The Efficacy of Spraying Fungicides to Control Fusarium Head Blight Infection in Spring Malting Barley

Dr. Heather Darby, UVM Extension Agronomist
Rory Malone, Henry Blair, and Hillary Emick
UVM Extension Crops and Soils Coordinators
(802) 524-6501

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Dr. Heather Darby, University of Vermont Extension
Heather.Darby[at]uvm.edu

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 does not always meet the strict 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 2020, the UVM Extension Northwest Crops and Soils Program initiated year six 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 2020 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 ND Genesis, a 2-row malting barley. 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 silage corn and the soil type was Benson rocky silt loam with 3-8% slopes. 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 9-Apr at a seeding rate of 350 live seeds m^2. The plot size was 5'x 20'.

Table 1. Trial agronomic information, 2020.

Location	Borderview Research Farm Alburgh, VT
Soil type	Benson rocky silt loam, 3-8% slopes
Previous crop	Silage corn
Row spacing (inch)	7
Seeding rate (live seed m^{-2})	350
Replicates	4
Varieties	ND Genesis and Robust
Planting date	9-Apr
Harvest date	21-Jul
Harvest area (ft)	5 x 20
Tillage operations	Spring plow, disk & spike tooth harrow

Fungicides trialed in the 2020 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 (Feekes state 10.5), and at 4-6 days past heading. Prosaro and Caramba were applied at heading. ChampION was applied at heading, at 4-6 days post-heading, and one plot per replicate was treated both at heading and at five days post-heading. Treatments consisted of a combination of applications of two fungicides. For one dual treatment, Miravis Ave was applied at heading, followed by Prosaro four days after heading. For the other dual treatment, Miravis Ace was applied at heading followed by Caramba four days after heading. 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 all treatments 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 (100,000 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). Six days after the heading application for the Robust barley, and five days after heading application for Genesis barley, plots not previously treated with a fungicide were sprayed with the fungicide treatments except for the control and *Fusarium* only plots (Table 2). The second part of the dual application treatments were applied four days after heading. 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
Genesis 10.3 Feekes- Early Applications	16-Jun
Genesis Heading Applications	23-Jun
Genesis Inoculated with *Fusarium*	24-Jun
Genesis Post-heading Applications	28-Jun
Robust 10.3 Feekes- Early Applications	12-Jun

Robust Heading Applications	17-Jun
Robust Inoculated with *Fusarium*	18-Jun
Robust Post-Heading Applications	23-Jun

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 21-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	100,000 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.

Data were analyzed using a general linear model procedure of SAS (SAS Institute, 2008). Replications were treated as random effects, and treatments were treated as fixed. Mean comparisons were made using the Least Significant Difference (LSD) procedure where the F-test was considered significant, at $p<0.10$. Variations in genetics, soil, weather, and other growing conditions can result in variations in yield and quality. Statistical analysis makes it possible to determine whether a difference between treatments is significant or whether it is due to natural variations in the plant or 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. This means that when the difference between two treatments within a column is equal to or greater to the LSD value for the column, there is a real difference between the treatments 90% of the time. In the example to the right, treatment C was significantly different from treatment A, but not from treatment B. The difference between C and B is 1.5, which is less than the LSD value of 2.0 and so these treatments were not significantly different 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 treatments were significantly different from one another. Treatment B was not significantly lower than the top yielding treatment, indicated in bold. A lack of significant difference is indicated by shared letters.

Treatment	Yield
A	6.0[b]
B	7.5[ab]
C	**9.0[a]**
LSD	2.0

RESULTS

Seasonal precipitation and temperature recorded at a weather station at Borderview Research Farm are displayed below in Table 4. April and May were colder than normal, followed by a warm June, and a hot, recording-setting July. July was 4.17° F warmer than the norm. All months during the growing season had lower precipitation than the 30-year average, with 3.81 inches less over the four-month period than average. Through the four months of the growing season there was an accumulation of 3433 Growing Degree Days (GDDs), 55 GDDs above the 30-year norm.

Table 4. Temperature and precipitation summary for Alburgh, VT, 2020.

Alburgh, VT	April	May	June	July
Average temperature (°F)	41.6	56.1	66.9	74.8
Departure from normal	-3.19	-0.44	1.08	4.17
Precipitation (inches)	2.09	2.35	1.86	3.94

Departure from normal	-0.72	-1.04	-1.77	-0.28
Growing Degree Days (32-95°F)	315	746	1046	1326
Departure from normal	-99	-13	35	132

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 statistical interactions between treatments and varieties.

