NORTHWEST CROPS & SOILS PROGRAM

2016 High Glucosinolate Mustard as a Biofumigant Trial

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UNIVERSITY OF VERMONT EXTENSION
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2016 HIGH GLUCOSINOLATE MUSTARD AS A BIOFUMIGANT TRIAL

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Brassicaceae plants (mustard family) contain chemicals called glucosinolates. These compounds are present in the leaves, stems, roots, and seeds of the plants. When the plant biomass is incorporated into the soil, these glucosinolates are broken down into a number of secondary compounds, including a compound called isothiocyanate. Isothiocyanate can be biocidal to seeds, insects, nematodes, and other microbes (fungi, bacteria, etc.). In recent years, plant breeders have worked to develop varieties of mustards with high glucosinolate content to be used as biofumigants in crop production. These high glucosinolate mustards (HGM) are being used as cover crops and the entire plant biomass is incorporated into the soil. Interestingly, mustards can also be used as oilseed crops with a potential use in biofuel production. Extraction of the oil from the seed produces a meal that is also high in glucosinolates as well as nitrogen. Hence, the meal used as a soil amendment could potentially provide nutrients and suppress weeds, pests, and diseases.

Little research has been done in the Northeast to quantify the effects of HGM as a cover crop and biofumigant. The commercial demand for potatoes *(Solanum tuberosum)* hinges on appearance. Consumers often refuse potatoes with skin defects such as common scab *(Streptomyces spp.)* or rhizoctonia and potatoes for seed are rejected if they have significant skin damage. *Rhizoctonia solani*, a soil fungus, is particularly common in cool, wet growing regions like the Northeast. Snap beans *(Phaseolus vulgaris)* often suffer from soil borne, root diseases. In this trial, HGM was evaluated for its efficacy at reducing the incidence of soil borne diseases, minimizing weed pressure, and increasing yields for potatoes and snap beans.

MATERIALS AND METHODS

A trial was conducted at Borderview Research Farm in Alburgh, Vermont and at High Mowing Organic Seeds in Wolcott, Vermont. At Borderview Research Farm, the experimental design was a randomized split plot design with four replications. Main plot treatments consisted of three planting dates and split plot treatments consisted of four HGM varieties. The varieties were ‘Caliente 199’, ‘Caliente 119’, ‘Caliente 61’, and ‘Terminator’. Planting dates included 17-Aug, 24-Aug, and 31-Aug 2015. Plot size was 10’x20’. The experimental plot was seeded with a Great Plains plot drill at a rate of 25 lbs ac^{-1}. On 15-Sep vigor was recorded by visually assessing each of the plots and rating them on a 1-5 scale (low to high vigor). On 20-Oct mustard plant height and population was recorded. Biomass was also sampled by clipping the contents of two randomly placed 0.25 m^2 quadrats per plot. A subsample of mustard was dried at 105° F till it reached a stable temperature, in order to determine percent dry matter. Mustard samples then were analyzed using wet chemistry to determine its nutrient content. On 24-Oct, the mustard was terminated using a brush hog and incorporated immediately using disc harrows.

On 20-Apr 2016, each plot was soil sampled for nitrates and general nutrient content. On 5-May ‘Yukon Gold’ potatoes were planted in the middle 3’x10’ area of each plot. On 31-May, populations of potatoes per plot was recorded. On 9-Jun, the number of broadleaf and grass weeds in a 0.25 m^2 quadrat per plot was recorded to determine weed populations. On 9-Jun, weed cover was determined as a percent of total plant cover using the web based IMAGING crop response analyzer. Digital images were taken with a compact digital camera, Canon PowerShot G12 (Melville, NY) (10.4 Megapixels). Digital images were analyzed with the automated imaging software, which was programmed in MATLAB (MathWorks, Inc., Natick, MA) and later converted into a free web-based software (www.imaging-crop.dk). On 1-Aug, potatoes were harvested by hand and yield was recorded. A subsample of 10 potatoes was evaluated visually for scab and rhizoctonia infection (Image 1) and severity was recorded using a 1-4 scale (1=trace/no disease and 4= high infection).

Image 1. Potato scab, *Streptomyces spp.*, and *Rhizoctonia solani*, left to right, Alburgh, VT, 2016.

