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THE EFFICACY OF SPRAYING FUNGICIDES TO CONTROL FUSARIUM HEAD BLIGHT INFECTION IN SPRING MALTING BARLEY

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The "localvore" movement and public interest in sourcing local foods has extended into beverages, and the demand for local brewing and distilling ingredients sourced in the Northeast remains high. One market that has generated interest from both farmers and end-users is malted barley. The Northeast is home to over 180 microbreweries and 37 craft distillers. Until recently, local malt was not readily available to brewers or distillers. The expanding malting industry provides farmers with new markets for grain crops. Regional maltsters continue to find it challenging to source enough local grain to match demand for their product. The local barley that is available sometimes does not meet the rigid quality standards for malting. One major obstacle for growers is *Fusarium* head blight (FHB) infection of grain. This fungal disease is currently the most significant disease facing organic and conventional grain growers in the Northeast, resulting in loss of yield, shriveled grain, and most importantly, mycotoxin contamination. A vomitoxin called deoxynivalenol (DON) is the primary mycotoxin associated with FHB. The fungus can overwinter in soils and spores can be transported by air currents. *Fusarium* can infect plants at spike emergence through grain fill. Consuming DON at over 1 ppm poses a health risk to both humans and livestock, and products with DON values greater than 1 ppm are considered unsuitable for human consumption by the FDA.

Fungicide applications have proven to be relatively effective at controlling FHB in other barley growing regions. Limited work has been done in this region on the optimum timing for a fungicide application to barley specifically to minimize DON. There are limited studies evaluating organic approved biofungicides, biochemicals, or biostimulants for management of this disease. In April 2019, the UVM Extension Northwest Crops and Soils Program initiated year five of a spring barley fungicide trial to determine the efficacy and timing of fungicide application to reduce FHB infection on cultivars with varying degrees of disease susceptibility.

MATERIALS AND METHODS

A field experiment was established at the Borderview Research Farm located in Alburgh, Vermont in the spring of 2019 to investigate the effects of cultivar resistance, fungicide efficacy, application timing on FHB and DON infection in spring malting barley. The experimental design was a randomized complete block, with a split-plot arrangement of cultivar as the whole-plot and fungicide+timing treatments as the sub-plots. The main plot of cultivar included Robust, a 6-row malting barley that is a FHB susceptible variety, and Conlon, a 2-row malting barley with moderate FHB resistance. The fungicide+timing treatments are listed in Table 2.

The seedbed was prepared by conventional tillage methods. All plots were managed with practices similar to those used by producers in the surrounding areas (Table 1). The previous crop planted at the site was spring wheat. Prior to planting, the trial area was disked and spike tooth harrowed to prepare for planting. The plots were seeded with a Great Plains Cone Seeder on 30-Apr at a seeding rate of 350 live seeds per m^2. Plot size was 5'x 20'.

Table 1. General plot management of the trial, 2019.

Location	Borderview Research Farm Alburgh, VT
Soil type	Benson rocky silt loam
Previous crop	Spring wheat
Row spacing (inch)	7
Seeding rate (live seed m^{-2})	350
Replicates	4
Varieties	Conlon and Robust
Planting date	30-Apr
Harvest date	29-Jul
Harvest area (ft)	5 x 20
Tillage operations	Spring plow, disk & spike tooth harrow

Fungicides trialed in the 2019 spring barley fungicide trial included Miravis Ace, Prosaro, Caramba, and ChampION (Tables 2 and 3). Miravis Ace was applied at Feekes stage 10.3 (when the grain head is half-emerged from the sheath), at heading, and at five days past heading. Prosaro was applied at heading. Caramba was applied at heading and at five days post-heading. ChampION was applied at heading, at five days post-heading, and one plot per replicate was treated both at heading and at five days post-heading. Cold and erratic weather in the early growing season resulted in marked differences in maturity between varieties. Each variety was treated as it reached the appropriate state of maturity (Table 2).

