Agriculture Demonstration of Practices and Technologies (ADOPT)

Project Final Report

The final project report should be made available electronically (MS Word). Additional data tables and or graphs may be submitted in spreadsheet format. Due to formatting, printing and distribution requirements, final reports will not be accepted as PDF documents. Completed reports must be returned by email to Evaluation.Coordinator@gov.sk.ca.

Project Title:	Demonstrating the Efficacy of Foliar-Applied Nitrogen Fixing Bacteria for Canola
Project Number:	20220417
Producer Group Sponsoring the Project:	Saskatchewan Canola Development Commission
Project Location(s): *Provide the name or number of the rural municipality, nearest town or legal land location if possible. Provide the name of any cooperating landowner(s).*	Indian Head, R.M. #156 (Indian Head Agricultural Research Foundation); Melfort, R.M. #428 (Northeast Agriculture Research Foundation); Outlook, R.M. #284 (Irrigation Crop Diversification Corporation); Prince Albert, R.M. #481 (Conservation Learning Centre); Redvers, R.M. #61 (Southeast Research Farm); Scott, R.M. #380 (Western Applied Research Corporation); Swift Current, R.M. #137 (Wheatland Conservation Area Inc.); Yorkton, R.M. #244 (East Central Research Foundation)
Project start date *(month & year):*	4/1/2023
Project end date *(month & year):*	3/31/2024

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Abstract *(maximum 200 words)*

Detail key elements from the project objectives, methodology, results and conclusions to provide a short concise summary of the project. List extension activities such as field days or workshops and include the number of people who visited the project.

In 2023, field trials were conducted at eight Saskatchewan locations to evaluate and demonstrate the potential ability of commercially-available, foliar-applied biological products to aid in nitrogen (N) nutrition and improve yield in canola. The locations were Indian Head, Melfort, Outlook (irrigated), Prince Albert, Redvers, Scott, Swift Current, and Yorkton. The treatments were a factorial combination of three N fertility levels (60, 110, or 160 kg N/ha) and three foliar

treatments (untreated control, Envita®, or Utrisha™-N). The N levels included residual soil nitrate and the foliar treatments were applied at the 4-6 leaf stage and label recommended rates. Except for two locations, we observed consistent yield responses to increasing N fertilizer rates and all sites showed the expected N fertilizer response for seed protein and oil concentrations. There were, however, no indications of improved N status associated with the foliar treatments for any response variables, regardless of N fertilizer level or location. As such, we recommend that farmers do not back off on their N fertilizer rates if using such products and include check strips to evaluate efficacy on their own farms. Many of the Agri-ARM sites featured this demonstration during their annual field days and dissemination of results during winter extension meetings is ongoing.

Project Objectives

Provide a short statement outlining the project objectives. Identify the key concept this project was designed to demonstrate. For example, you might use a statement such as *"This project was intended to demonstrate and compare the benefits of……" or "The objective of this project was to demonstrate the impact of…."*

The objective of this project was to demonstrate the effects of commercially-available, foliar-applied nitrogen (N) fixing bacteria products on the yield and seed quality of canola grown under a range of N fertility levels and contrasting environmental conditions.

Project Rationale

Briefly describe why this project is of interest to local producers. Why is it important to have this project? What are the potential beneficial outcomes? What is the perceived need?

Nitrogen is the most commonly limiting nutrient in the production of non-legume crops in Saskatchewan and, in many cases, the most expensive input. This is especially true in recent years as fertilizer prices have reached record high levels. Further to the economic considerations, national and international targets for reducing greenhouse gas emissions associated with N fertilization in agriculture are putting pressure on producers to maximize the efficiency of N fertilization and, potentially, reduce overall N inputs. Consequently, products that have potential to reduce N fertilizer requirements in crop production have received substantial attention and interest from Saskatchewan grain producers and commodity groups. Furthermore, many in the agricultural industry expect biological products to play an increasingly important role in the efficient and sustainable production of crops. The proposed project aims to demonstrate, under field conditions and a wide-range of soil/climatic environments, the agronomic performance of new biological products such as Envita® (Azotic Technologies; 1 x 107 CFU/ml *Gluconacetobacter diazotrophicus*) and Utrisha™-N (Corteva Agriscience; 3 x 107 CFU/ml *Methylobacterium symbioticum* SB23). These products may have the ability to facilitate biological N fixation in crops that would otherwise be unable to do so; thus, potentially subsidizing soil and fertilizer N and improving the overall fertilizer N-use efficiency in Saskatchewan crop production. While others exist, these two biological N-fixing technologies are expected to have the greatest market share in western Canada and are likely the most familiar to Saskatchewan producers. As one of the most economically important crops in Saskatchewan and largest users of N, canola is an excellent test crop for this project. This topic was specifically identified as a research and extension priority by SaskCanola directors and members.

Methodology

Fully describe how the project was set up and run. You should provide enough information so that any reader can understand what you did, and where and when you did it. From that they can determine if your report has any relevance to their own operation. For example, your description should include all relevant items such as 1) the number and size of any field plots, 2) what was seeded, 3) what treatments were applied to the plots, 4) the schedule or timing of any relevant activities such as seeding, treatment application or harvest, and 5) what was measured to evaluate the success of any treatment. If your project dealt with animals, you should be sure to include 1) the number of animals in each trial group, 2) the treatment or procedure applied to each group, and 3) what was measured to evaluate the success of each treatment.

Field trials with canola were initiated at eight Saskatchewan locations in the spring of 2023. The locations were representative of a broad range of Saskatchewan growing regions and, in alphabet order, included Indian Head (thin-Black soil zone), Melfort (Black soil zone), Outlook (Brown soil zone, irrigated), Prince Albert (Black soil zone), Redvers (Black soil zone), Scott (Dark Brown soil zone), Swift Current (Brown soil zone), and Yorkton (Black soil zone). The treatments were a factorial combination of three N fertilizer levels and three foliar-applied, N fixing biological products, arranged in a Randomized Complete Block Design (RCBD) and replicated four times at each location. The target N levels, adjusted for residual soil NO_3-N (0-60 cm), were 60 (low), 110 (medium), and 160 kg N/ha (high). It was our expectation for N to be limiting at both the low and medium levels while, at the high level, the N rates would be more typical for canola but still not excessive for most regions. The foliar-applied biological treatments were either an untreated control (none applied), Envita® (95 ml/ac plus 0.1% Agrol 90), and Utrisha™-N (135 g/ac). These treatments were applied at the 4-6 leaf stage, in a minimum water volume of 93 l/ha (10 US gal/ac), and we used distilled water to minimize any potential negative impacts of chlorine or other additives on the biological products being demonstrated. We also did our best to apply the treatments either early in the morning or on relatively cool days. While prolonged humid conditions may have also been ideal, this was not necessarily possible as we had to hit the target crop stages and have limited windows that were suitable for the treatment applications. Furthermore, farmers do not generally have the luxury of waiting for ideal conditions to apply crop protection products or biologicals such as those evaluated in the current project.

Selected agronomic information and dates of operations are provided in Table 5 of the Appendices. Plot size varied across locations to accommodate the specific seeding and spraying equipment. Weeds were controlled using registered pre-emergent and in-crop herbicides and preventative fungicide applications were recommended to ensure that disease would not be a yield limiting factor. Although not all sites applied a fungicide, the risk of disease was generally low and it is highly unlikely that this had any impact on yields or the observed responses. Pre-harvest herbicides or desiccants were used at the discretion of individual site managers and, wherever possible, only the centre rows of each plot were harvested to avoid potentially confounding edge effects.

Various data were collected to evaluate the treatments and help explain the results. Composite soil samples were collected for the specific study areas and analyzed by Agvise Laboratories for residual nutrients and other basic properties. To provide information on the overall establishment at each site and test for potential N fertilizer rate effects, plant counts were completed after emergence was complete and the average number of plants/m^2 for each plot was calculated. Yields were determined by weighing the seed harvested from a known plot area, adjusting the weights for dockage and to a uniform moisture content of 10%, and converting the values to kg/ha. Seed protein and oil concentrations were determined using NIR grain analyzers; however, only seed oil was determined at Outlook. Weather data for each site were recorded using either Environment Canada or privately owned weather stations and are summarized for the May-August, inclusive, period.

All response data was analyzed using the generalized linear mixed model (GLIMMIX) of SAS. For seed yield, seed protein, and seed oil, the effects of site (S), N fertilizer level (N), foliar treatment (F), and all possible interactions were considered fixed while replicate effects (nested within site) were considered random. For plant density, foliar treatment was excluded from the model since these treatments had not yet been applied when the measurements were completed. We permitted and tested for heterogeneity in variance estimates across locations for all response variables; however, the more complex model was only used when doing so significantly improved convergence. Treatment means were separated using Tukey's test and orthogonal contrasts were used to test whether the overall N-rate responses were linear, quadratic, or not significant. All treatment effects and differences between means were considered significant at $P \leq 0.05$; however, p-values of 0.05-0.1 may also be acknowledged. Data from three sites, Prince Albert, Scott, and Swift Current, were excluded from the combined analyses due to either there being no response to N whatsoever (Prince Albert and Scott) or severe hail damage (Swift Current); however, data from these sites were still analyzed individually using simplified models and are reported on and discussed as appropriate.

Results *(you must provide the following information)*

Present and discuss any project results, including any data or measurements taken to evaluate the demonstration. Include things that didn't appear to work. These results are just as important to share. List extension activities such as field days or workshops. List the activity, the date it occurred, and the number of people who attended.

Soil Test Results and Growing Season Weather Conditions

Soil test results for all eight sites are provided in Table 1 below. While our intention was to have initially low residual N at all sites, this was not always possible with the actual amounts ranging from 20-72 kg NO_3-N/ha (0-60 cm). Nitrogen fertilizer rates were adjusted for residual NO_3-N, with the lowest N level targeting 60 kg N/ha (soil plus fertilizer); however, this could not be achieved at Melfort, Prince Albert, and Yorkton where the low N level ended up with 71, 97, and 68 kg N/ha, respectively, after the N from any phosphorus and sulfur fertilizer products were accounted for. Except for Prince Albert, these levels were considered to be close enough to the target that we did not treat the low N levels at these sites any differently in the statistical analyses. Soil pH, organic matter, and C.E.C. values varied widely but were all considered typical for their corresponding locations. Nutrients other than N were intended to be non-limiting and were not specifically of interest for this project.

Table 1. Selected soil test analyse results for biological N fixation product demonstrations conducted for canola at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), and Yorkton (YK) in 2023. With the exception of soil NO_3-N and S, which are estimated for 0-60 cm, all measurements are for the the 0-15 cm soil depth.