Impact of Fungicide and Timing

There were significant differences between treatments for DON concentrations (Table 6, Figure 1). Harvest metrics are shown in Table 5 and DON concentrations and FHB severity are shown in Table 6. Harvest moisture, test weight, yield,100 kernel weights, and FHB incidence and severity did not differ statistically by treatment.

All treatments and timings, including the control and the *Fusarium* inoculated plots, had DON concentrations below the 1 ppm threshold recommended by the FDA. It is important to note that DON results were below the detection minimum of 0.5, which means these results may not be precise. Eight treatments had DON concentrations less than that of the uninoculated control (0.19 ppm). These included Miravis Ace at heading, Miravis Ace followed by Caramba, Miravis Ace followed by Prosaro, Miravis Ace at Feekes 10.3, Miravis Ace post heading, Caramba, and Prosaro. The treatment with the lowest DON concentration was Miravis Ace at heading at 0.03 ppm, which was significantly lower than all ChampION treatments, and the *Fusarium* inoculated plots. The *Fusarium* inoculated plots had the highest DON concentrations as expected, and they were statistically similar to only the three ChampION treatments and the control. All treatments were similar to the control, which is not surprising considering it was a hot and dry June and July, with poor conditions for DON.

There were no significant differences between treatments in the severity of FHB infection and incidence of infection. Caramba applied at heading had the lowest in average FHB severity (7.66%), and Prosaro applied at headed had the lowest FHB incidence (0.02%). 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 trial average for FHB severity was 13.0% and the average incidence of FHB infection was 0.049%.

Table 5. Harvest quality by fungicide treatment and timing, Alburgh, VT, 2020.

Treatment	Harvest moisture	Test weight	Yield at 13.5% moisture	100 kernel weight
	%	lbs bu^{-1}	lbs ac^{-1}	g
Miravis Ace Post-Heading	14.20	45.7	3228	4.58
Miravis Ace Feekes 10.3	14.13	45.3	3406	4.51
Miravis Ace Heading	14.09	45.3	3369	4.49
Miravis Ace (Heading) & Caramba (Post)	15.13	45.8	3962	4.55

Miravis Ace (Heading) & Prosaro (Post)	14.50	45.1	3814	4.50
Caramba Heading	14.41	44.4	3314	4.46
ChampION Post-Heading	13.95	46.8	3746	4.53
ChampION Heading & Post-Heading	14.13	45.8	3946	4.54
ChampION Heading	13.96	45.3	3392	4.41
Inoculated *Fusarium* spores	14.40	46.2	3656	4.65
Prosaro Heading	13.76	45.6	3240	4.59
Non-sprayed, non-inoculated control	14.01	45.3	3281	4.40
LSD (p=0.10)†	NS‡	NS	NS	NS
Trial Mean	14.2	45.6	3530	4.52

† LSD- Least significant difference at p=0.10.

‡NS- Not significant.

Table 6. DON concentrations and FHB severity by fungicide treatment and timing, Alburgh, VT, 2020.

Treatment	DON	Average FHB severity	Incidence of FHB infected heads
	ppm	%	%
Miravis Ace Post-Heading	0.11^{abc}	10.2	0.041
Miravis Ace Feekes 10.3	0.07^{ab}	11.8	0.062
Miravis Ace Heading	**0.03^{a}**	12.1	0.036
Miravis Ace (Heading) & Caramba (Post)	0.04^{a}	15.5	0.070
Miravis Ace (Heading) & Prosaro (Post)	0.05^{a}	11.0	0.058
Caramba Heading	0.14^{abc}	**7.66**	0.026
ChampION Post-Heading	0.27^{cd}	15.3	0.054
ChampION Heading & Post-Heading	0.26^{cd}	10.9	0.073
ChampION Heading	0.22^{bcd}	14.9	0.050
Inoculated *Fusarium* spores	0.33^{d}	14.4	0.064
Prosaro Heading	0.14^{abc}	14.9	**0.020**
Non-sprayed, non-inoculated control	0.19^{abcd}	17.0	0.033
LSD (0.10)	0.153	NS	NS
Trial Mean	0.15	13.0	0.049

†Treatments within a column with the same letter are statistically similar. LSD- Least significant difference. NS- Not significant. The top performing treatment in each column is indicated in **bold.**