At High Mowing Organic Seeds, the experimental design was a randomized split plot with four replications. Main plot treatments consisted of two planting dates and split plot treatments consisted of two HGM varieties and a spring mustard meal application. The varieties were ‘Caliente 199’ and ‘Terminator’ and were planted on 31-Jul and 17-Aug 2015 into 10’x20’ plots at 25 lbs ac^{-1}. The mustard meal was applied by hand on 25-May 2016 at 522 lbs ac^{-1}. On 4-Sep vigor was recorded by visually assessing each of the plots and rating them on a 1-5 scale (1=low and 5=high vigor). On 18-Sep and 8-Oct 2015, mustard plant height and population was recorded. Biomass was also sampled on 18-Sep and 8-Oct by clipping the contents of two randomly placed 0.25 m^2 quadrats per plot. A subsample of mustard was dried at 105° F till it reached a stable temperature, in order to determine percent dry matter. Mustard samples then were analyzed using wet chemistry to determine its nutrient content. On 24-Sep and 16-Oct, the first and second planting dates, respectively, of mustard were terminated and incorporated using a rototiller.

On 6-May 2016, each plot was soil sampled for nitrates and general nutrient content. On 27-May, ‘Hystyle’ snap beans, which are susceptible to root rot, and ‘Accelerate’ snap beans, which are not susceptible were planted in each plot. On 15-Jun populations of snap bean plants per plot was recorded. On 7-Jul the number of broadleaf and grass weeds in a 0.25 m^2 quadrat per plot was recorded to determine weed populations. On 7-Jul weed cover was determined as a percent of total plant cover using the web based IMAGING crop response analyzer. Digital images were taken with a compact digital camera, Canon PowerShot G12 (Melville, NY) (10.4 Megapixels). Digital images were analyzed with the automated imaging software, which was programmed in MATLAB (MathWorks, Inc., Natick, MA) and later converted into a free web-based software (www.imaging-crop.dk). On 25-Jul, leaf disease was assessed. On 2-Aug, beans were harvested by hand and yield was recorded. A subsample of 10 plants was evaluated visually for root disease infection (Image 2) and severity was recorded using a 0-10 scale (0=no disease and 10= high infection).

Image 2. Root disease infection on snap beans, Wolcott, VT, 2016.

Table 1. Agronomic information for high glucosinolate mustard (HGM) as a biofumigant trial 2016, Alburgh, VT.

Location	**Borderview Research Farm, Alburgh, VT**	**High Mowing Organic Seeds, Wolcott, VT**
Soil type	Benson rocky silt loam, 8-15% slope	Colton-Duxbury sandy loam, 3-8% slope
Previous crop	Barley	Tomatoes, peppers, cucumbers
Replications	4	4
Plot size (ft)	10x20	10x20
Soil amendments	10-Aug 2015, 5000 gal ac^{-1} of manure 30-Apr 2016, 3 tons ac^{-1} of Pro-Gro (5-4-3)	17-Aug 2015, 100 lbs ac^{-1} of sulfur of potash 25-May 2016, 1 ton ac^{-1} of Pro-Gro (5-4-3)
HGM varieties	‘Caliente 199’, ‘Caliente 119’, ‘Caliente 61’, ‘Terminator’	‘Caliente 199’, ‘Terminator’
HGM planting dates	17-Aug, 24-Aug, 31-Aug 2015	31-Jul, 17-Aug 2015
HGM row spacing	7.5”	7.5”
Planting equipment	Great Plains NT60 Cone Seeder	Carter plot drill
Planting rate (lbs ac^{-1})	25	25
HGM termination date	24-Oct 2015	24-Sept and 16-Oct 2015

Vegetable varieties planted	‘Yukon gold’ potato	‘Hystyle’ snap bean, susceptible to root rot ‘Accelerate’ snap bean, resistant to root rot
Vegetable planting date	5-May 2016	27-May 2016
Row spacing (inches)	30	30
Vegetable plot size (ft)	3x10	10x20
Vegetable harvest date	1-Aug 2016	2-Aug 2016

Data were analyzed using mixed model analysis using the mixed procedure of SAS (SAS Institute, 1999). Replications within trials were treated as random effects, and soil amendment treatments were treated as fixed. Mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant (p<0.10).