Heading date applications were applied when the barley reached 50% spike emergence (Table 2). The adjuvant 'Induce' was added to the Miravis Ace and Caramba applications at a rate of 0.125%. All but one plot (control) in each replicate was inoculated on the same day that the heading treatment was applied, with a spore suspension (40,000 spores/ml) consisting of a mixture of isolates of *Fusarium graminearum* endemic to the area. The control plots were sprayed with water with no *Fusarium* spores. One plot per replicate was inoculated with *Fusarium* but was not treated with a fungicide (*Fusarium* only). Five days after the heading application, plots not previously treated with a fungicide were sprayed with the fungicides treatments except for the control and *Fusarium* only plots (Table 2). The applications were made using a Bellspray Inc. Model T4 backpack sprayer. This model had a carbon dioxide pressurized tank and a four-nozzle boom attachment. It sprayed at a rate of 10 gallons per acre.

Table 2. Treatment Application Dates.

Variety and Treatment	Application Date
Conlon 10.3 Feekes Miravis Ace	22-Jun
Conlon Inoculated with *Fusarium*	24-Jun
Conlon Heading Applications	24-Jun
Conlon Post-heading Applications	29-Jun
Robust 10.3 Feekes Miravis Ace	27-Jun
Robust Heading Applications	29-Jun
Robust Inoculated with *Fusarium*	29-Jun
Robust Post-Heading Applications	2-Jul

On 10-Jul, when the barley reached the soft dough growth stage, FHB intensity was assessed by randomly clipping 60-100 heads from each plot, counting spikes, and visually assessing each head for FHB infection. The infection rate was assessed by using the North Dakota State University Extension Service's "A Visual Scale to Estimate Severity of *Fusarium* Head Blight in Wheat" online publication.

Grain plots were harvested with an Almaco SPC50 plot combine on 29-Jul. The harvest area was 5' x 20'. Grain moisture, test weight, and yield were measured at harvest. Harvest moisture and test weight were determined for each plot using a DICKEY-john Mini GAC moisture and test weight meter. Higher test weight in barley is associated with better malting quality. The acceptable test weight for barley is 48 lbs bu^{-1}.

Following harvest, barley was cleaned with a small Clipper cleaner (A.T. Ferrell, Bluffton, IN). A one-pound subsample was collected to determine quality. Approximately 300 g of each sample was ground into flour using the Perten LM3100 Laboratory Mill. Deoxynivalenol (DON) concentrations were analyzed using Veratox DON 2/3 Quantitative test from the NEOGEN Corp. This test has a detection range of 0.5 to 5 ppm. Samples with DON values greater than 1 ppm are considered unsuitable for human consumption by the FDA.

Following is a list of the fungicides and application rates evaluated in this trial (Table 3). Descriptions have been provided from manufacturer information.

Table 3. Plot treatments-fungicide application rates.

Treatments	Application rate
Control	Water
Caramba	14 fl oz ac^{-1} +.125% Induce ac^{-1}
ChampION	1.5 lbs ac^{-1}
Miravis Ace	13.7 fl oz ac^{-1}+ .125% Induce ac^{-1}
Prosaro	6.5 fl oz ac-1 +.125% Induce ac^{-1}
Fusarium graminearum	40,000 spores/ml

Caramba® (EPA# 7969-246) fungicide is a highly effective fungicide containing the active ingredient metconazole, resulting in significant yield protection and reductions of deoxynivalenol (DON) levels in grain. It is not only effective on head scab, but provides control of late-season foliar diseases as well.

ChampION® (EPA# 55146-1) is a 77% copper hydroxide-based, broad-spectrum fungicide for disease control. When copper hydroxide is mixed with water, it releases copper ions, which disrupt the cellular proteins of the fungus. This product is approved for use in organic production systems.

Miravis® Ace (EPA# 100-1601) is a combination of propiconazole and Adepidyn®fungicide – the first SDHI mode of action available for *Fusarium* head blight control. It distributes evenly within the leaf and creates a reservoir within the wax layer of the leaf that withstands rain and degradation. It also provides protection against Septoria leaf spot and other foliar disease.

Prosaro® (EPA# 264-862) fungicide provides broad-spectrum disease control, stops the penetration of the fungus into the plant and the spread of infection within the plant and inhibits the reproduction and further growth of the fungus.