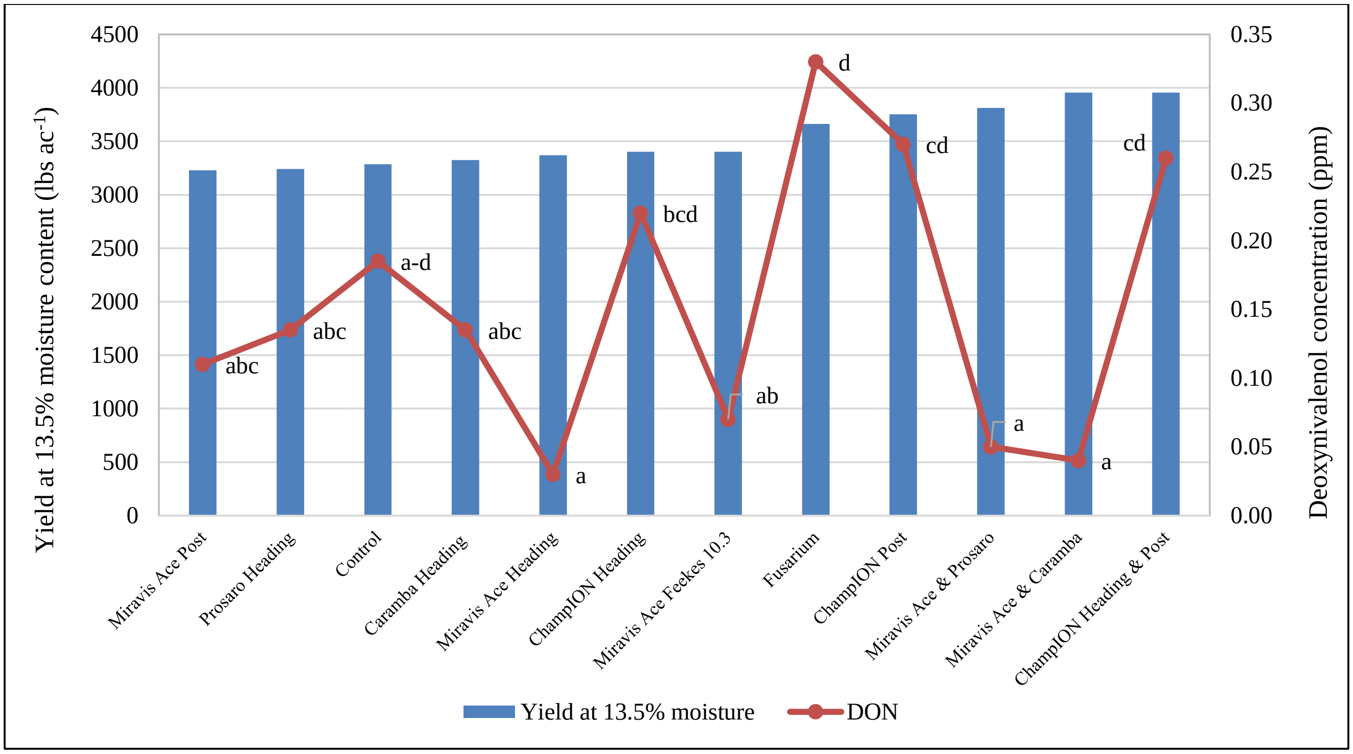

Figure 1. The impact of application timing and fungicide on barley yield and DON concentration.
Treatments with the same letter did not differ significantly by DON concentration. No yields differed significantly by treatment.

Impact of Variety

There were significant differences between varieties in harvest moisture, test weight, 100 kernel weights, yield, and DON concentrations (Table 7, Figure 2). There were no significant differences by variety in FHB severity and incidence of FHB infection.

Table 7. Harvest quality and FHB assessment by variety, Alburgh, VT, 2020.

Variety	Harvest moisture	Test weight	Yield @13.5% moisture	100 kernel weight	DON	Average FHB severity	Incidence of FHB infected heads
	%	lbs bu^{-1}	lbs ac^{-1}	g	ppm	%	%
Genesis	15.4	45.1	**3660**	**4.96**	**0.08**	13.4	0.056
Robust	**13.1**	**46.0**	3399	4.07	0.22	**12.6**	**0.040**
LSD (0.10)	0.33	0.55	250	0.082	0.07	NS	NS
Trial Mean	14.2	45.6	3530	4.52	0.15	13.0	0.049

† The top performing treatment in each column is indicated in **bold.** LSD- Least significant difference. NS- Not significant.

Robust had a significantly lower harvest moisture and higher test weight than Genesis. Both varieties had to be dried down for storage. Genesis yielded 261 lbs ac^{-1} higher than Robust. The DON concentrations in Genesis (0.08 ppm) were significantly lower than the DON concentration in Robust barley (0.22 ppm), although both were well below the FDA threshold of 1 ppm. FHB severity and incidences were similar between the two varieties.