Treatment	**Yield**
A	6.0
B	7.5*
C	**9.0***
LSD	2.0

Variations in yield and quality can occur because of variations in genetics, soil, weather, and other growing conditions. Statistical analysis makes it possible to determine whether a difference among treatments is real or whether it might have occurred due to other variations in the field. At the bottom of each table a LSD value is presented for each variable (i.e. yield). Least Significant Differences (LSDs) at the 0.10 level of significance are shown, except where analyzed by pairwise comparison (t-test). Where the difference between two treatments within a column is equal to or greater than the LSD value at the bottom of the column, you can be sure that for 9 out of 10 times, there is a real difference between the two treatments. Treatments that were not significantly lower in performance than the top-performing treatment in a particular column are indicated with an asterisk. In this example, hybrid C is significantly different from hybrid A but not from hybrid B. The difference between C and B is equal to 1.5, which is less than the LSD value of 2.0. This means that these hybrids did not differ in yield. The difference between C and A is equal to 3.0, which is greater than the LSD value of 2.0. This means that the yields of these hybrids were significantly different from one another. The asterisk indicates that hybrid B was not significantly lower than the top yielding hybrid C, indicated in bold.

RESULTS

Seasonal precipitation and temperature were recorded with a Davis Instrument Vantage Pro2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT. Most of the 2015 growing season was dryer than normal, with August-October experiencing 3.30-3.91 less inches of precipitation per month than normal (Table 2). September 2015 was 4.6°F warmer than usual, while August and October were comparable to historical averages. Overall, there were an accumulated 1599 Growing Degree Days (GDDs) for August-October 2015, approximately 204 more than the historical average. For the 2016 growing season, temperatures were generally comparable to averages, with August warmer than usual. Precipitation again was lower than usual, with May-August experiencing 6.10 less inches of precipitation than normal. There were an accumulated 3149 GDDs for May-August 2016, approximately 152 more than the historical average.

Table 2. Seasonal weather data[1] collected in Alburgh, VT, 2015-2016.

	2015			2016			
Alburgh, VT	**August**	**September**	**October**	**May**	**June**	**July**	**August**
Average temperature (°F)	69.7	65.2	46.5	58.1	65.8	70.7	71.6
Departure from normal	0.90	4.60	-1.70	1.80	0.00	0.10	2.90
Precipitation (inches)	0.00	0.34	0.04	1.50	2.80	1.80	3.00
Departure from normal	-3.91	-3.30	-3.56	-1.92	-0.88	-2.37	-0.93
Growing Degree Days (base 44°F)	812	650	137	543	745	919	942
Departure from normal	45	152	7	68	1	1	82

[1]Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger. Alburgh precipitation data from August-October was provided by the NOAA data for Highgate, VT. Historical averages are for 30 years of NOAA data (1981-2010) from Burlington, VT.

To gauge weather patterns experienced at High Mowing Organic Seeds in Wolcott, VT, seasonal precipitation and temperature were recorded with observation stations in Walden, VT. Most of the 2015 growing season was cooler than normal, as August-October was 1.00-7.96°F cooler per month than usual (Table 3). Precipitation was generally normal, except August experienced 1.83 fewer inches of precipitation as compared with averages. Overall, there were an accumulated 802 GDDs for August-October 2015, approximately 200 fewer than the historical average. For the 2016 growing season, temperatures again were cooler than averages as May-August was 4.94-8.19°F cooler per month than usual. Precipitation was generally considered normal, however, August experienced 1.55 more inches of rain than usual. There were an accumulated 1366 GDDs for May-August 2016, approximately 563 fewer than the historical average.

Table 3. Seasonal weather data[1] collected in Walden, VT, 2015-2016.

	2015			2016			
Walden, VT	**August**	**September**	**October**	**May**	**June**	**July**	**August**
Average temperature (°F)	62.9	59.0	39.2	50.1	57.4	63.0	62.9
Departure from normal	-4.87	-1.00	-7.96	-6.20	-8.19	-6.96	-4.94
Precipitation (inches)	2.39	4.05	4.55	3.11	4.76	4.55	5.77
Departure from normal	-1.83	0.66	0.68	-0.25	0.75	0.43	1.55

Growing Degree Days (base 50°F)	413.0	330.5	58.0	218.0	304.5	420.5	422.5
Departure from normal	-139	2	-63	-72	-164	-198	-129

[1]Based on national weather service data from cooperative observation stations in Walden, VT.
Historical averages are for 30 years of NOAA data (1981-2010) from St. Johnsbury, VT.