Parameter	IH-23	ME-23	OL-23	PA-23	RV-23	SC-23	SW-23	YK-23
pH	7.7	7.3	7.9	5.7	7.8	5.3	6.6	6.5
Organic Matter (%)	5.7	7.2	2.6	6.2	2.8	3.1	2.5	6.3
CEC (meq)	44.7	34.6	22.2	20.2	31.0	14.9	17.0	21.4
NO_3-N (kg/ha) [Z]	20	44	20	72[Y]	32	38	24	47[Y]
Olsen-P (ppm)	7	15	5	5	4	30	18	15
K (ppm)	655	368	277	273	205	260	495	385
kg S/ha (kg/ha) [Z]	58	85	198[Y]	74[Y]	65	101	54	45[Y]

[Z] Values for residual NO_3-N and S are for the 0-60 cm soil profile

[Y] Corresponding values were reported for 0-30 cm and estimated for the 0-60 cm depth by multiplying by 1.5

Mean monthly temperatures for each location are presented along with the long-term (1981-2010) averages in Table 2 while precipitation amounts are in Table 3. All locations were considerably warmer than average, with May and June being particularly hot. July was slightly cooler than average to approximately average while August temperatures were approximately average to slightly above average. Over the four-month period from May through August, growing season temperatures ranged from 1.4-1.9 °C above average. Turning our attention to precipitation, all locations but one were much drier than average. Swift Current was the exception, with 95% of average precipitation and, with 179 mm in total, this location was also the wettest in absolute terms, despite typically being the most arid of the Agri-ARM locations. Unfortunately, the plots at Swift Current were also damaged by a hail storm that resulted in an estimated 60% yield loss. Outlook was the driest of the sites with only 95 mm of precipitation (46% of average); however, this location is irrigated and received an additional 246 mm of irrigation water in June through August. The remaining locations received 49-70% of the long-term average precipitation amounts, or 111-179 mm. Excluding Outlook, which was irrigated, Indian Head, Melfort, and Yorkton were the driest in both absolute terms and as a percentage of the long-term average.

Table 2. Mean monthly temperatures along with long-term (LT; 1981-2010) averages for the 2023 growing season at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (RV), Scott (SC), Swift Current (SW), and Yorkton (YK), Saskatchewan.

Year	May	June	July	August	May-Aug
	---------- Mean Temperature (°C) ----------				
IH-23	14.0	19.4	16.7	17.7	17.0 (+1.4)
IH-LT	10.8	15.8	18.2	17.4	15.6
ME-23	14.1	19.2	16.9	17.3	16.9 (+1.7)
ME-LT	10.7	15.9	17.5	16.8	15.2
OL-23	15.2	19.5	18.5	18.7	18.0 (+1.9)
OL-LT	11.5	16.1	18.9	18.0	16.1
PA-23	14.4	18.8	16.6	17.1	16.7 (+1.6)
PA-LT	10.4	15.3	18.0	16.7	15.1
RV-23	14.5	19.7	17.6	17.9	17.4 (+1.4)
RV-LT	11.1	16.2	18.7	18.0	16.0
SC-23	14.9	17.2	17.1	17.4	16.7 (+1.9)
SC-LT	10.8	14.8	17.3	16.3	14.8
SW-23	14.8	17.7	18.4	18.8	17.4 (1.6)
SW-LT	11.0	15.7	18.4	17.9	15.8
YK-23	13.8	19.7	16.7	17.8	17.0 (+1.8)
YK-LT	10.4	15.5	17.9	17.1	15.2

Table 3. Mean monthly precipitation amounts along with long-term (LT; 1981-2010) averages for the 2023 growing season at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (RV), Scott (SC), Swift Current (SW), and Yorkton (YK), Saskatchewan.

Year	May	June	July	August	May-Aug
	---------- Total Precipitation (mm) ----------				
IH-23	12.9	49.6	15.9	40.8	119 (49%)
IH-LT	51.8	77.4	63.8	51.2	244
ME-23	17.9	26.4	16.4	50.0	111 (49%)
ME-LT	42.9	54.3	76.7	52.4	226
OL-23	17.2	15.3 (117)	15.5 (86)	46.6 (43)	95 (46%)
OL-LT	42.6	63.9	56.1	42.8	205
PA-23	22.8	52.8	40.8	51.2	168 (67%)
PA-LT	44.7	68.6	76.6	61.6	252
RV-23	84.1	33.0	10.8	37.6	166 (62%)
RV-LT	60.0	95.2	65.5	46.6	267
SC-23	16.6	81.1	29.7	31.7	159 (70%)
SC-LT	38.9	69.7	69.4	48.7	227
SW-23	41.0	32.9	63.3*	42.1	179 (95%)
SW-LT	42.1	66.1	44.0	35.4	188
YK-23	16.8	67.9	18.0	33.3	136 (50%)
YK-LT	51.3	80.1	78.2	62.2	272

[Z] Values in parentheses Outlook are irrigation water

[Y] Hailstorm at Swift Current on July 22/2023 resulted in an estimated 60% seed yield loss

Canola Establishment, Yield, and Seed Quality

To give a sense of the overall environmental conditions and productivity at each site, location means for each response variable are presented in Table 4 below. Again, Prince Albert, Scott, and Swift Current were excluded from the combined analyses so neither letter groupings nor standard error values are provided for these locations. Not unexpectedly given the wide range of environmental conditions, the site effects were highly significant ($P < 0.001$) for all response variables (Table 6). Overall differences between sites will be referred back to where appropriate while discussing treatment effects and individual response variables.

Table 4. Main effect means for location, or site effects on canola plant density, seed yield, seed protein concentration, and seed oil concentration. Values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$). Values in parentheses are the standard error of the treatment means (S.E.M.).

Location	Plant Density	Seed Yield	Seed Protein	Seed Oil
	----- plants/m^2 -----	-------- kg/ha --------	---------- % ----------	---------- % ----------
Indian Head [Z]	104 A (2.25)	2246 C (99.7)	18.4 AB (0.76)	46.0 AB (0.86)
Melfort [Z]	76 C (2.25)	2115 C (99.7)	16.7 B (0.13)	47.0 A (0.17)
Outlook [Z]	108 A (2.25)	3502 A (100.0)	–	43.4 B (0.23)
Prince Albert [Y]	80	3018	18.7	44.9
Redvers [Z]	61 D (2.25)	2401 BC (99.7)	18.5 A (0.16)	44.2 B (0.20)
Scott [Y]	95	2614	22.7	44.1
Swift Current [Y]	44	529	29.4	40.5
Yorkton [Z]	92 B (2.25)	2780 B (99.7)	20.4 A (0.66)	43.7 B (0.83)
	---------- p-value ----------			
Pr > F	<0.001	<0.001	<0.001	<0.001

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), and the S x N interaction as fixed effects

[Y] Data were excluded from the combined analyses and, therefore, cannot be compared to other sites

Plant densities were primarily measured to provide insights into the overall establishment at each location in addition to any potential impacts of the N fertility treatments. According to the overall tests of fixed effects in the combined analysis (Table 6), emergence was affected by site ($P < 0.001$) and N rate ($P = 0.037$) but no S x N interaction was detected ($P = 0.579$). The highest plant populations were achieved at Indian Head and Outlook (104-108 plants/m^2), followed by Yorkton (92 plants/m^2), Melfort (76 plants/m^2), and Redvers (61 plants/m^2). Plant populations at Prince Albert, Scott, and Swift Current were 80, 95, and 44 plants/m^2, respectively. Detailed results for N effects on emergence are deferred to the Appendices (Table 8) and the overall N effect was small and somewhat difficult to explain with slightly lower populations at the medium N level (85 plants/m^2) compared to either the low or high levels (90-91 plants/m^2). The trend was not observed at all individual locations and small enough that mean plant densities did not differ between N levels for any sites individually. At both Scott and Swift Current (analyzed separately), plant densities were significantly lower at the highest N level, not uncommon depending on soil texture, seeding equipment, and conditions at seeding. Establishment was not affected by N level at Prince Albert.

Detailed results for canola seed yield are provided in Tables 9 and 10 of the Appendices, but summarized graphically in Figs. 1-3 below. Yield was affected by both site ($P < 0.001$) and N level ($P < 0.001$); however, the lack of an S x N interaction ($P = 0.224$) tells us that the N response was consistent across sites. There was no effect of foliar treatment on yield ($P = 0.224$); however, a marginally significant S x F interaction ($P = 0.076$) and the fact that this was a key part of the project objectives justifies presentation of the individual site responses, regardless of their significance.

