested whether presence of pollinators might allow plants to compensate for developmental stress, in this case shortage of water. The moisture stress (plants received only 30% of their normal watering amount) was imposed at two limited times: the vegetative stage (from the fourth leaf to the first visible petal; Seedling Drought), and the pod-filling stage (end of flowering to harvest; Pod-Filling Drought).

We used untreated seeds from 7 hybrid varieties: 2 from Bayer CropScience, 2 from Monsanto, and 1 from Crop Production Services (Canada), and one open-pollinated variety (Westar, from the Plant Gene Resources of Canada group at AAFC). These varieties were chosen as 4 of the least- and 4 of the most-responsive to pollination, in terms of their pod weights (from Experiment 1). We also tried to choose varieties with similar in-greenhouse flowering phenologies. In each of 2 greenhouses (one with pollinators, one without), we planted a total of 192 seedlings of all 8 varieties in a spatial blocking design that recognized greenhouse limitations in the ability to deliver different our 3 watering treatments (A — 100% water = 100 ml twice daily; B — water restricted to 30% of full amounts at the vegetative stage (4th leaf to first petal), and C — water restricted to 30% of full amounts at the pod filling stage (end of flowering to harvest). The spatial layout, which included spatial blocking (24 horizontal, 8 vertical), and each variety occurring once in each horizontal block, and equally in all 8 vertical blocks, is featured in our 2017 interim report.

We compared the traits of plants growing under moisture stress to those growing under no moisture stress (full access to sufficient water). We analyze one of those traits in this report: yield (biomass of seeds). We used 8 varieties in this experiment (6 hybrid, 2 open-pollinated), fitting the 3-way ANOVA sqrt(seed biomass) ~ variety:drought treatment:presence of pollinators.

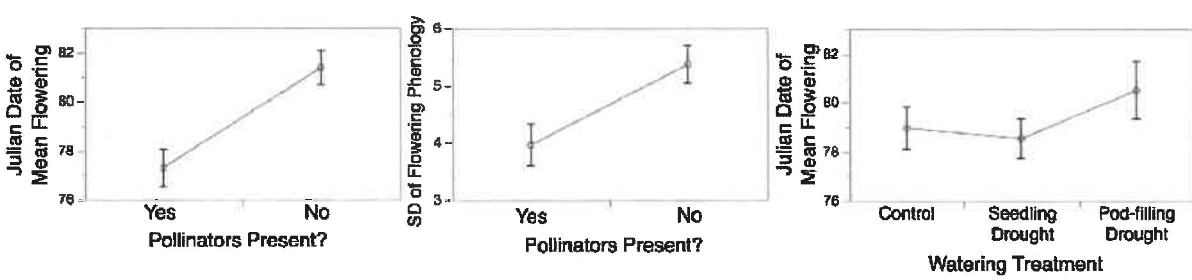
We found differences in yield between the pollinator treatments (lower yield in the presence of pollinators) that distract from the effect that we seek to explain: the within-pollinator treatment changes in yield caused by drought. To visualize these differences, we show how each of the two drought treatments differed from their neighbours receiving sufficient water, expressed as a percent difference. Overall, drought during the pod-filling stage had a more negative effect on final yield than did drought during the seedling stage. More strikingly, presence of pollinators reduced the loss of seed yield (ln[biomass]) in response to drought by roughly 11.5%, or, 19.7% in untransformed units (g). Plants experiencing Seedling Drought did not differ from their full-water brethren. Roughly speaking, presence of pollinators can increase seed yield (g) during both forms of drought by roughly 20%, relative to their absence.



The P values in the figure above provide significance of the contrast of the contrast on which the difference is computed (i.e., [drought/control]-1).

Canola plants begin flowering on main their main stem, and later on most flowers are on side branches. We measured all reproductive traits both on the main stem, and on the collective side branches. When we re-ran the 3-way ANOVA whose main pollination-based results are shown above (using the biomass of all seeds found on each plant), we found that the outcome was the same using the seed mass from branches, but different when using the seed mass from main stems. Hence, the main impact of pollinators on reducing drought stress occurs from branch pods.

We quantified the flowering phenologies of each plant, using the distribution of flowering effort across the season for those individuals with 5 or more non-zero days of flower counts (flowers were counted every 3 days). Did presence of pollinators advance phenology and shrink its variation, relative to their absence? Yes, as shown in the figures below (showing least square means from 3-way ANOVAs with Watering Treatment, Presence of Pollinators, and Variety as main effects). Presence of bees shifted the flowering phenology about 4 days earlier in mean (leftmost figure, below), and 1.3 days lower in standard deviation (middle figure). Drought experienced at the pod stage also lengthened the flowering season by 1.5 days for drought at the pod-filling stage, relative to control plants (rightmost figure).