ALBURGH, VT RESEARCH RESULTS

The impact of variety

Both Caliente 119 and Caliente 61 performed significantly better than other varieties for height and yield (4420 and 4410 lbs ac^{-1}, respectively). The varieties Caliente 61and Terminator had plant populations that were significantly greater than other varieties. This may be an indication of better early season vigor. Interestingly, the visual rating of early season vigor did not differ by variety. The HGM varieties were statistically similar in nutrient concentrations (Table 4).

Table 4. High glucosinolate mustard variety characteristics across planting dates, Alburgh, VT, 2015.

Variety	Early vigor†	Height	Population	Dry matter Yield	Carbon	Nitrogen	Phosphorus	Potassium
	1 to 5 rating	inches	plants ac^{-1}	lbs ac^{-1}	%	%	mg kg^{-1}	mg kg^{-1}
Caliente 61	3.25	25.3*	2580000*	4410*	39.9	3.14	3700	31200
Caliente 119	3.42	**27.2***	2030000	**4420***	40.6	2.94	3430	29000
Caliente 199	3.42	19.9	2210000	3410	40.1	3.10	3350	27500
Terminator	3.50	20.6	**3160000***	2980	40.1	3.24	3470	28900
LSD (0.10)	NS	2.94	724409	704	NS	NS	NS	NS
Trial mean	3.40	23.2	2500000	3800	40.2	3.12	3490	29100

†Early season vigor was rated on a 1 to 5 scale with 1 = low vigor and 5 = high vigor.
*Treatments marked with an asterisk did not perform statistically worse than the top performing treatment (p=0.10). Treatments in **bold** were top performers for the given variable.
NS – There was no statistical difference between treatments in a particular column (p=0.10).

Mustard varieties did not significantly impact the soil pH, organic matter, or phosphorus, potassium, or nitrate concentrations measured the following spring (Table 5).

Table 5. The impact of high glucosinolate mustard variety on soil characteristics, across planting dates, Alburgh, VT, 2016.

Variety	pH	Organic matter	Phosphorus	Potassium	Nitrate
		%	ppm	ppm	mg kg^{-1}
Caliente 61	5.92	3.46	1.70	63.2	6.88
Caliente 119	6.07	3.34	1.44	56.8	8.44
Caliente 199	6.06	3.46	1.65	59.8	7.03
Terminator	5.88	3.22	1.67	56.8	6.23
Control	5.97	3.31	1.65	62.8	5.40
LSD (0.10)	NS	NS	NS	NS	NS
Trial mean	5.98	3.36	1.62	59.9	6.80

NS – There was no statistical difference between treatments in a particular column (p=0.10).

The HGM varieties did not differ significantly in how they impacted soil compaction and active carbon (Table 6). Aggregate stability was highest in plots where Caliente 119 was grown. This variety also had the highest biomass yields. Although not significant, Caliente 119 also had the highest level of active carbon.

Table 6. The impact of high glucosinolate mustard variety on plot soil health characteristics, sampled 21-Apr 2016 across planting dates, Alburgh, VT, 2016.

Variety	Compaction in top 6” of soil profile	Compaction in top 18” of soil profile	Wet aggregate stability	Active carbon
	lbs in^{-2}	lbs in^{-2}	%	mg C kg^{-1} soil
Caliente 61	31.3	164	50.5*	521
Caliente 119	27.1	126	**55.0***	574
Caliente 199	40.8	146	44.6	506
Terminator	39.5	151	51.9*	525
Control	38.1	145	47.8	485
LSD (0.10)	NS	NS	6.91	NS
Trial mean	35.4	146	50.0	522

*Treatments marked with an asterisk did not perform statistically worse than the top performing treatment (p=0.10). Treatments in **bold** were top performers for the given variable.
NS – There was no statistical difference between treatments in a particular column (p=0.10).

Mustard variety did not have a significant effect on the following season’s potato yields or weed populations (Table 7). However, a significant difference was seen for disease severity. Plots where Caliente 61 was grown the year before had significantly lower rates of rhizoctonia and scab infection. Caliente 119 also significantly reduced scab infection compared to the control and was comparable to Caliente 61. Interestingly, these two varieties also yielded the highest, indicating perhaps more biomass is needed for greater biofumigant efficacy. Overall disease incidence was low.