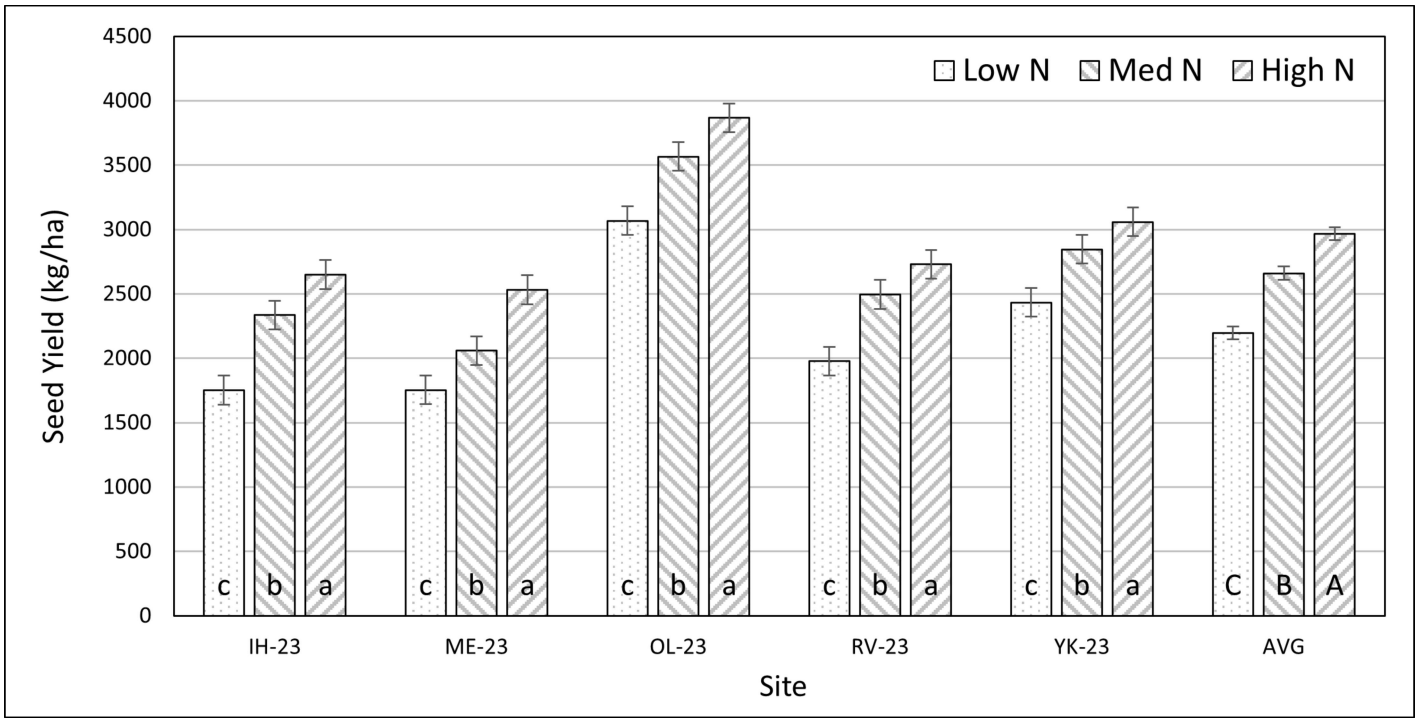

Figure 1. Nitrogen (N) fertility level effects on canola seed yields for individual sites and averaged across sites. The N fertility levels were Low (60 kg N/ha), medium (110 kg N/ha), and high (160 kg N/ha), including residual soil N. The locations were Indian Head (IH-23), Melfort (ME-23), Outlook (OL-23), Redvers (RV-23), and Yorkton (YK), while AVG denotes the overall, 5-site average. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

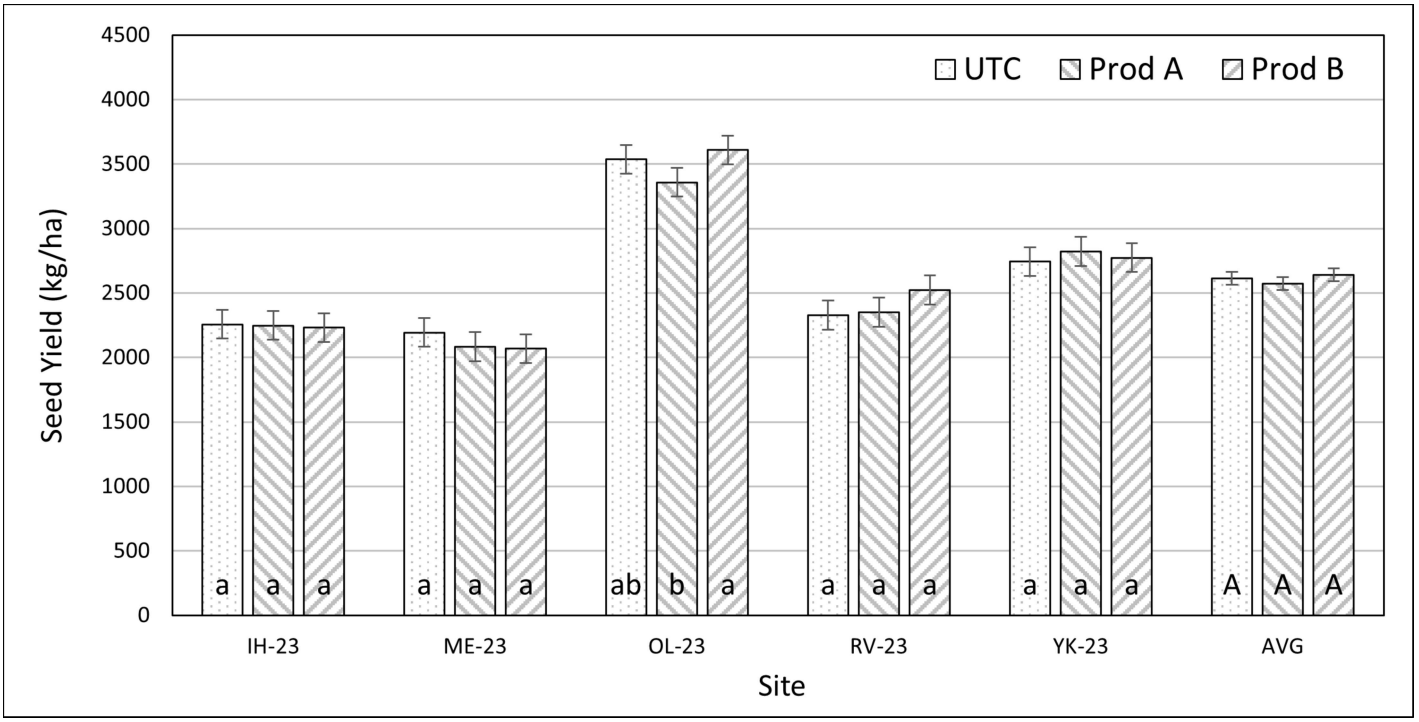

Figure 2. Foliar-applied nitrogen (N) fixing bacteria treatment effects on canola seed yields for individual sites and averaged across sites. The foliar treatments were UTC (untreated check), Prod A (95 ml/ac Envita + 0.1% Agrol 90), and Prod B (135 g/ac Utrisha-N), applied at the 4-6 leaf stage. The locations were Indian Head (IH-23), Melfort (ME-23), Outlook (OL-23), Redvers (RV-23), and Yorkton (YK), while AVG denotes the overall, 5-site average. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

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Averaged across treatments, yields ranged from 529 kg/ha at Swift Current to 3502 kg/ha at Outlook (Table 4). Again, yields of all eight locations cannot be directly compared since not all were included in the combined analyses. Of those that were, and averaged across them, canola yields increased with each incremental increase in the N fertility level (Fig. 1; Table 9). At Swift Current, yields at the highest N level were greater than those at the lowest while there was no yield response to N whatsoever at Scott or Prince Albert (Table 9). With the exception of Prince Albert and Scott, the response was linear for all sites individual ($P < 0.001$); however, when averaged across the five sites included in the combined analyses, the response was quadratic ($P = 0.024$) due to slightly diminishing returns going from the medium to high N fertilizer levels. Averaged across the five sites in the combined analyses, foliar treatment had no impact on canola yields; however, the marginally significant ($P = 0.076$) S x F interaction could arguably justify a closer look at individual sites. This interaction appeared to be primarily due to Outlook, where Utrisha™-N yielded higher than Envita®, but neither differed from the untreated control (Fig. 2; Table 9). There were no significant effects of foliar treatment on canola yield at Prince Albert, Scott, or Swift Current, regardless of N rate (Tables 7 and 9). Although no significant N x F interactions for yield were detected at individual sites or when averaged across them, these individual treatment means are provided in Table 10 (all sites and averaged across sites) and Fig. 3 below (averaged across sites).

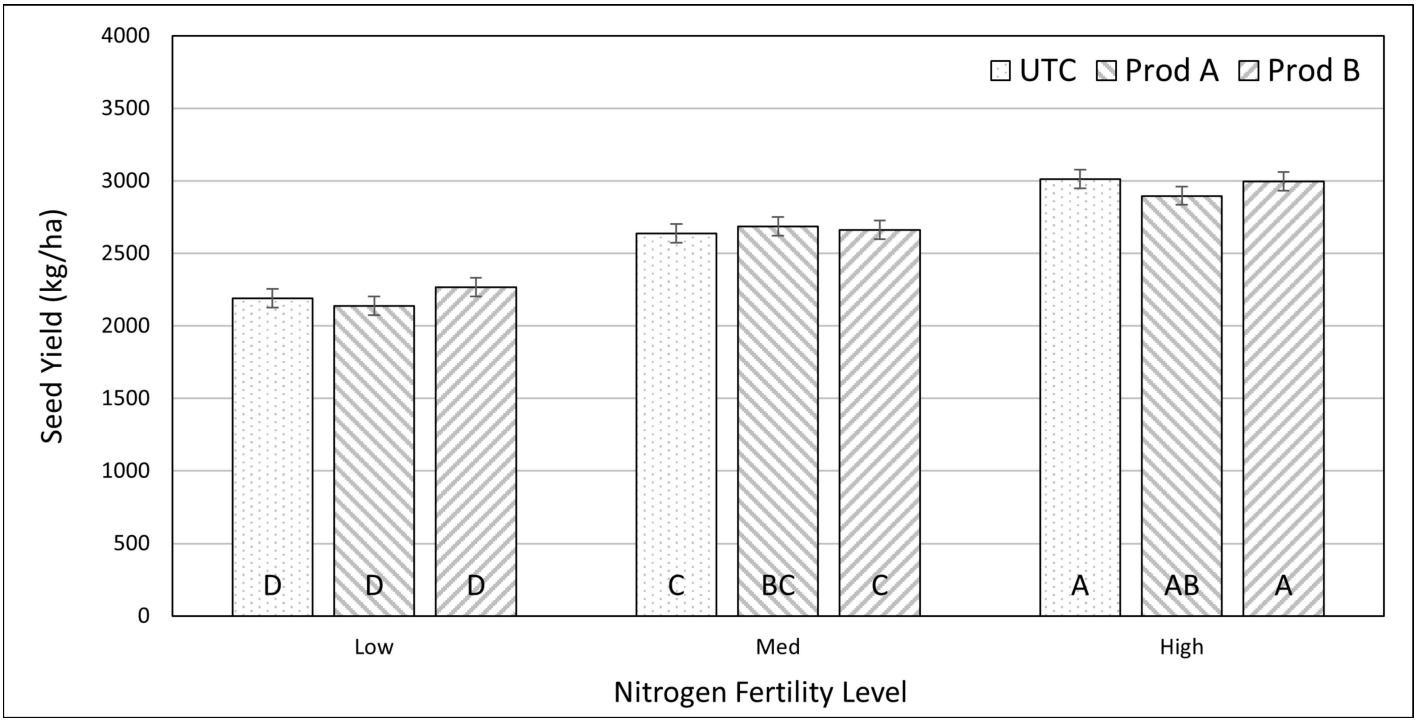

Figure 3. Nitrogen (N) fertility level by foliar-applied N fixing bacteria treatment effects on canola seed yields, averaged across 5 sites. The N fertility levels were Low (60 kg N/ha), medium (110 kg N/ha), and high (160 kg N/ha), including residual soil N. The foliar treatments were UTC (untreated check), Prod A (95 ml/ac Envita + 0.1% Agrol 90), and Prod B (135 g/ac Utrisha-N), applied at the 4-6 leaf stage. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

In general, canola seed protein will increase with improvements in N fertility, with the most rapid accumulation often occurring after yield increases with additional N begin to diminish. With that, we would generally expect positive responses to the foliar treatments to result in higher seed protein. We have already seen that there were no significant yield increases associated with the foliar treatments. According to the overall tests of fixed effects (Table 6), canola seed treatment was affected by site and N level with a significant S x N interaction ($P < 0.001$-0.003) detected. The effect of foliar treatment was not significant ($P = 0.676$) and nor were the S x F, N x F, or S x N x F interactions ($P = 0.250$-0.735). Again, seed protein was not measured at Outlook.