We measured the same vegetative traits as in Experiment 1, and will examine the determinants of these yield responses to drought, and its timing. We expect to present these results in a soon-to-be written manuscript.

Overall, we find support for the hypothesis that presence of pollinators ameliorates the negative effects of drought on plant yield, increasing yield (in grams) by ~20% in drought. This is accomplished primarily by shifting the plant's flowering phenology earlier and narrower, and is primarily a response to seed production on branches (not the main stem), where the average contribution of branches to whole-plant seed biomass is roughly half of the total.

Experiment 3. The effect of plant spacing and nitrogen on pollinator benefits: A test in a field context.

Methods:

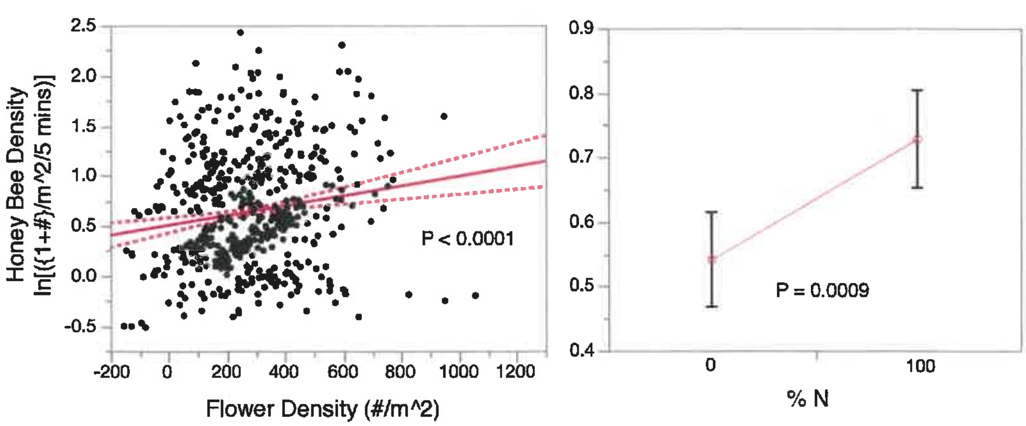
This field experiment examined 3 treatments (N fertilization [none, conventional], Pollinators [present, absent], and Plant Spacing [half-conventional = 75 seeds/m^2, conventional=150 seeds/m^2]) using 4 hybrid varieties of canola collectively grown in 80 experimental plots at the AAFC Research Station in Beaverlodge, AB. The 80 plots allowed for a randomized (E-W spatial) block design, replicating each variety-fertilization-spacing combination 5 times in each of 2 years (2017, 2018). The Pollinators Absent treatment was achieved using screen tents (of basal area 1 m by 1 m, and height of 1.5 m), placed over plants just before the 10% bloom stage, and removed after harvest. In each of two years, we measured plant traits at harvest, and, for subplots outside of the pollinator exclosure tents, measured flower counts, bee visitation, and nectar secretion during bloom. We also measured nectar secretion of plants within the pollinator exclusion tents (also at the sub-plot level).

In 2017, we also added 3 new treatments (but dropped these in 2018, because of the unsustainable work load). First, we added two "snapshot" treatments, where plants were harvested earlier in development, at 20% bloom and at peak bloom. Snapshot treatments allow us to examine how pollination changes the timing of development of the primary stem and secondary branches. Second, we introduced a "no-breed" treatment, where plants were prevented from investing in flowers through their lifetimes. This treatment provides a contrast that considers plant vegetative traits in the absence of breeding. Collectively, we anticipate that these new treatments will allow for inferences about the developmental changes caused by presence or absence of pollinators. But they do not feature in the analyses presented below.

In 2018, we also measured floral morphology at the sub-plot level, and measured sub-plot yield. This latter measurement will allow us partially to relate yield of individual plants to yield measured on the basis of field area.

Results

We begin by examining natural variation in the experiment, focusing on bees and flowers outside of our pollinator exclosures. First we found that bee visitation of canola was attuned primarily to floral abundance and Nitrogen (mixed model ancova: ln(#bees+1) ~ flower abundance + %N (2 levels) + Variety (4 levels) + Seed Density + Julian Date + Year (2 levels) plot|year (random effect), with no significant interactions)(see the following two figures, which, as with all figures in this report, show partial effects that statistically adjust for the other variables in the model, meaning that some nonsensical values, like negative honey bee densities and flower counts, can occur).