Table 7. The impact of high glucosinolate mustard variety on potatoes and weeds across planting date, Alburgh, VT, 2016.

Variety	Potato population	Potato yield	Rhizoctonia‡	Scab‡	Broadleaf weeds	Grass weeds	Weed cover
	plants ac^{-1}	tons ac^{-1}	1 to 4 rating	1 to 4 rating	plants $0.25m^{-2}$	plants $0.25m^{-2}$	%
Caliente 61	28700	10.3	**0.406**	**1.28***	11.1	45.2	26.3
Caliente 119	29200	9.93	0.798	1.37*	12.2	43.8	23.8
Caliente 199	28200	10.3	0.842	1.58	5.42	51.1	28.8
Terminator	28800	10.6	0.729	1.68	7.08	51.8	33.7
Control	28000	10.6	0.958	1.68	11.6	64.6	31.7
LSD (0.10)	NS	NS	0.304	0.241	NS	NS	NS
Trial mean	28600	10.3	0.747	1.52	9.47	51.3	28.9

‡Rhizoctonia and scab were rated on a 1 to 4 scale with 1(trace) = 0-1% of skin infected, 2 (light) = >1-5% of skin infected, 3 (moderate) = >5-10% of skin infected, 4 (heavy) = >10% of skin infected
*Treatments marked with an asterisk did not perform statistically worse than the top performing treatment (p=0.10) shown in **bold.**
NS – There was no statistical difference between treatments in a particular column (p=0.10).

The impact of planting date

The earliest planting date performed significantly better for height, yield (4190 lbs ac^{-1}), and carbon accumulation since it had a longer growing season. Yields of mustard biomass were comparable between the first and second planting dates.

Table 8. The impact of planting date high glucosinolate mustard performance, Alburgh, VT, 2015.

Planting date	Early vigor†	Height	Population	Yield	Carbon	Nitrogen	Phosphorus	Potassium
	1 to 5 rating	inches	plants ac^{-1}	lbs ac^{-1}	%	%	mg kg^{-1}	mg kg^{-1}
17-Aug	3.25	**35.2**	2100000	**4190***	**41.8**	2.46	2930	27600
24-Aug	3.44	22.2	2460000*	3990*	39.6	2.99	**3390**	30100
31-Aug	3.50	12.3	**2930000***	3230	39.2	**3.87**	1430	29700
LSD (0.10)	NS	2.55	627356	609	1.72	0.21	303	NS
Trial mean	3.4	23.2	2500000	3800	40.2	3.12	3490	29100

†Early season vigor was rated on a 1 to 5 scale with 1 = low vigor and 5 = high vigor.
*Treatments marked with an asterisk did not perform statistically worse than the top performing treatment (p=0.10) shown in **bold.**
NS – There was no statistical difference between treatments in a particular column (p=0.10).

Mustard planting date across all varieties did not have a significant impact on pH, organic matter, potassium content, or soil nitrate concentration measured the following spring (Table 9). A significant difference was shown for phosphorus, with the second and third planting dates having a higher concentration than the first.

Table 9. The impact of high glucosinolate mustard planting date on plot soil characteristics, sampled 20-Apr 2016, Alburgh, VT, 2016.

Variety	pH	Organic matter	Phosphorus	Potassium	Nitrate
		%	ppm	ppm	mg kg^{-1}
17-Aug	5.93	3.33	1.40	59.4	6.23
24-Aug	5.99	3.41	1.64*	62.8	7.83
31-Aug	6.02	3.33	**1.82***	57.5	6.34
LSD (0.10)	NS	NS	0.261	NS	NS
Trial mean	5.98	3.36	1.62	59.9	6.80

*Treatments marked with an asterisk did not perform statistically worse than the top performing treatment (p=0.10). Treatments in **bold** were top performers for the given variable.
NS – There was no statistical difference between treatments in a particular column (p=0.10).

When evaluating the impact of mustard planting date on potato yield the following season, no significant differences were seen for potato production, potato disease, or weed populations (Table 10). Based on this first year of data the HGM variety selection appeared to have more of an impact than the planting date especially in regards to disease suppression.

Table 10. The impact of high glucosinolate mustard planting date on potato performance and weed populations, Alburgh, VT, 2015.