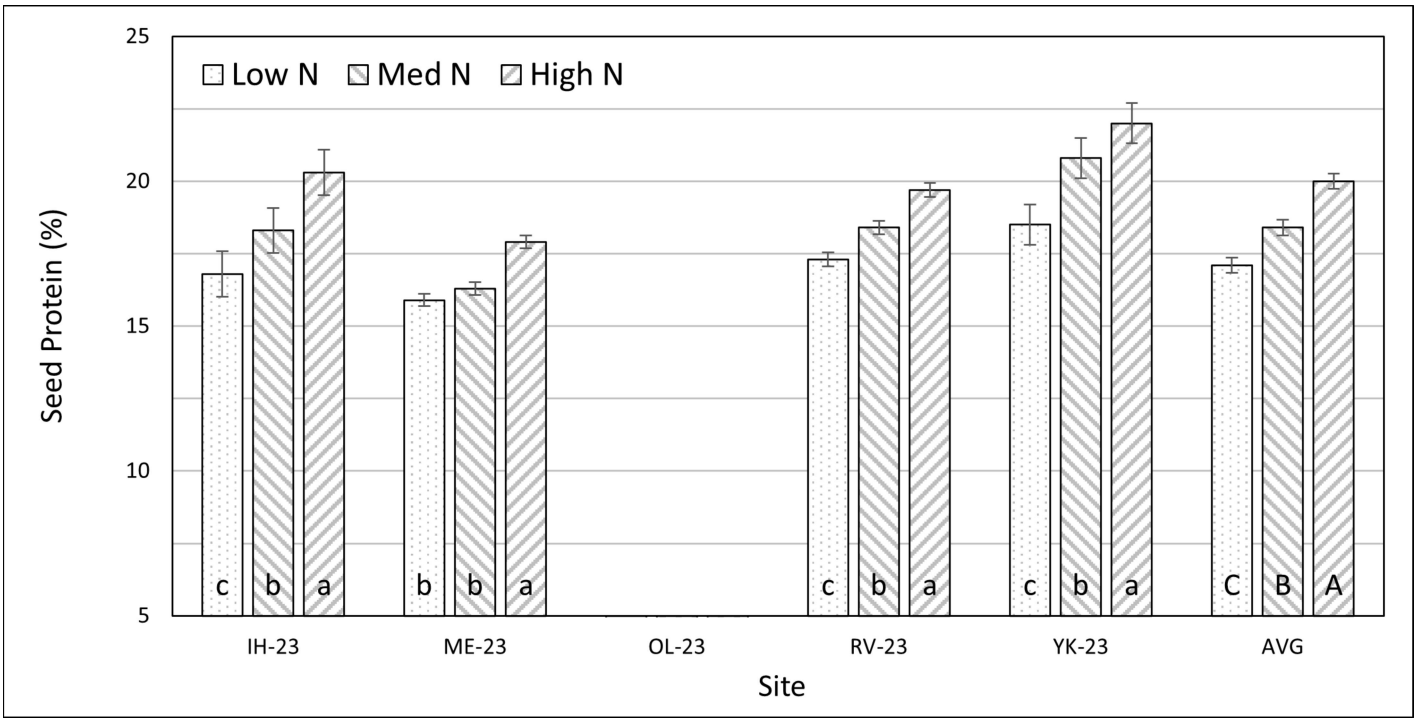

Figure 4. Nitrogen (N) fertility level effects on canola seed protein concentrations for individual sites and averaged across sites. The N fertility levels were Low (60 kg N/ha), medium (110 kg N/ha), and high (160 kg N/ha), including residual soil N. The locations were Indian Head (IH-23), Melfort (ME-23), Outlook (OL-23), Redvers (RV-23), and Yorkton (YK), while AVG denotes the overall, 4-site average (Outlook did not measure seed protein). Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

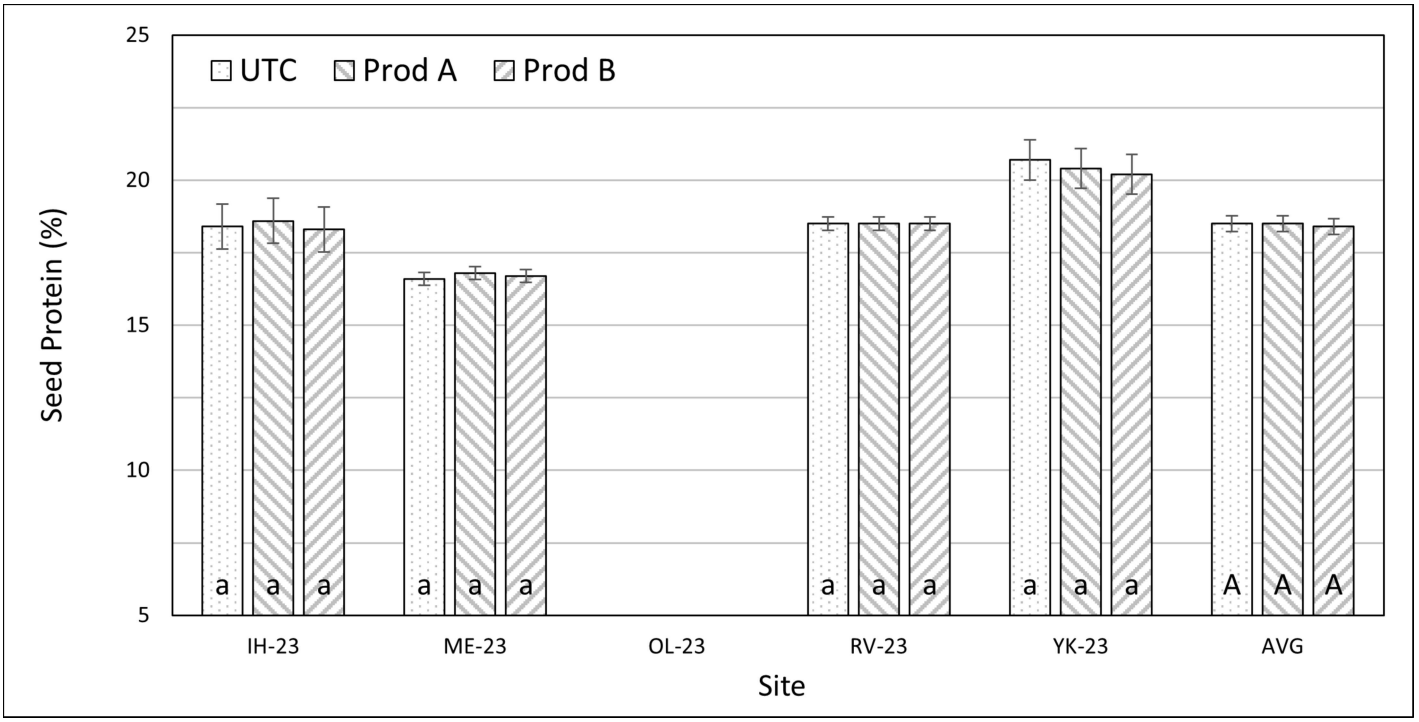

Figure 5. Foliar-applied nitrogen (N) fixing bacteria treatment effects on canola seed protein concentrations for individual sites and averaged across sites. The foliar treatments were UTC (untreated check), Prod A (95 ml/ac Envita + 0.1% Agrol 90), and Prod B (135 g/ac Utrisha-N), applied at the 4-6 leaf stage. The locations were Indian Head (IH-23), Melfort (ME-23), Outlook (OL-23), Redvers (RV-23), and Yorkton (YK), while AVG denotes the overall, 4-site average (Outlook did not measure seed protein). Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

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Overall, and regardless of whether they were included in the combined analyses, mean seed protein concentrations for each location ranged from as low as 16.7% at Melfort to 29.0% at Swift Current (Table 4). Averaged across the sites included in the combined analyses, seed protein increased linearly ($P < 0.001$) from 17.1% at the lowest N level to 20% at the highest (Table 11, Fig. 4). The S x N interaction, however, tells us that this varied for individual sites. The sole discrepancy was at Melfort, where protein concentrations were similar between the low and medium levels while, for all other sites, protein increased with each incremental increase in N fertility. With no overall effect of foliar treatment ($P = 0.676$) nor S x F interaction ($P = 0.735$) according to the overall tests of fixed effects in the combined analyses (Table 6), canola seed protein was not affected by foliar treatment when averaged across sites or for any of them individually (Fig. 5; Table 11). The N x F interaction and S x N x F interactions indicated that the response to foliar treatments was not affected by N fertilizer level; however, means are presented for interest sake in Fig. 6 below and Table 12 of the Appendices. At Prince Albert, Scott, and Swift Current, analyzed individually, seed protein consistently increased with N fertilizer rate ($P < 0.001$-0.009) but was not affected by foliar treatment ($P = 0.119$-0.726), nor were there any N x F interactions ($P = 0.258$-0.879).