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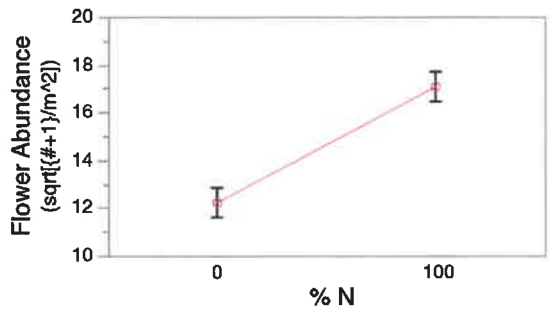
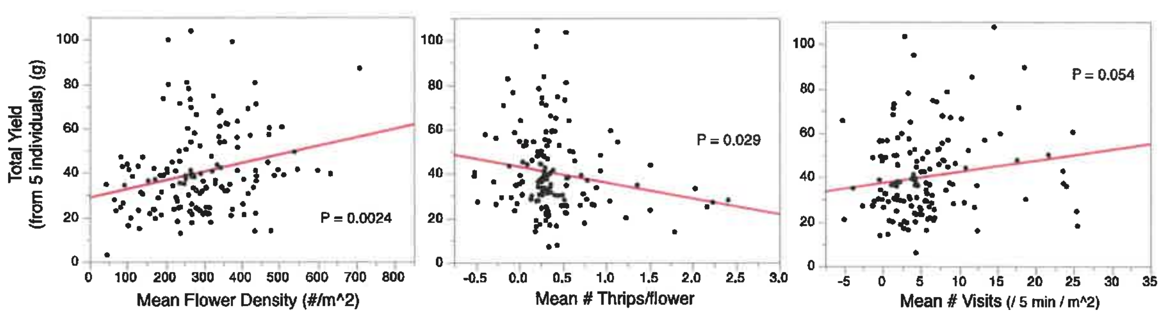
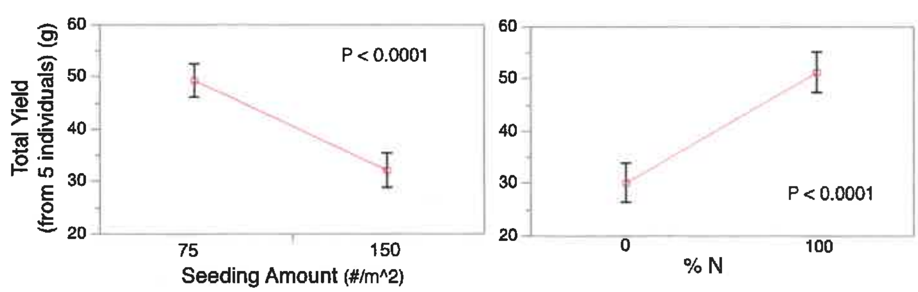
Given that flowers are the magnet for bee attention (see figure above), what treatments enhanced their number? Only N mattered: unfertilized plots had fewer flowers (mixed model ancova: sqrt(#flowers+1) ~ %N (2 levels) + Variety (4 levels) + Seed Density + Julian Date + Year (2 levels) + plot(year)[random effect], with no significant interactions)(see the following figure).



There are two ways of looking at effects of open pollination on canola yield at the plot level: considering mean bee and floral traits without regard to treatment, and considering them together with experimental treatments. We begin with the first approach. Combined yield from 5 focal plants (note that is is not area-specific yield) was increased by flower density and bee visitation, and decreased by flower thrips (ancova: Yield from 5 individuals ~ Mean Flower Density + Mean Thrips Abundance + Mean Bee Visitation + Year (2 levels))(see the following figures).



But these pollinator- and flower-dependent trends in yield are statistically obscured when we include the experimental treatments (%N, Seeding Amount, Variety) into the same model. At the plot level, the yield of individual plants is enhanced by lower seeding amount and presence of N fertilizer. (see the following figures; Variety is also significant, but not shown). That is, treatments matter for yield, and they dwarf the impact of natural variation in pollinators and thrips.