Variety	Population	Potato yield	Rhizoctonia‡	Scab‡	Broadleaf weeds	Grass weeds	Weed cover
	plants ac^{-1}	tons ac^{-1}	1 to 4 rating	1 to 4 rating	# plants 0.25m^{-2}	# plants 0.25m^{-2}	%
17-Aug	28500	9.83	0.722	1.41	9.85	47.9	25.4
24-Aug	28700	11.0	0.665	1.60	8.10	48.9	26.7
31-Aug	28400	10.2	0.853	1.55	10.5	57.1	34.5
LSD (0.10)	NS	NS	NS	NS	NS	NS	NS
Trial mean	28600	10.3	0.747	1.52	9.47	51.3	28.9

‡Rhizoctonia and scab were rated on a 1 to 4 scale with 1(trace) = 0-1% of skin infected, 2 (light) = >1-5% of skin infected, 3 (moderate) = >5-10% of skin infected, 4 (heavy) = >10% of skin infected
NS – There was no statistical difference between treatments in a particular column (p=0.10).

WOLCOTT, VT RESEARCH RESULTS

The impact of variety

At the High Mowing Seeds location, mustard varieties did not differ significantly in yield or nutrient concentration (Table 11).

Table 11. The impact of variety on plot characteristics and harvest yield of high glucosinolate mustard across the planting dates, Wolcott, VT, 2015.

Variety	Early vigor†	Height	Population	Yield	Carbon	Nitrogen	Phosphorus	Potassium
	1 to 5 rating	cm	plants ac^{-1}	lbs ac^{-1}	%	%	mg kg^{-1}	mg kg^{-1}
Caliente 199	2.88	89.5	1480000	525	39.7	2.20	3780	22600
Terminator	2.50	96.0	1500000	515	40.1	2.18	3890	22300
LSD (0.10)	NS	NS	NS	NS	NS	NS	NS	NS
Trial mean	2.69	92.8	1490000	520	39.9	2.19	3830	22500

†Early season vigor was rated on a 1 to 5 scale with 1 = low vigor and 5 = high vigor.
NS – There was no statistical difference between treatments in a particular column (p=0.10).

When measured the following spring, mustard variety did not impact soil characteristics compared to the control (Table 12).

Table 12. The impact of high glucosinolate mustard variety on soil characteristics across planting dates, Wolcott, VT, 2015.

Variety	pH	Organic matter	Phosphorus	Potassium	Nitrate
		%	ppm	ppm	mg kg^{-1}
Caliente 199	6.34	5.84	6.21	54.5	4.26
Terminator	6.37	6.42	6.06	59.9	4.72
Control	6.27	6.01	6.03	49.5	4.28
LSD (0.10)	NS	NS	NS	NS	NS
Trial mean	6.32	6.09	6.10	54.6	4.42

NS – There was no statistical difference between treatments in a particular column (p=0.10).

Mustard variety did not have a significant impact on weed populations the following season. When evaluating the impact of mustard variety on snap bean production the following season, no significant difference was seen for yield or root disease severity for the snap bean variety Accelerate (Table 13). Plant populations of Accelerate were significantly higher in the HGM plots compared to the control.

For the snap bean variety Hystyle, Terminator and Caliente 199 again had the highest populations. These varieties also outperformed the control for Hystyle bean yield, with Terminator plots yielding 4540 lbs ac^{-1} and Caliente 199 yielding 4000 lbs ac^{-1}.

Table 13. The impact of high glucosinolate mustard variety on Accelerate and Hystyle snap bean performance and weed populations across planting dates, Wolcott, VT, 2016.

Variety	Accelerate			Hystyle			Broadleaf weeds	Grass weeds	Weed cover
	Population	Yield	Root disease‡	Population	Yield	Root disease‡			
	plants ac^{-1}	lbs ac^{-1}	0 to 10 rating	plants ac^{-1}	lbs ac^{-1}	0 to 10 rating	# plants 0.25m^{-2}	# plants 0.25m^{-2}	%
Caliente 199	9530*	5110	4.20	**27300***	4000*	3.42	87.3	29.0	28.6
Terminator	**10800***	4720	4.88	26800*	**4540***	3.61	99.1	30.4	32.6
Control	6100	4210	4.02	17800	2690	4.18	218	77.1	42.8
LSD (0.10)	3420	NS	NS	4940	1370	NS	NS	NS	NS
Trial mean	8820	4680	4.37	24000	3740	3.74	135	45.5	34.7

‡ Root disease was rated on a 1 to 10 scale with 0 = no disease incidence and 10 = high disease incidence.
*Treatments marked with an asterisk did not perform statistically worse than the top performing treatment (p=0.10). Treatments in **bold** were top performers for the given variable.
NS – There was no statistical difference between treatments in a particular column (p=0.10).