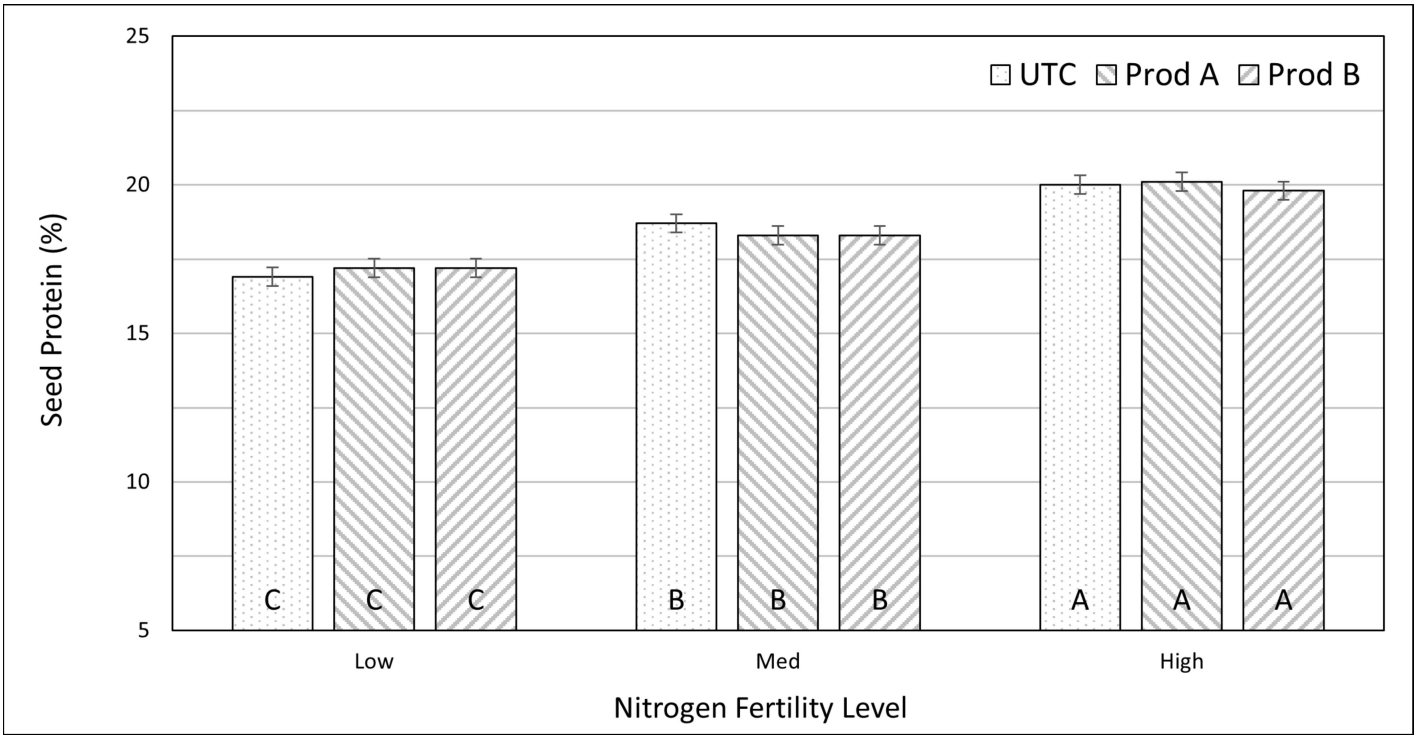

Figure 6. Nitrogen (N) fertility level by foliar-applied N fixing bacteria treatment effects on canola seed protein concentrations, averaged across 4 sites. The N fertility levels were Low (60 kg N/ha), medium (110 kg N/ha), and high (160 kg N/ha), including residual soil N. The foliar treatments were UTC (untreated check), Prod A (95 ml/ac Envita + 0.1% Agrol 90), and Prod B (135 g/ac Utrisha-N), applied at the 4-6 leaf stage. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

Averaged across treatments and regardless of whether they were included in the combined analyses, seed oil ranged from 40.5% at Swift Current to 47% at Melfort (Table 4). Seed oil concentration in canola is inversely related to protein and, while not necessarily a desirable response, would be expected to decline with improvements in N fertility status. Essentially, the responses for canola seed oil mirrored those just discussed for protein; however, the effect was opposite in that the values declined with increasing N fertilizer rate (Fig. 7, Table 13). Foliar treatments had no impact on seed oil concentration and there were no interactions associated with this factor, indicating that the lack of response was consistent regardless of location (Fig. 8, Table 13) or N level (Fig. 9; Table 14).

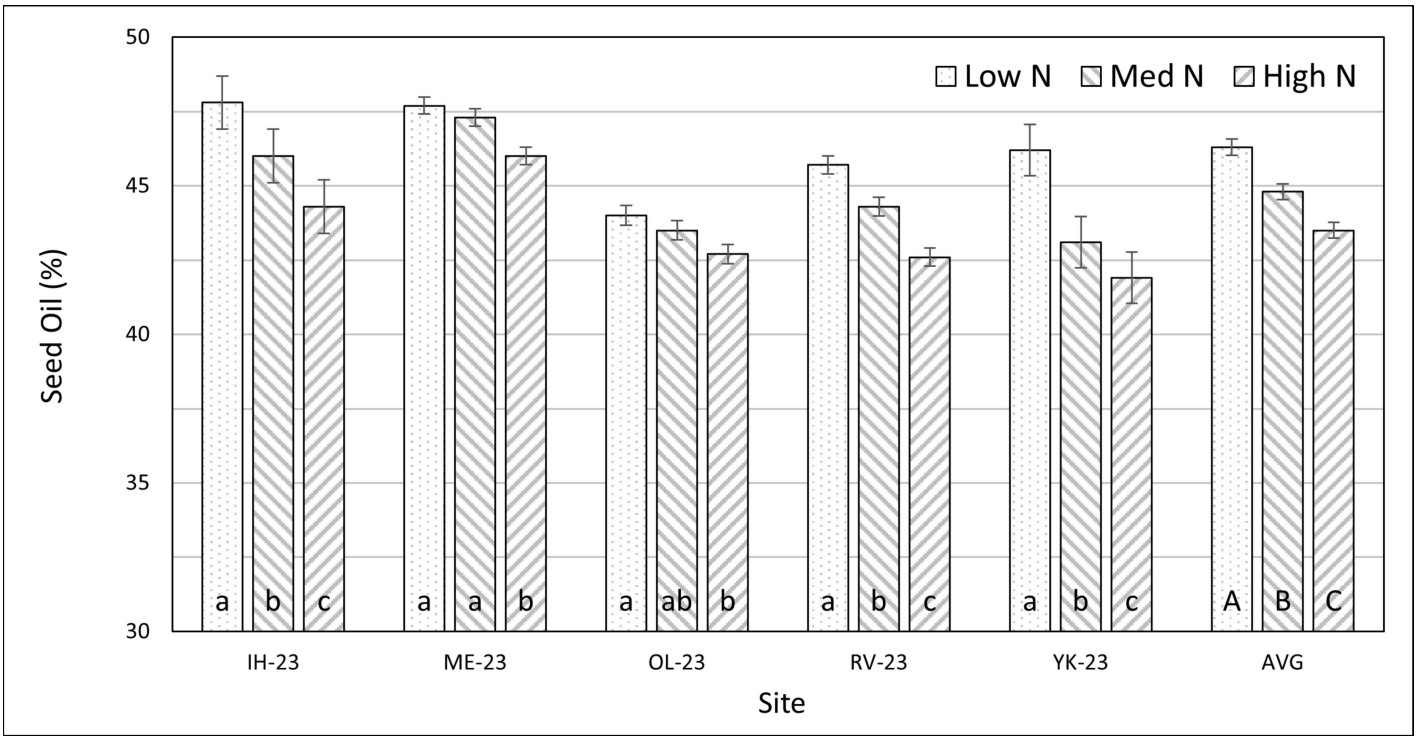

Figure 7. Nitrogen (N) fertility level effects on canola seed oil concentrations for individual sites and averaged across sites. The N fertility levels were Low (60 kg N/ha), medium (110 kg N/ha), and high (160 kg N/ha), including residual soil N. The locations were Indian Head (IH-23), Melfort (ME-23), Outlook (OL-23), Redvers (RV-23), and Yorkton (YK), while AVG denotes the overall, 5-site average. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

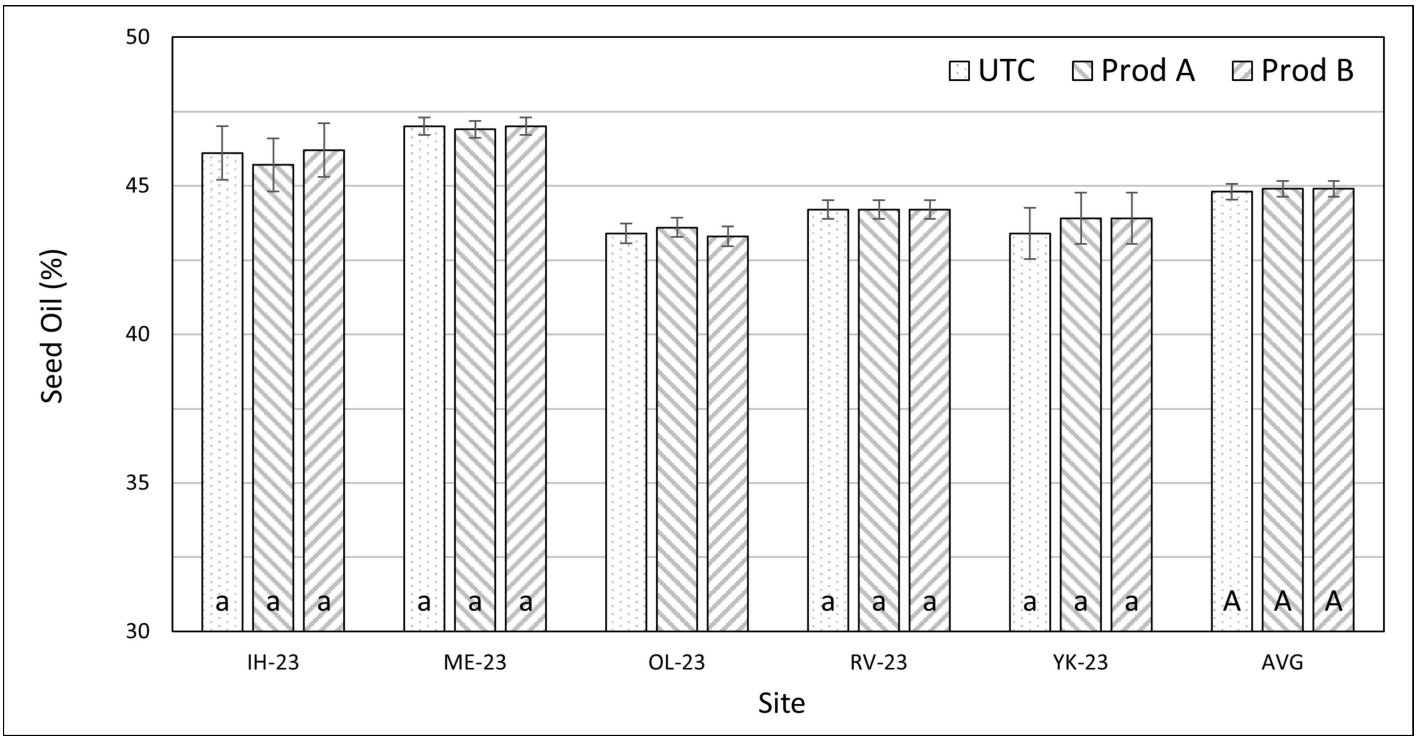

Figure 8. Foliar-applied nitrogen (N) fixing bacteria treatment effects on canola seed oil concentrations for individual sites and across sites. The foliar treatments were UTC (untreated check), Prod A (95 ml/ac Envita + 0.1% Agrol 90), and Prod B (135 g/ac Utrisha-N), applied at the 4-6 leaf stage. The locations were Indian Head (IH-23), Melfort (ME-23), Outlook (OL-23), Redvers (RV-23), and Yorkton (YK), while AVG denotes the overall, 5-site average. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