All data was analyzed using a mixed model analysis where replicates were considered random effects and the treatments and varieties were considered fixed effects. The LSD procedure was used to separate treatment and cultivar means when the F-test was significant (p< 0.10).

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 varieties 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 (e.g. yield). Least Significant Differences at the 10% level of probability are shown. Where the difference between two varieties within a column is equal to or greater than the LSD value at the bottom of the column, you can be sure in 9 out of 10 chances that there is a real difference between the two varieties. In the accompanying example, variety A is significantly different from variety C, but not from variety B. The difference between A and B is equal to 725, which is less than the LSD value of 889. This means that these varieties did not differ in yield. The difference between A and C is equal to 1454, which is greater than the LSD value of 889. This means that the yields of these varieties were significantly different from one another. The asterisk indicates that variety B was not significantly lower than the top yielding variety.

Variety	Yield
A	3161
B	3886*
C	**4615***
LSD	**889**

RESULTS

Seasonal precipitation and temperature recorded at a weather station at Borderview Research Farm are shown in Table 4. April, May, and June were all colder than normal. April and May had higher precipitation than the 30-year average, while June was somewhat drier. July was both hotter and drier than the 30-year average. From April through July, there was an accumulation of 3261 Growing Degree Days (GDDs), 91 GDDs below the 30-year average.

Table 4. Temperature and precipitation summary for Alburgh, VT, 2019.

Alburgh, VT	April	May	June	July
Average temperature (°F)	42.7	53.3	64.3	73.5
Departure from normal	-2.11	-3.11	-1.46	2.87
Precipitation (inches)	3.65	4.90	3.06	2.34
Departure from normal	0.83	1.45	-0.63	-1.81
Growing Degree Days (32-95°F)	346	660	970	1286
Departure from normal	-38	-96	-44	88

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger.
Historical averages are for 30 years of data provided by the NOAA (1981-2010) for Burlington, VT.

Barley Variety x Fungicide+Timing Interactions:

There were no significant interactions between treatment and variety.

Impact of Fungicide and Timing

There were significant differences between treatments for harvest moisture, yield, DON concentrations, FHB severity, and incidence of infected heads (Tables 5 and 6, Figure 1). The *Fusarium* only treatments had the lowest average harvest moisture at 16.8% moisture content. All barley harvested required drying down for storage.

Yields in the spring barley variety trial were all over 3600 lbs ac^{-1}, with an average yield of just over two tons ac^{-1} for the trial. The highest yield by treatment was the Miravis Ace applied five days after heading, at 4460 lbs ac^{-1}. This was statistically similar to the control, Caramba applied five days after heading, ChampION applied at both heading and five days after heading, Miravis Ace applied at Feekes stage 10.3, Miravis Ace applied at heading, and Prosaro applied at heading.

All treatments and timings, including the control and the *Fusarium* only plots, had DON concentrations below the 1-ppm threshold recommended by the FDA. Three treatments had DON concentrations of only 0.10 ppm – the uninoculated control, Miravis Ace applied five days post heading, and Miravis Ace applied at heading. This was statistically similar to all other treatments except the inoculated but untreated plots, which had an average DON concentration of 0.24 ppm.

There were significant differences between treatments in both the incidence and severity of FHB infection. The incidence of infected heads refers to the proportion of barley spikes showing any sign of FHB infection compared to the uninfected spikes in that treatment. The average infected head severity refers to the extent to which infected heads are affected by FHB symptoms. The Miravis Ace treatment applied five days after heading was the lowest in both average FHB severity (5.34%) and incidence of infected heads (24.7%). The severity was statistically similar in the inoculated untreated plots, the ChampION treatment applied both at heading and post heading, and Miravis Ace applied at Feekes stage 10.3. The incidence of infected heads was statistically similar in the unsprayed, uninoculated control, Caramba treatment applied at heading, Caramba treatment applied five days after heading, Miravis Ace applied at Feekes stage 10.3, the Miravis Ace applied at heading, and the Prosaro treatment applied five days after heading.