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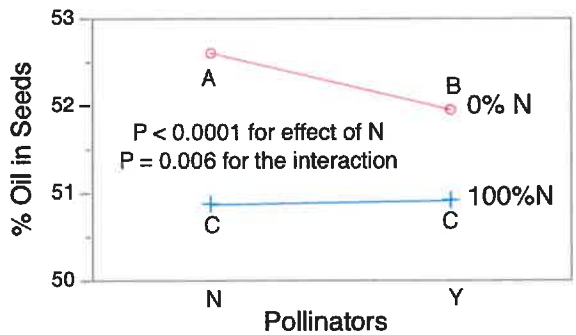
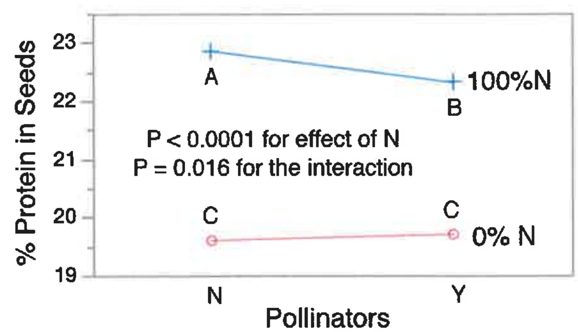
How did experimentally induced variation in pollinators (i.e., inside or outside of a pollinator-excluding tent) affect canola seed quality and quantity?

Pollinators affected the protein and oil content of canola seeds, but only by slightly modifying a strong effect of N on these two traits.

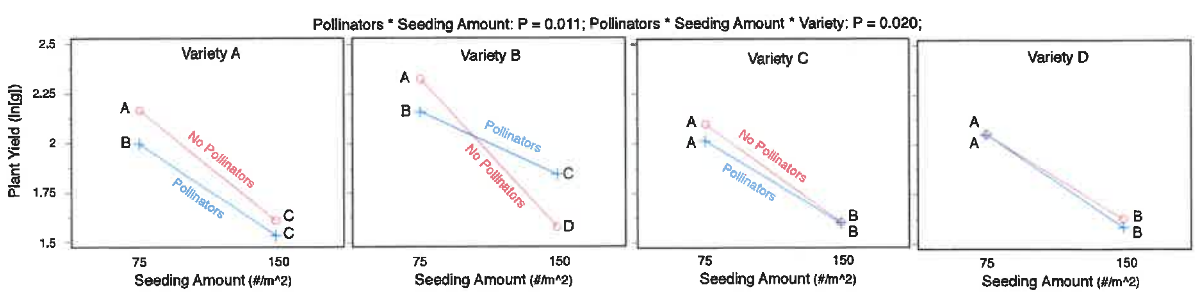
In the case of % oil content, varieties differed in their amounts (not shown), and N strongly decreased the content. Pollinators marginally reduced the oil content of unfertilized plants (ancova: % oil ~ Seeding Amount + %N + Pollinators + %N•Pollinators + Year + Plot(Year) [random])(see the following figure). Similarly, pollinators marginally reduced the protein content of fully fertilized plants (ancova: % oil ~ same model as for % oil)(see the following figure). That is, in both cases, presence of pollinators reduced the quality of seeds, relative to the treatment associated with maximum quality (no N, in the case of oil; N in the case of protein).



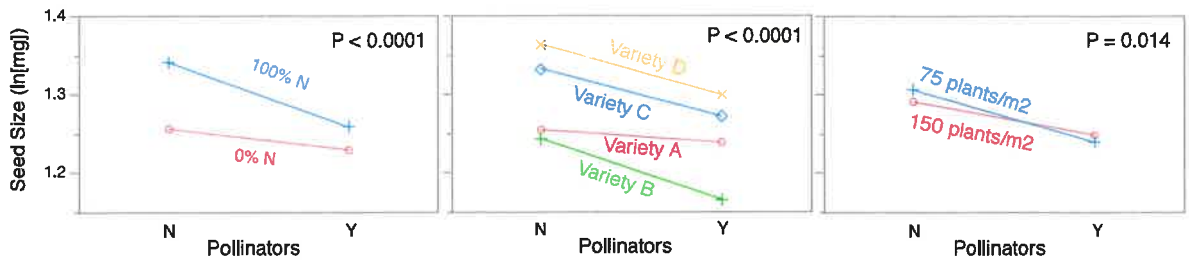


The effect of pollinators on yield was more nuanced than their effect on seed quality, but, regardless of nuance, pollinators rarely enhanced yield (ancova: Plant Yield (g) ~ Seeding Amount : %N : Pollinators : Variety + Year + Plot(Year, Seeding Amount, Pollinators, %N, Variety)[random]; R^2=0.36). Pollinators interacted with planting density in explaining yield, but their overall pattern was to decrease yield under low seeding amounts. This effect was primarily caused in 2 Varieties: A and B (see figure below), although in Variety B, pollinators actually enhanced yield at normal planting densities (150 seeds/m^2).