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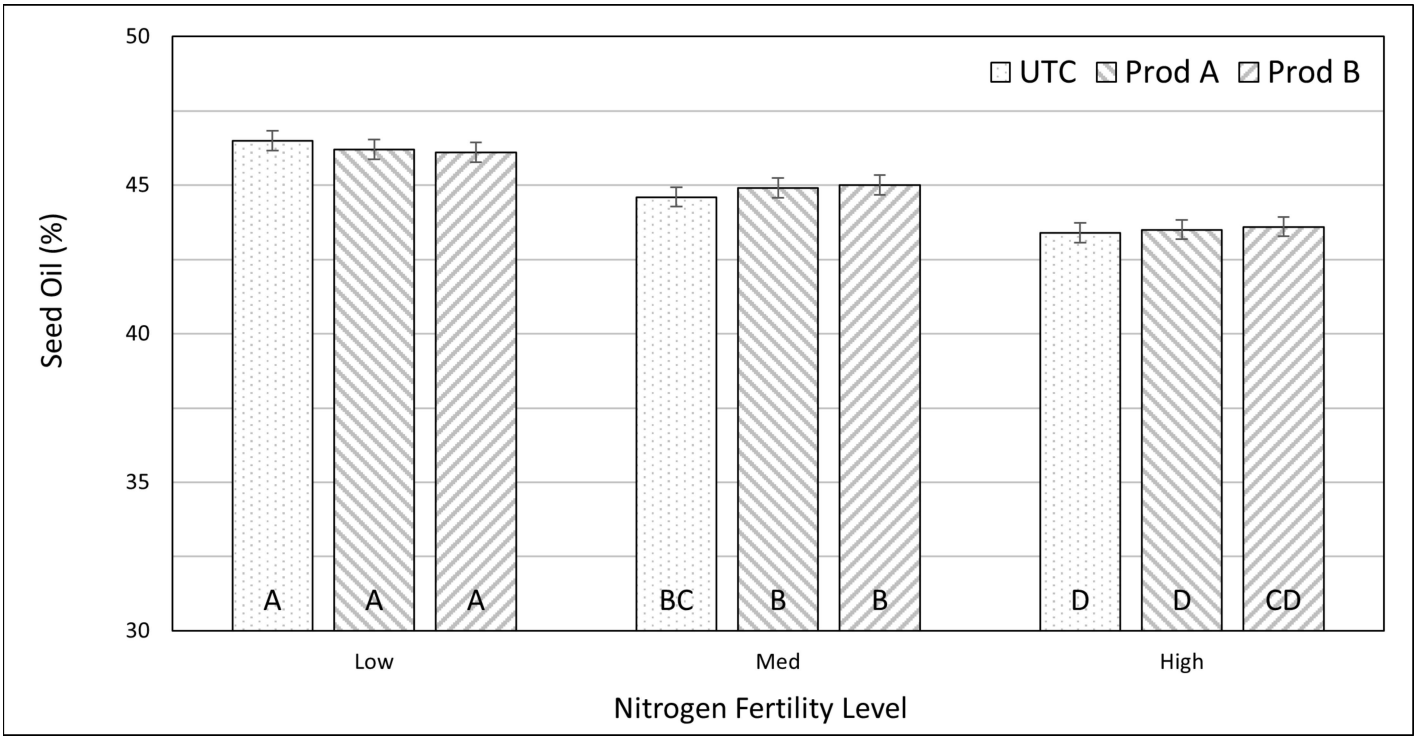

Figure 9. Nitrogen (N) fertility level by foliar-applied N fixing bacteria treatment effects on canola seed oil concentrations, averaged across 5 sites. The N fertility levels were Low (60 kg N/ha), medium (110 kg N/ha), and high (160 kg N/ha), including residual soil N. The foliar treatments were UTC (untreated check), Prod A (95 ml/ac Envita + 0.1% Agrol 90), and Prod B (135 g/ac Utrisha-N), applied at the 4-6 leaf stage. Error bars are S.E.M. and values within a site denoted by the same letter do not significantly differ (Tukey's, $P \leq 0.05$).

Extension Activities

At Indian Head, this project was highlighted by Chris Holzapfel during the 2023 Indian Head Crop Management Field Day, held on July 18 (160 participants). Representing the Canola Council of Canada, Thom Weir and Warren Ward showed the trial during a Canola 4R N Management Tour on August 15; however, this event was poorly attended since harvest was well underway in the area at this time. Kayla Slind highlighted the trials during the Scott Field Day on July 12 (120 participants) and Lana Shaw toured the Redvers trial during the SERF Field Day on July 27 (50 participants). Mike Hall acknowledged the trial during then ECRF farm tour on July 20 (80 participants), Dale Leftwich presented on the topic during NARF/AAFC Joint Annual Field Day on July 26, 2023 (70 participants), and Robin Lokken showed the trials during the CLC Field Day on July 27 (68 participants). Gursahib Singh presented results from Outlook during the 2023 Irrigation Saskatchewan Conference, held Dec. 5-7 in Saskatoon with approximately 300 participants. Chris Holzapfel presented results from the project at the IHARF Winter Meeting and AGM at Balgonie on February 7 (150 participants) and during the 2024 ICAN Conference on February 8 at Moose Jaw (40 participants). Project highlights will also be shared by Brianne McInnes (NARF) during the Top Notch Farming meeting at Melfort on February 13, 2024. Robin Lokken presented project results at the Spiritwood Top Notch Farming meeting on February 6, and will also discuss the project at the CLC Crop Talk event on March 13, 02024. Koralie Mack and Kayla Slind presented Scott's results during Top Notch Farming meeting in St. Walburg (20 participants) and Unity (30 participants) on February 7 and 8th, respectively. Jessica Enns will be presenting results at both the Crop Opportunities Meeting in North Battleford on March 7 and the Agri-ARM Research update on March 19. This final project report will also be available online at the IHARF website (www.iharf.ca) and the websites of several other Agri-ARM collaborators.

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Conclusions and Recommendations

Describe what was learned from the demonstration. Highlight any significant conclusions and provide recommendations for the application and adoption of the project results. Be sure that you have presented the relevant data to support your conclusions. Identify any further research, development and communication needs, if applicable.

With the exception of 2/8 sites which were excluded from the combined statistical analyses, we observed the expected increases in seed yield and protein concentrations along with reductions in seed oil concentrations with the addition of N fertilizer in the form of the side-banded urea. We did not, however, observe any effects on these variables that could indicate improved N status or biological N_2 fixation associated with the foliar applications of the biological products demonstrated in this project. This was the case, regardless of the environmental conditions encountered (i.e., site) or overall N fertility level (i.e., N fertilizer rate). While we cannot rule out that positive responses might occur with either different crop types or under environmental conditions that were not met in the current project, we did our best to allow the foliar products to succeed. This included careful storage of the products, using distilled water as a carrier, ensuring adequate water volumes, attempting to apply the biological products during cooler conditions, and testing them under N limiting conditions. These results are generally consistent with those of a similar project conducted with spring wheat, field-scale trials funded by SaskWheat and SaskCanola, and complementary, ongoing research at the University of Saskatchewan. With all this in mind, we recommend that farmers avoid reducing their N fertilizer rates when using biological products intended to improve N nutrition in crop production and utilize untreated check strips (preferably replicated) to confirm whether or not they are realizing any benefits on their own farms.

Sustainable Canadian Agricultural Partnership (Sustainable CAP) Performance Indicators

a) List of performance indicators

Sustainable CAP Indicator	Total Number
Scientific publications from this project (List the publications under section b)	
• Published	0
• Accepted for publication	0
HQPs trained during this project	
• Master's students	0
• PhD students	0
• Post docs	0
Knowledge transfer products developed based on this project (presentations, brochures, factsheets, flyers, guides, extension articles, podcasts, videos). List the knowledge transfer products under section (c)	18 (and counting)

[1] Please only include the number of unique knowledge transfer products.

b) List of scientific journal articles published/accepted for publication from this project.

Title	Author(s)	Journal	Date Published or Accepted for Publication	Link (if available)
n/a	n/a	n/a	n/a	n/a

c) List of knowledge transfer products/activities developed from this project.

Knowledge Transfer Product or Activity	Event/Location Where Knowledge Transfer Was Conducted	Estimated # of Producers Participated In Knowledge Transfer	Link (if available)
C. Holzapfel (IHARF) Plot Tour	Crop Management Field Day, Indian Head (July 18, 2023)	160	https://iharf.ca/indian-head-crop-management-field-day/
T. Weir and W. Ward (CCC) Plot Tour	CCC-IHARF SK 4R Field Day, Indian Head (August 15, 2023)	2	https://www.canolacouncil.org/event/saskatchewan-4r-field-day/
K. Slind (WARC) Plot Tour	Scott Field Day, Scott (July 12, 2023)	120	https://www.westernappliedresearch.com/events/
L. Shaw (SERF) Plot Tour	SERF Field, Redvers (July 27)	50	https://southeastresearchfarm.org/resources-events/
D. Leftwich (SCDC) Plot Tour	NARF/AAFC Joint Annual Field Day, Melfort (July 26, 2023)	70	https://neag.ca/events/
R. Lokken (CLC) Plot Tour	CLC Field Day	68	https://conservationlearningcentre.com/events/
M. Hall (ECRF) Plot Tour	ECRF Annual Field Day, Yorkton (July 20, 2023)	80	http://www.ecrf.ca/?page=tour
G. Singh (ICDC) Presentation	Irrigation Saskatchewan Conference, Saskatoon (December 5-7, 2023)	300	https://www.irrigationsaskatchewan.com /SIPA/event/irrigation-saskatchewan-2023-conference/
R. Lokken (CLC) Presentation	Top Notch Farming Meeting, Spiritwood (February 6, 2024)	28	https://www.saskcanola.com/upcoming-events/top-notch-farming-spiritwood
C. Holzapfel (IHARF) Presentation	2024 IHARF Soil and Crop Management Seminar & AGM, Balgonie (February 7, 2024)	150	https://iharf.ca/iharf-soil-and-crop-management-seminar-agm/
C. Holzapfel (IHARF) Presentation	2024 ICAN Conference, Moose Jaw (February 8, 2024)	40	https://www.icanhelpyourfarm.com/
B. McInnes (NARF) Presentation	Top Notch Farming Meeting, Melfort (February 13, 2024)	TBD	https://www.saskcanola.com/upcoming-events/top-notch-farming-melfort
R. Lokken (CLC) Presentation	Crop Talk 2024, Prince Albert (March 13, 2024)	TBD	https://conservationlearningcentre.com/events/
K. Mack (WARC) Presentation	Top Notch Meeting, St. Walburg (Feb. 7, 2024)	20	https://www.saskcanola.com/upcoming-events/top-notch-farming-st-walburg
K. Slind (WARC) Presentation	Top Notch Farming Meeting, Unity (February 8, 2024)	30	https://www.saskcanola.com/upcoming-events/top-notch-farming-unity
J. Enns (WARC) Presentation	Agri-ARM Research Update, March 19, 2024 (virtual)	TBD	https://attendee.gotowebinar.com/register/468816801821751389
J. Enns (WARC) Presentation	Crop Opportunity, North Battleford/Virtual (March 7, 2024)	TBD	https://www.westernappliedresearch.com/events/
Full Report – Available Online	IHARF Website (also on other Agri-ARM websites)	TBD	https://iharf.ca/full-reports/