Table 5. Harvest quality by fungicide treatment and timing.

Treatment	Harvest moisture	Test weight	Yield @13.5% moisture
	%	lbs bu^{-1}	lbs ac^{-1}
Non-sprayed, non-inoculated control	17.7^{abcd}	**47.3**	4145^{abc}
Inoculated *Fusarium* spores	**16.8^{a}**	46.8	3717^{c}
Caramba Heading	17.8^{abcd}	46.8	3710^{c}
Caramba Post-heading	17.9^{bcd}	47	4232^{abc}
ChampION 2 Applications	17.4^{abc}	46.9	3818^{bc}
ChampION Heading	17.7^{abcd}	46.6	3653^{c}

ChampION Post-heading	17.5[abcd]	46.6	3747[c]
Miravis Ace Feekes 10.3	17.2[ab]	47	4415[ab]
Miravis Ace Heading	18.4[cd]	46.8	4131[abc]
Miravis Ace Post-heading	18.5[d]	47.1	**4460[a]**
Prosaro Heading	17.3[ab]	46.4	3990[abc]
LSD (0.10)	1.09	NS	604
Trial Mean	17.6	46.8	4002

The top performing treatment in each column is indicated in **bold**.
Treatments with the same letter did not differ significantly.
NS - None of the treatments were significantly different from one another.

Table 6. DON concentrations and FHB severity by fungicide treatment and timing

Treatment	DON	Average FHB severity	Incidence of FHB infected heads
	ppm	%	%
Non-sprayed, non-inoculated control	**0.10[a]**	7.46[bc]	42.9[ab]
Inoculated *Fusarium* spores	0.24[b]	6.67[ab]	47.9[b]
Caramba Heading	0.21[ab]	7.47[bc]	32.5[ab]
Caramba Post-heading	0.18[ab]	7.81[bc]	34.7[ab]
ChampION 2 Applications	0.15[ab]	6.38[ab]	49.3[b]
ChampION Heading	0.16[ab]	8.67[c]	47.7[b]
ChampION Post-heading	0.20[ab]	7.66[bc]	53.3[b]
Miravis Ace Feekes 10.3	0.11[ab]	6.32[ab]	33.9[ab]
Miravis Ace Heading	**0.10[a]**	7.38[bc]	40.7[ab]
Miravis Ace Post-heading	**0.10[a]**	**5.34[a]**	**24.7[a]**
Prosaro Heading	0.21[ab]	6.67[ab]	25.4[a]
LSD (0.10)	0.13	1.59	2.21
Trial Mean	0.16	7.08	39.4

The top performing treatment in each column is indicated in **bold**.
Treatments with the same letter did not differ significantly.