The impact of planting date

As to be expected, the first planting date performed better for height and yield (878 lbs ac^{-1}) considering that it experienced a longer growing season. This test site has a shorter growing season compared to Borderview Research Farm and as a result lower HGM yields were observed.

When evaluating the impact of planting date on mustard performance, no significant differences were seen for population or carbon, phosphorus, or potassium content (Table 14). A significant difference was seen for vigor and nitrogen content, with the second planting date performing better.

Table 14. The impact of planting date on high glucosinolate mustard performance across varieties, Wolcott, VT, 2015.

Planting date	Early vigor†	Height	Population	Yield	Carbon	Nitrogen	Phosphorus	Potassium
	1 to 5 rating	cm	plants ac^{-1}	lbs ac^{-1}	%	%	mg kg^{-1}	mg kg^{-1}
31-Jul	2.38	**114**	1420000	**878**	40.0	1.84	3850	23000
17-Aug	**3.00**	71.5	1550000	162	39.8	**2.53**	3810	22000
LSD (0.10)	0.583	8.25	NS	264	NS	0.227	NS	NS
Trial mean	2.69	92.8	1490000	520	39.9	2.19	3830	22500

†Early season vigor was rated on a 1 to 5 scale with 1 = low vigor and 5 = high vigor.
Treatments in **bold** were top performers for the given variable (p=0.10).
NS – There was no statistical difference between treatments in a particular column (p=0.10).

Mustard planting date impacted some soil characteristics the following spring, with the 31-Jul planting having a higher pH and higher potassium concentration (Table 15).

Table 15. The impact of high glucosinolate mustard planting dates on soil characteristics, Wolcott, VT, 2015.

Variety	pH	Organic matter	Phosphorus	Potassium	Nitrate
		%	ppm	ppm	mg kg^{-1}
31-Jul	**6.38**	6.23	6.33	**60.7**	4.43
17-Aug	6.27	5.95	5.88	48.6	4.41
LSD (0.10)	0.115	NS	NS	8.67	NS
Trial mean	6.32	6.09	6.10	54.6	4.42

Treatments in **bold** were top performers for the given variable (p=0.10).
NS – There was no statistical difference between treatments in a particular column (p=0.10).

When evaluating the impact of mustard planting date on weed populations the following season, no significant difference was seen for population of broadleaf or grass weeds, however, the 17-Aug planting date showed significantly less weed cover (Table 16).

Mustard planting date impacted population and root disease for the snap bean variety Accelerate, with the 31-Jul planting having a greater population and lower root disease severity. Mustard planting date did not significantly impact bean production or disease incidence for the variety Hystyle.

Table 16. The impact of high glucosinolate mustard planting date on Accelerate and Hystyle snap bean performance and weed populations, Wolcott, VT, 2016.

Variety	Accelerate			Hystyle			Broadleaf weeds	Grass weeds	Weed cover
	Population	Yield	Root disease‡	Population	Yield	Root disease‡			
	plants ac^{-1}	lbs ac^{-1}	0 to 10 rating	plants ac^{-1}	lbs ac^{-1}	0 to 10 rating	# plants $0.25m^{-2}$	# plants $0.25m^{-2}$	%
31-Jul	**10500**	4990	**3.91**	25400	3570	4.02	154	76.8	44.0
17-Aug	7120	4380	4.83	22500	3910	3.46	116	14.3	**25.3**
LSD (0.10)	2790	NS	0.882	NS	NS	NS	NS	NS	11.2
Trial mean	8820	4680	4.37	2400	3740	3.74	135	45.5	34.7

‡ Root disease was rated on a 1 to 10 scale with 0 = no disease incidence and 10 = high disease incidence.
Treatments in **bold** were top performers for the given variable (p=0.10).
NS – There was no statistical difference between treatments in a particular column (p=0.10).