Acknowledgements

Include actions taken to acknowledge support by the Ministry of Agriculture, the Canadian Agriculture Partnership (for projects approved between 2017 and 2023) and the Sustainable Canadian Agriculture Partnership (for projects approved between 2023 and 2028).

Financial support was provided under the Sustainable Canadian Agricultural Partnership, as federal-provincial-territorial initiative. The Saskatchewan Canola Development Commission administered the project in-kind. Envita® was provided in-kind by Syngenta Canada and Utrisha™-N was provided by Corteva. We would also like to acknowledge the Board of Directors from each of the participating organizations in addition to the many technical and professional staff, without whom this project could not have been completed. IHARF, NARF, WARC, and WCA have strong working relationships and memorandums of understanding with Agriculture and Agri-Food Canada which should also be acknowledged.

Appendices

Identify any changes expected to industry contributions, in-kind support, collaborations or other resources.

Table 5. Selected agronomic information and dates of operations for the 2023 biological N fixation product trials with canola at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (RV), Scott (SC), Swift Current (SW), and Yorkton, Saskatchewan.

Activity	IH-23	ME-23	OL-23	PA-23	RV-23	SC-23	SW-23	YK-23
Previous Crop	Wheat	Wheat	Wheat	Oat	Barley	Wheat	Wheat	Wheat
Pre-Emergent Herbicide	May-20 (glyphosate)	May-16 (glyphosate)	nil	May 12 (glyphosate)	May-22 (glyphosate)	May-16 (glyphosate)	May-8 (glyphosate)	nil
Seeding Date	May-16	May-24	May-16	May 29	May-22	May-18	May-11	May-23
Row Spacing	31 cm	31 cm	25 cm	25 cm	25 cm	25 cm	21 cm	31 cm
Soil NO_3-N (0-60 cm)	20 kg/ha	44 kg/ha	20 kg/ha	72 kg/ha	32 kg/ha	38 kg/ha	24 kg/ha	47 kg/ha
kg N-P_2O_5-K_2O-S/ha [z]	28-40-20-20	27-56-0-17	4-20-0-0	25-50-0-17	17-34-0-11	17-21-0-17	37-57-0-28	21-28-0-17
Emergence Counts	Jun-12	Jun-9	Jun-12	Jun-19	unknown	Jun-16	Jun-6	Jun-5
In-crop Herbicide 1	Jun-9 (Liberty)	Jun-2 (Centurion)	Jun-5 (Liberty)	June 8 (Poast Ultra)	Jun-21 (Liberty)	Jun-7 (Liberty)	Jun-7 (Liberty)	Jun-6 (Liberty)
In-crop Herbicide 2	Jun-9 (Centurion)	Jun-10 (Liberty)	nil	nil	nil	Jun-7 (Centurion)	Jun-7 (Centurion)	Jun-20 (Centurion)
In-crop Herbicide 3	n/a	Jun-10 (Facet L)	nil	nil	nil	nil	nil	nil
Foliar Treatment Date	Jun-16	Jun-21	Jun-14	June 22	Jun-13	Jun-16	Jun-12	Jun-12
Fungicide Date	Jul-5 (Cotegra)	n/a	nil	nil	nil	Jul-5 (Dyax)	nil	Jul-5 (Acapella)
Pre-harvest Herbicide	Aug-25 (glyphosate)	Aug-29 (glyphosate)	nil	Sep-7 (Reglone)	nil	Aug-16 (Reglone)	nil	Aug-22 (Reglone)
Harvest Date	Sep-5	Sep-11	Sep-7	Sep-15	Sep-2	Aug-29	Aug-21	Aug-31

[z] Fertility information only includes nutrients provided by phosphorus, potassium, and/or sulfur products applied (i.e., do not include soil residual nutrients or N provided by supplemental urea applied to achieve the target N levels)

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Table 6. Tests of fixed effects for site, nitrogen level (N), foliar treatment (F), and all possible interactions for selected canola response variables at five Saskatchewan locations in 2023. Data were analysed using the Generalized Linear Mixed Model procedure of SAS. P-values less than 0.05 are considered significant while values below 0.1 may also be acknowledged.

Effect	Plant Density	Seed Yield	Seed Protein	Seed Oil
	---------- Pr > F (p-value) ----------			
Site (S)	<0.001	<0.001	<0.001	<0.001
Nitrogen (N)	0.037	<0.001	<0.001	<0.001
S x N	0.579	0.224	0.003	<0.001
Foliar (F)	–	0.224	0.676	0.846
S x F	–	0.076	0.735	0.769
N x F	–	0.354	0.267	0.338
S X N X F	–	0.434	0.250	0.060

Table 7. Tests of fixed effects for nitrogen level (N), foliar treatment (F), and the N x F for selected canola response variables at Prince Albert (PA), Scott (SC), and Swift Current (SW), in 2023. Data were analysed for each site individually using the Generalized Linear Mixed Model procedure of SAS. P-values (Pr > F) less than 0.05 are considered significant while values below 0.1 may also be acknowledged.

Effect	PA-23	SC-23	SW-23
	---------- Plant Density ----------		
Nitrogen (N)	0.438	0.002	<0.001
	---------- Seed Yield ----------		
Nitrogen (N)	0.703	0.508	0.003
Foliar (F)	0.869	0.535	0.931
N x F	0.817	0.768	0.304
	---------- Seed Protein Concentration ----------		
Nitrogen (N)	0.009	<0.001	0.008
Foliar (F)	0.119	0.226	0.726
N x F	0.307	0.351	0.781
	---------- Seed Oil Concentration ----------		
Nitrogen (N)	0.016	<0.001	0.005
Foliar (F)	0.171	0.339	0.821
N x F	0.352	0.258	0.879

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Table 8. Main effect means for plant density and multiple comparison test results for nitrogen (N) level in canola at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
Nitrogen [X]	Plant Density (plants/m^2)								
Low	106.9 a	82.6 a	105.2 a	85.7 a	66.6 a	100.8 a	47.0 a	91.2 a	90.5 A
Medium	98.7 a	71.5 a	105.7 a	78.8 a	58.2 a	98.4 a	46.7 a	88.9 a	84.6 B
High	105.7 a	74.7 a	111.8 a	76.3 a	59.4 a	87.1 b	37.9 b	96.0 a	89.5 AB
S.E.M.	3.87	3.87	3.87	5.27	3.87	3.92	1.33	3.87	1.73
	Pr > F (p-value)								
Pr > F	0.271	0.116	0.405	0.438	0.252	0.002	<0.001	0.417	0.037
N Rate – lin	0.825	0.149	0.231	0.219	0.186	<0.001	<0.001	0.384	0.681
N Rate – quad	0.110	0.134	0.545	0.734	0.314	0.175	0.014	0.320	0.011

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), and the S x N interaction as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N) as the sole fixed effect

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

Table 9. Main effect means and multiple comparison test results for nitrogen (N) level and foliar-applied biological for canola seed yield at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
Nitrogen [X]	---------- Seed Yield (kg/ha) ----------								
Low	1752 c	1754 c	3069 c	2993 a	1978 c	2560 a	437 b	2434 c	2198 C
Medium	2336 b	2059 b	3567 b	2969 a	2496 b	2658 a	541 ab	2847 b	2661 B
High	2650 a	2533 a	3868 a	3093 a	2730 a	2623 a	609 a	3059 a	2968 A
S.E.M.	112.0	112.0	112.0	244.3	112.0	77.5	61.5	112.0	50.3
	---------- Pr > F (p-value) ----------								
Pr > F	<0.001	<0.001	<0.001	0.703	<0.001	0.508	0.003	<0.001	<0.001
N Rate – lin	<0.001	<0.001	<0.001	0.528	<0.001	0.461	<0.001	<0.001	<0.001
N Rate – quad	0.081	0.272	0.212	0.587	0.065	0.371	0.651	0.188	0.024
Foliar [Y]	---------- Seed Yield (kg/ha) ----------								
UTC	2257 a	2194 a	3537 ab	2971 a	2328 a	2561 a	525 a	2744 a	2613 A
Envita	2248 a	2084 a	3358 b	3049 a	2351 a	2654 a	539 a	2822 a	2573 A
Utrisha-N	2232 a	2068 a	3609 a	3035 a	2524 a	2626 a	523 a	2774 a	2641 A
S.E.M.	112.0	112.0	112.0	244.3	112.0	77.5	61.5	112.0	50.3
	---------- Pr > F (p-value) ----------								
Pr > F	0.959	0.300	0.016	0.869	0.057	0.535	0.931	0.674	0.224

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), Foliar Treatment (T), and all possible interactions as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N), Foliar Treatment, and the N x F interaction as fixed effects