Nitrogen was the principal determinant of plant yield: 100% N roughly doubled yield over no fertilizer (least square means for yield: no fertilizer = 3.75 g, fertilizer = 7.75 g). Seeding Amount was the second biggest factor: with lower seeding amount causing a roughly 80% increase in yield (least square means for yield: 75 seeds/m^2 = 7.22 g, 150 seeds/m^2 = 4.06 g).



Mean seed size had many experimental determinants, of which pollinators were important (alone, and in 4 interactions). Counter-intuitively, pollinators reduced seed size by an average of 5% (ancova: Plant Yield (g) ~ Seeding Amount : %N : Pollinators : Variety + Year + Plot(Year, Seeding Amount, Pollinators, %N, Variety)[random]; R^2=0.45). In the 3 two-way interactions in which Pollinators were involved, in all cases, yield was lower with pollinators in the more favourable circumstance (high N, low seeding amount).



Having considered total yield and seed size in the analyses above, seed number is not an independent measure (given that yield = # * size). But we note that analyses of seed number, with the same structure as the preceding two models, found an R^2 and effects similar to that of total yield, at least with respect to the contribution of pollinators to explaining plant performance. We conclude that pollinators influence plant yield primarily through changes in seed number, not seed size. But, in general, pollinators did not enhance the reproduction of canola.

Note that we leave the testing of the mechanistic hypotheses for impacts of pollinators on canola reproduction that we raised in the proposal to later. Instead, this "final" report focuses more on describing the seed yield and quality outcomes of the presence of pollinators, in a field context.

Overall, we found little support in the field trials for a beneficial effect of pollinators on the seed quality or quantity of individual canola plants. Using observational data, bees responded positively to flowers, flowers to fertilization, and yield to bees and flowers. But these results were dwarfed by the contrasts in components of yield that were attributable to pollinators, and in these contrasts, pollinators were associated with lower yields. In Experiment 1, we found that canola varieties differed in their developmental and reproductive responses to pollinators. Differences in the reproductive responses of canola varieties to pollinators also obtained in Experiment 3, but all varieties showed some response to pollinators, either alone (seed size) or interaction with seeding density (yield). Seed quality, measured either as % oil or % protein content, was diminished by pollination treatments, in concert with the stronger effect of fertilization (%N) on quality.

One possibility for our finding of a consistent negative effect of pollinators is that screen tents provide a favourable microclimate for seed production, such that what we call "no pollinators" may be better characterized as a "warm microclimate". We are following up on this idea, using microclimate data recorded with HOBO data-loggers positioned inside and outside a sample of screen tents. As such, our conclusions from the field trials about the effects of pollinators on yield must be viewed as preliminary.

Public Outreach in which this research was featured:

Hoover S (2017) More bang for your buzz: Varietal Differences and Canola Pollination. Beaverlodge Beekeepers Field Day, Beaverlodge, AB (June 2017)

Hoover S (2017) Apiculture Research Program Update. Southern Alberta Beekeepers, Fort MacLeod, AB (March 2017)

Hoover S (2017) Lethbridge Research Centre Apiculture Research Program. Calgary Beekeepers Club, Calgary, AB (March 2017)

Adamidis GC, Hoover S, Melathopoulos A, Pernal S, Harker N, Cartar RV. (2018) Bees and canola: Understanding a win-win situation. Alberta canola producers commission, Murray Hartman's ScienceOrama - Canola Research Update. 21 March 2018, Nisku, AB, Canada.

Adamidis GC, Hoover S, Melathopoulos A, Pernal S, Harker N, Cartar RV. (2018) Bees and canola: Understanding a win-win situation. Beaverlodge Research Farm, 65th Annual Beekeepers' Field Day. 22 June 2018, Grande Prairie AB, Canada.

Hoover S (2018) Pollinating crops in Alberta. Lethbridge College, Lethbridge AB.

Pernal, S.F. (2018) Overview of Beaverlodge Research Farm. New Employee Orientation Session, 01 May 2018, Beaverlodge, AB. (featured a synopsis of the project)

Hoover S (2018) Bang for your buzz: managing bees for canola pollination. Invited Seminar, University of Manitoba, Winnipeg, MB.