The impact of mustard meal

Both mustard variety as a whole plant and mustard meal, did not significantly impact snap bean performance or weed populations (Table 17).

Table 17. The impact of mustard variety (whole plant) and mustard meal on plot characteristics and harvest yield of Accelerate and Hystyle snap beans across planting dates, Wolcott, VT, 2016.

Variety	Accelerate			Hystyle			Broadleaf weeds	Grass weeds	Weed cover
	Population	Yield	Root disease‡	Population	Yield	Root disease‡			
	plants ac^{-1}	lbs ac^{-1}	0 to 10 rating	plants ac^{-1}	lbs ac^{-1}	0 to 10 rating	# plants $0.25m^{-2}$	# plants $0.25m^{-2}$	%
Caliente 199	11500	4920	4.25	29000*	4190	3.14	86.3	38.0	35.0
Terminator	12400	5080	4.28	**29500***	4060	4.17	107	47.5	43.1
Mustard meal	11500	5560	5.08	20100	3900	5.03	53.8	11.8	22.2
Control	12400	4960	3.21	17600	2470	4.74	267	145	53.9
LSD (0.10)	NS	NS	NS	8290	NS	NS	NS	NS	NS
Trial mean	10800	5130	4.20	24100	3660	4.27	129	60.5	38.6

‡ Root disease was rated on a 1 to 10 scale with 0 = no disease incidence and 10 = high disease incidence.
*Treatments in **bold** were top performers for the given variable (p=0.10).
NS – There was no statistical difference between treatments in a particular column (p=0.10).

When evaluating the impact of mustard meal in comparison to incorporating whole mustard plant, the mustard meal showed a significantly lower rate of root disease infection in the Hystyle snap beans (Table 18). Contrasts that compared the impact of meal compared to whole mustard plants on weeds indicated no significant difference (data not shown).

Table 18. Contrast comparing mustard meal vs whole plant incorporation for snap bean root disease severity, Wolcott, VT, 2016.

	Accelerate root disease‡	Hystyle root disease‡
	0 to 10 rating	
Mustard meal	5.08	3.66
Mustard whole plant	4.26	5.02
p-value	0.21	0.10

‡ Root disease was rated on a 1 to 10 scale with 0 = no disease incidence and 10 = high disease incidence.

DISCUSSION

Based on the research results shown here, variety selection, planting dates, and mustard meal may affect the impact that HGM has on pest pressure and vegetable performance. At the Alburgh location, both mustard variety and planting date impacted mustard height and biomass, while mustard variety also impacted potato skin disease. At the Wolcott location, mustard planting date impacted both mustard performance (biomass, height) and weed pressure on snap beans. At the Wolcott location, where meal was also evaluated, the ground mustard improved disease control over the whole plant biomass in the beans with high root rot susceptibility. Also, it is worth noting that the efficacy of high glucosinolate mustards may vary among pathogen or weed species.

The mustard grown in this trial did not produce as much biomass as commonly seen in the Pacific Northwest, where HGM has become a popular biofumigant. It is possible that more HGM biomass is needed to have a stronger impact on subsequent vegetable plantings. Earlier HGM plantings tended to have a higher mustard yield, indicating that planting date is an important factor to consider. In addition, growers have experimented with rolling, packing, covering with a tarp, or irrigating freshly incorporated HGM to help create a seal over the soil surface and increase release of biofumigants in the soil. It is possible that other techniques may be more effective at using HGM as a biofumigant. It is also possible that a fall-applied mustard meal may have different effects compared to the spring-applied meal used in this trial. Additional research is needed to continue developing best agronomic practices for this pest control measure.

It is important to remember that these data represent only one year of research, and in only one location. More data should be considered before making agronomic management decisions.

ACKNOWLEDGEMENTS

The UVM Extension Northwest Crops and Soils Team would like to thank the Vermont Agency of Agriculture, Food, and Markets Specialty Crop Block Grant Program for funding this research. Special thanks to Roger Rainville and the staff at Borderview Research Farm for their generous help with the trials. We would like to acknowledge Nate Brigham, Kelly Drollette, Lindsey Ruhl, Julian Post, and Xiaohe "Danny" Yang for their assistance with data collection, and data entry. This information is presented with the understanding that no product discrimination is intended and neither endorsement of any product mentioned, nor criticism of unnamed products, is implied.

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