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

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Table 10. Individual nitrogen (N) level x foliar-applied biological treatment means for canola seed yield and multiple comparison test results at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
N x Foliar	----------	----------	----------	---------- Seed Yield (kg/ha) ----------	----------	----------	----------	----------	----------
Low – UTC	1753 b	1876 d	3120 cd	2868 a	1827 c	2543 a	429 a	2367 d	2191 D
Low – Envita	1769 b	1716 d	2803 d	3081 a	1935 c	2646 a	456 a	2459 cd	2137 D
Low – Utrisha	1735 b	1669 d	3285 cd	3030 a	2171 bc	2492 a	426 a	2475 cd	2267 D
Med – UTC	2330 a	2099 bcd	3629 abc	3038 a	2481 ab	2596 a	489 a	2645 bcd	2637 C
Med – Envita	2334 a	2025 cd	3594 abc	2856 a	2460 ab	2638 a	526 a	3014 ab	2686 BC
Med – Utrisha	2342 a	2054 bcd	3477 bc	3013 a	2548 a	2738 a	608 a	2883 abc	2661 C
High – UTC	2688 a	2608 a	3861 ab	3008 a	2677 a	2545 a	657 a	3220 a	3011 A
High – Envita	2643 a	2511 a	3677 abc	3209 a	2660 a	2677 a	634 a	2993 ab	2897 AB
High - Utrisha	2618 a	2480 ab	4065 a	3061 a	2852 a	2647 a	537 a	2964 ab	2996 A
S.E.M.	142.5	142.5	142.5	289.4	142.5	113.9	76.3	142.5	63.9
	----------	----------	----------	---------- Pr > F (p-value) ----------	----------	----------	----------	----------	----------
Pr > F	<0.001	<0.001	<0.001	0.817	<0.001	0.768	0.304	<0.001	0.354

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), Foliar Treatment (T), and all possible interactions as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N), Foliar Treatment, and the N x F interaction as fixed effects

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

Table 11. Main effect means and multiple comparison test results for nitrogen (N) level and foliar-applied biological for canola seed protein concentrations at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
Nitrogen [X]	Seed Protein (%)								
Low	16.8 c	15.9 b	–	18.0 b	17.3 c	21.8 b	28.7 b	18.5 c	17.1 C
Medium	18.3 b	16.3 b	–	19.1 a	18.4 b	22.7 a	29.5 ab	20.8 b	18.4 B
High	20.3 a	17.9 a	–	19.1 a	19.7 a	23.6 a	30.1 a	22.0 a	20.0 A
S.E.M.	0.78	0.22	–	1.08	0.24	0.94	0.49	0.69	0.27
	Pr > F (p-value)								
Pr > F	<0.001	<0.001	–	0.009	<0.001	<0.001	0.008	<0.001	0.008
N Rate – lin	<0.001	<0.001	–	0.007	<0.001	<0.001	0.002	<0.001	<0.001
N Rate – quad	0.305	0.044	–	0.097	0.726	0.894	0.761	0.065	0.439
Foliar [Y]	Seed Protein (%)								
UTC	18.4 a	16.6 a	–	18.3 a	18.5 a	22.9 a	29.3 a	20.7 a	18.5 A
Envita	18.6 a	16.8 a	–	18.7 a	18.5 a	22.8 a	29.5 a	20.4 a	18.5 A
Utrisha-N	18.3 a	16.7 a	–	19.1 a	18.5 a	22.3 a	29.6 a	20.2 a	18.4 A
S.E.M.	0.78	0.22	–	1.08	0.24	0.94	0.49	0.69	0.27
	Pr > F (p-value)								
Pr > F	0.723	0.797	–	0.119	0.988	0.226	0.726	0.206	0.676

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), Foliar Treatment (T), and all possible interactions as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N), Foliar Treatment, and the N x F interaction as fixed effects

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

Table 12. Individual nitrogen (N) level x foliar-applied biological treatment means for canola seed protein concentrations and multiple comparison test results at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
N x Foliar	----------	----------	----------	----------	Seed Protein (%)	----------	----------	----------	----------
Low – UTC	16.7 d	15.8 c	–	17.5 a	17.3 b	22.3 ab	28.7 a	18.0 d	16.9 C
Low – Envita	17.0 cd	15.9 c	–	17.6 a	17.2 b	22.1 ab	28.6 a	18.7 cd	17.2 C
Low – Utrisha	16.8 cd	15.9 c	–	18.8 a	17.5 b	20.9 b	28.9 a	18.7 cd	17.2 C
Med – UTC	18.2 cd	16.3 bc	–	18.4 a	18.2 ab	22.9 ab	29.5 a	22.1 a	18.7 B
Med – Envita	18.3 bc	16.3 bc	–	19.2 a	18.5 ab	22.4 ab	29.7 a	20.3 bc	18.3 B
Med – Utrisha	18.2 cd	16.4 bc	–	19.6 a	18.5 ab	22.8 ab	29.3 a	19.9 c	18.3 B
High – UTC	20.4 a	17.6 ab	–	19.1 a	19.8 a	23.6 a	29.6 a	22.1 a	20.0 A
High – Envita	20.4 a	18.1 a	–	19.3 a	19.7 a	23.9 a	30.2 a	22.1 a	20.1 A
High - Utrisha	20.0 ab	17.9 ab	–	18.9 a	19.5 a	23.3 a	30.5 a	21.9 ab	19.8 A
S.E.M.	0.84	0.38	–	1.14	0.38	1.00	0.63	0.75	0.31
	----------	----------	----------	----------	Pr > F (p-value)	----------	----------	----------	----------
Pr > F	<0.001	<0.001	–	0.307	<0.001	0.351	0.781	<0.001	0.735

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), Foliar Treatment (T), and all possible interactions as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N), Foliar Treatment, and the N x F interaction as fixed effects

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

Table 13. Main effect means and multiple comparison test results for nitrogen (N) level and foliar-applied biological for canola seed oil concentrations at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
Nitrogen [X]	---------- Seed Oil (%) ----------								
Low	47.8 a	47.7 a	44.0 a	45.5 a	45.7 a	45.0 a	41.3 a	46.2 a	46.3 A
Medium	46.0 b	47.3 a	43.5 ab	44.6 b	44.3 b	44.1 ab	40.3 ab	43.1 b	44.8 B
High	44.3 c	46.0 b	42.7 b	44.6 b	42.6 c	43.2 b	39.8 b	41.9 c	43.5 C
S.E.M.	0.90	0.29	0.33	0.92	0.31	0.95	0.51	0.86	0.27
	---------- Pr > F (p-value) ----------								
Pr > F	<0.001	<0.001	0.013	0.016	<0.001	<0.001	0.005	<0.001	<0.001
N Rate – lin	<0.001	0.0001	0.0033	0.012	<.0001	<0.001	0.002	<.0001	<0.001
N Rate – quad	0.865	0.2448	0.7294	0.128	0.7104	0.990	0.571	0.0171	0.7547
Foliar [Y]	---------- Seed Oil (%) ----------								
UTC	46.1 a	47.0 a	43.4 a	45.2 a	44.2 a	43.9 a	40.6 a	43.4 a	44.8 a
Envita	45.7 a	46.9 a	43.6 a	44.9 a	44.2 a	44.0 a	40.4 a	43.9 a	44.9 a
Utrisha-N	46.2 a	47.0 a	43.3 a	44.5 a	44.2 a	44.4 a	40.4 a	43.9 a	44.9 a
S.E.M.	0.90	0.29	0.33	0.92	0.31	0.95	0.51	0.86	0.27
	---------- Pr > F (p-value) ----------								
Pr > F	0.370	0.983	0.690	0.171	0.996	0.339	0.821	0.303	0.846

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), Foliar Treatment (T), and all possible interactions as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N), Foliar Treatment, and the N x F interaction as fixed effects

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

Table 14. Individual nitrogen (N) level x foliar-applied biological treatment means for canola seed oil concentrations and multiple comparison test results at Indian Head (IH), Melfort (ME), Outlook (OL), Prince Albert (PA), Redvers (PA), Scott (SC), Swift Current (SW), Yorkton (YK), and averaged across sites in 2023. For each location, values within a column followed by the same letter do not significantly differ (Tukey-Kramer, $P \leq 0.05$).

Main Effect	IH-23 [Z]	ME-23 [Z]	OL-23 [Z]	PA-23 [Y]	RV-23 [Z]	SC-23 [Y]	SW-23 [Y]	YK-23 [Z]	AVG [Z]
N x Foliar	Seed oil (%)								
Low – UTC	48.1 a	47.6 a	44.2 a	45.8 a	45.7 a	44.6 a	41.3 a	46.9 a	46.5 A
Low – Envita	47.6 a	47.6 a	43.9 a	45.9 a	45.9 a	44.6 ab	41.4 a	45.9 ab	46.2 A
Low – Utrisha	47.6 a	47.8 a	43.8 a	44.9 a	45.5 a	45.9 ab	41.1 a	45.7 ab	46.1 A
Med – UTC	46.3 ab	47.2 a	43.7 a	45.2 a	44.5 ab	44.0 ab	40.4 a	41.1 e	44.6 BC
Med – Envita	45.3 b	47.4 a	43.5 a	44.5 a	44.2 ab	44.5 ab	40.1 a	44.1 bcd	44.9 B
Med – Utrisha	46.3 ab	47.2 a	43.3 a	44.0 a	44.1 ab	43.9 ab	40.5 a	44.2 bc	45.0 B
High – UTC	44.0 b	46.1 a	42.2 a	44.6 a	42.4 b	43.2 b	40.2 a	42.0 cde	43.4 D
High – Envita	44.1 b	45.8 a	43.4 a	44.4 a	42.5 b	43.0 b	39.6 a	41.7 e	43.5 D
High - Utrisha	44.6 b	46.1 a	42.6 a	44.8 a	42.9 b	43.5 b	39.5 a	41.9 de	43.6 CD
S.E.M.	0.99	0.51	0.53	0.98	0.52	1.01	0.66	0.96	0.33
	Pr > F (p-value)								
Pr > F	<0.001	0.030	0.139	0.352	<0.001	0.258	0.879	<0.001	0.338

[Z] Data combined for analyses across sites with SITE (S), Nitrogen (N), Foliar Treatment (T), and all possible interactions as fixed effects

[Y] Data excluded from the combined analyses and analyzed individually with Nitrogen (N), Foliar Treatment, and the N x F interaction as fixed effects

[X] Nitrogen rates included fall soil residual (0-60 cm) and targeted 60, 110, and 160 kg total N/ha

Expenditure Statement

You must provide an expenditure statement showing how ADOPT funds were used. Expenditures must be reported using the budget categories shown in Appendix B of your contract. We recommend that you report your expenditures using the Excel spreadsheet we have developed for this purpose (ADOPT Expenditure Statement.xls). That spreadsheet is available from the research branch project manager or the evaluation coordinator.
Note that the ADOPT contract requires you to retain all receipts and financial records relating to the project for at least six years after the project is completed.

The expenditure statement was submitted in a separate document and is available upon request.