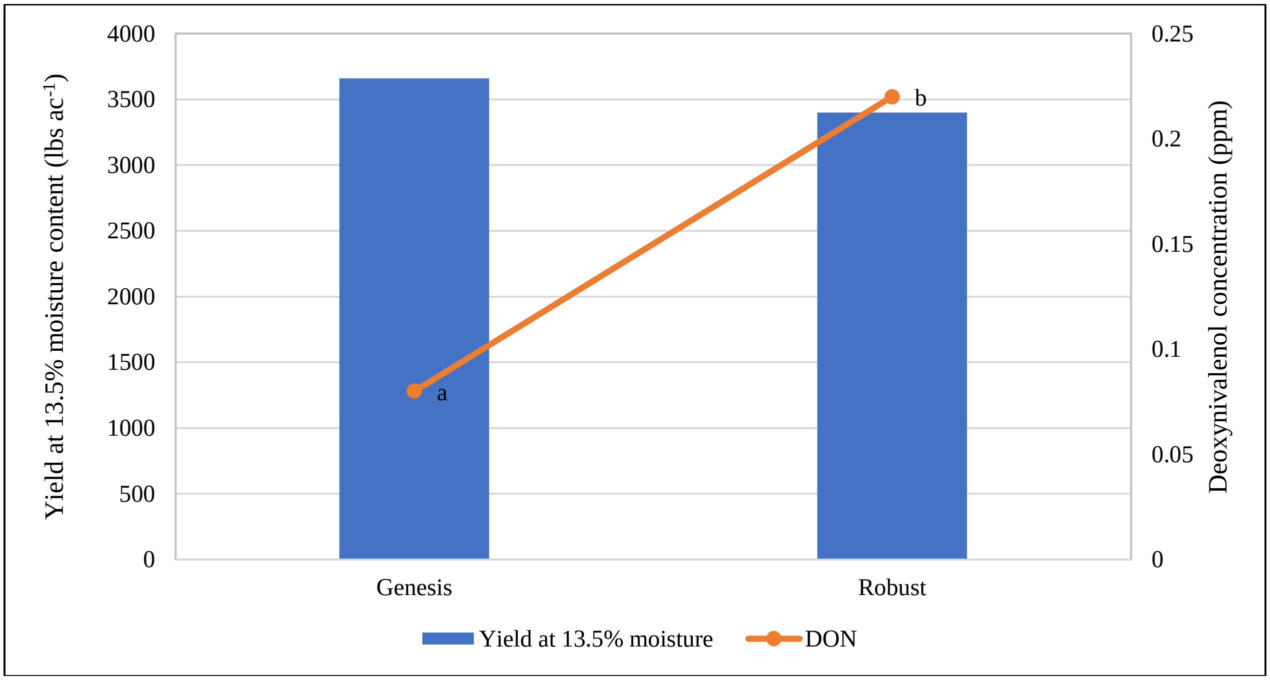

Figure 2. The impact of variety on barley yield and DON concentration.
Varieties with different letters varied significantly by DON concentration. No yields differed significantly by treatment.

DISCUSSION

Higher levels of *Fusarium* infection and resulting DON vomitoxin concentrations in grain are associated with cool and damp weather conditions at the time of grain fill and heading. While early spring weather was slightly cooler than normal, precipitation was below the 30-year average during the entire growing season, and temperatures were warmer than average at grain fill in June and July. These conditions were not conductive for the development of the DON vomitoxin or other fungal pathogens. There were low DON concentrations throughout all of Northwest Crop & Soils' small grains trials, including the fungicide trials. All fungicide applications reduced DON concentrations compared to the plots that were inoculated with *Fusarium* but not treated with fungicides. Some fungicide applications were statistically similar to the *Fusarium* inoculated plots, but that does not mean they would not be effective in a year with higher DON concentrations. These similarities can likely be attributed to the low DON concentrations overall due to the weather conditions. When fungicide applications in this trial are compared, the results of this trial suggest that Miravis Ave applied at heading, whether combined with other products or not, was the most successful at reducing DON in comparison to an uninoculated control. Last year Miravis Ace applications at all timings also had the lowest DON concentrations of the trial. However, it is important to note that the DON test has a detection range of 0.5 to 5 ppm, and all DON results in this trial were lower than the recommended range for accuracy.

This trial is expected to continue for additional years. It is important to remember that the results only represent one year of data. Ideally, this trial should be repeated in a year with wet and cool weather conditions favorable to fungal diseases.

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