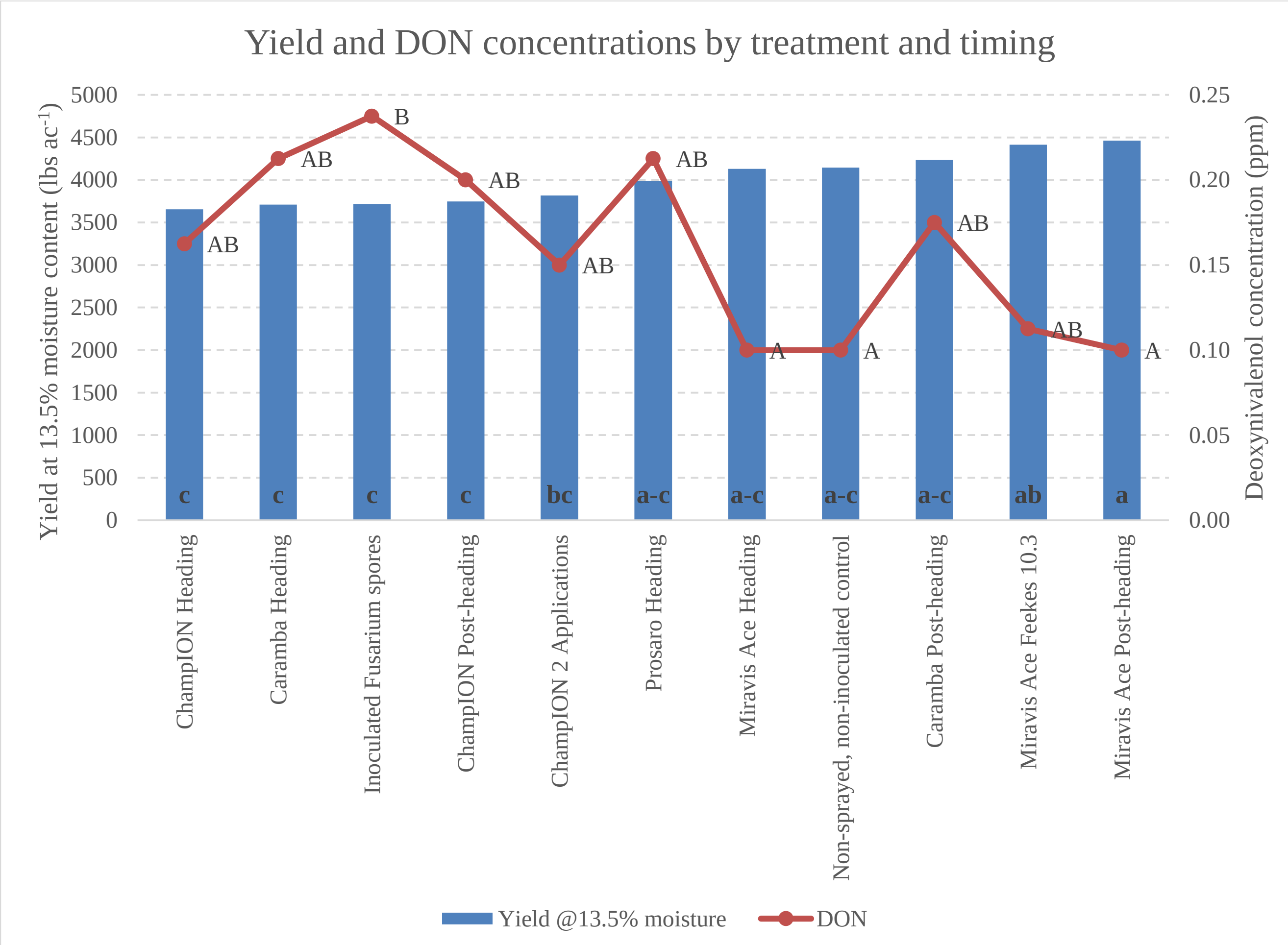

Figure 1. The impact of application timing and fungicide on barley yield and DON concentration. Treatments with the same letter did not differ significantly by DON concentration (capital letters) or yield (lowercase).

Impact of Variety

There were significant differences between varieties in harvest moisture, yield, DON concentrations, FHB severity and incidence of FHB infection (Table 7, Figure 2).

Table 7. Harvest quality and FHB assessment by variety.

Variety	Harvest moisture	Test weight	Yield @13.5% moisture	DON	Average FHB severity	Incidence of FHB infected heads
	%	lbs bu^{-1}	lbs ac^{-1}	ppm	%	%
Conlon	**17.3***	**46.9**	**4138***	**0.08***	**6.43***	**9.2***
Robust	18.0	46.8	3865	0.24	7.73	69.5
LSD (0.10)	0.47	NS	257	0.05	0.68	9.06
Trial Mean	17.6	46.8	4002	0.16	7.08	39.4

Varieties with an asterisk* performed statistically similarly to the top performer in **bold**. NS – not significantly different.

Conlon had slightly but significantly lower harvest moisture than Robust. Both varieties had to be dried down for storage. Conlon yielded 273 lbs ac^{-1} higher than Robust.

The DON concentrations in Conlon barley (0.08 ppm) were significantly lower than the DON concentration in Robust barley (0.24 ppm), although both were well below the FDA threshold of 1 ppm.

Robust had an incidence of infected heads over seven times higher than that of Conlon. While less than 10% of spikes of Conlon barley were infected with FHB, over half of the spikes of Robust barley were infected. The average severity of the infection in each spike was around 7% for both varieties.