Hoover S¸ Pernal S, Adamidis G, Melathopoulos A, Cartar R (2019) The Buzz on Canola Pollination. Beaverlodge Annual Field Day, Beaverlodge, AB

Cartar R (2019) "Speaker" at "Pollinators" booth at CanolaPALOOZA. LaCombe, AB.

Adamidis GC, Cartar RV, Melathopoulos A, Pernal S, Hoover S. (2019) Pollinators enhance crop yield and shorten the growing season by modulating plant functional traits: A comparison of 23 canola varieties. 33rd Annual Meeting of the Scandinavian Association of Pollination Ecology. 24-27 October 2019, Höör, Sweden.

5. Research and Action Plans

The data collection is complete, and we are now in the process of writing papers and submitting manuscripts from the work. The first manuscript, related to Experiment 1, is currently in review. It is:

Pollinators enhance the yield and shorten the season of canola crops by modulating their functional characteristics. George C. Adamidis, Ralph V. Cartar, Andony P. Melathopoulos, Stephen F. Pernal, Shelley E. Hoover. In revision. Scientific Reports.

6. Final Project Budget and Financial Reporting

Title	Description	2016-17	2017-18	2018-19	2019-20	Totals
Salary & Benefits		**20,700.00**	**49,251.88**	**34,254.43**		**104,206.31**
	Postdoctoral Fellowships	0.00	26,833.38	0.00		26,833.38
	Postdoctoral Salaries	0.00	19,166.70	30,666.72		49,833.42
	Research Assistants	20,700.00	0.00	0.00		20,700.00
	Canada Pension Plan	0.00	878.24	1,405.29		2,283.53
	Employment Insurance	0.00	443.04	712.68		1,155.72
	Extended Health Care Ins	0.00	854.04	658.92		1,512.96
	Ben - Group Life Insurance	0.00	51.88	39.38		91.26
	Dental Plan	0.00	724.19	545.92		1,270.11
	Workers Compensation	0.00	124.61	98.32		222.93
	Ben - LT Disability Insurance	0.00	150.60	110.40		261.00
	Accid Death & Dismember	0.00	25.20	16.80		42.00
	Benefits - Other	0.00	0.00	0.00		0.00
Other Expenditures		**6,900.00**	**72,835.13**	**24,421.76**		**104,156.89**
	Materials & Supplies	0.00	70,596.23	23,459.86	5,750	99,806.09
	Courier Delivery & Shipping	0.00	985.03	60.33		1,045.36
	Meeting Expenses	0.00	0.00	0.00		0.00
	Rentals - Other	6,900.00	0.00	0.00		6,900.00
	Travel - Standard	0.00	1,253.87	901.57		2,155.44
	Maintenance - Non-Cap Alts	0.00	0.00	0.00		0.00
	Internal Exp - Miscellaneous	0.00	0.00	0.00		0.00
	Other expenses				49.78	49.78
TOTAL Expenditures		**27,600.00**	**122,087.01**	**58,676.19**	**5,799.78**	**214,162.98**

Please forward an electronic copy of this completed document to:

Gail M. Hoskins
Crop Production Administrator and CARP Coordinator
Canola Council of Canada
400 – 167 Lombard Ave.
Winnipeg, MB R3B 0T6
Phone: (204) 982-2102
Fax: (204) 942-1841
E-Mail: hoskinsg@canolacouncil.org

Gail Hoskins

From: Ralph Cartar <cartar@ucalgary.ca>

Sent: Monday, September 02, 2019 9:49 AM
To: Gail Hoskins
Subject: final report for CARP 2016-20
Attachments: 2016-20 CARP Final Report.pdf

Dear Gail

Here's our final report for project 2016-20. I think you should view it as a progress report, because our analysis of its most ambitious experiment, the field trials, is just starting.

I've tried my best to reveal what we now understand about the work, but it's mostly filled with my interpretations, not those of my colleagues.

Please remember not to post this report on the Research Hub until I get feedback from the seed companies with whom we have MTAs. To that end, I've put a "not for public distribution" header and footer on the "results" section. But it should be fine for internal distribution at CCC.

This project was a lot of work, involving an army of people, and I think we've learned a lot about how canola works (with pollinators).

Having the Canola Council's support of this research was tremendous, and we're most grateful. We especially appreciate the CCC's willingness to support the project's postdoc (George) for a final 4 months. Unfortunately, as is often the case with postdocs, he moved on to a new job opportunity instead. So project 2016-20 has suffered in his absence, but he remains closely tied to the research.

I attach the report. Its final page has the one page summary. Hopefully it's not too obtuse!

All the best, Ralph