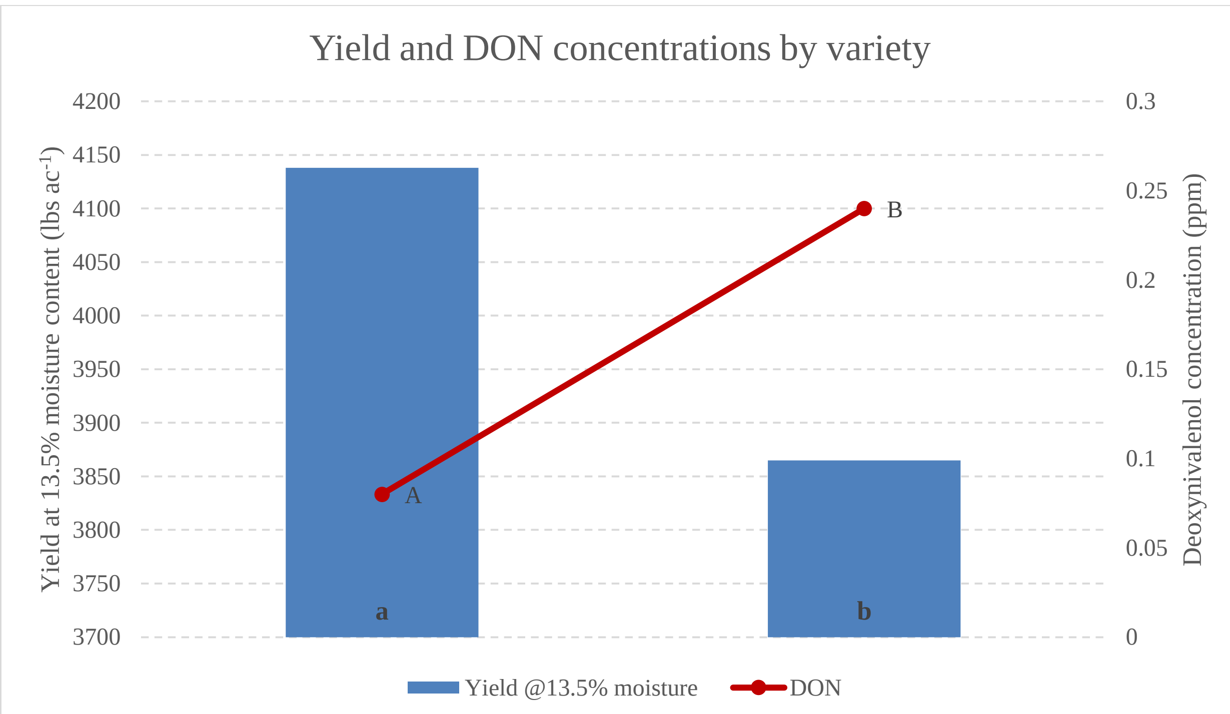

Figure 2. The impact of variety on barley yield and DON concentration.
Varieties with different letters varied significantly by DON concentration (capital letters) or yield (lowercase).

DISCUSSION

Levels of *Fusarium* infection and resulting DON vomitoxin concentrations in grain are associated with weather conditions at the time of grain fill and heading. Colder, wetter weather through this period is associated with more *Fusarium* infection and higher levels of DON. While the spring weather was very cold and wet during early growing season, this delayed maturity until weather warmed in June. While grain was late to head (about a week later than normal), by the second half of June the weather was warmer and much drier than it had been earlier in the season and conditions were not conducive for development of the DON vomitoxin. There were low DON concentrations throughout the small grains trials, including the fungicide trials. The weather remained mild through the rest of growing season and produced high yields of barley at harvest.

All fungicide applications reduced DON concentrations significantly compared to the plots that were inoculated with *Fusarium* but not treated with fungicides. The Miravis Ace applications, including all timings, had the lowest DON concentrations of the trial.

This trial is expected to continue for additional years. It is important to remember that the results only represent one year of data.

ACKNOWLEDGEMENTS

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