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 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 2021, the UVM Extension Northwest Crops and Soils Program initiated year seven of a spring barley fungicide trial to determine the efficacy and optimal timing of fungicide application to reduce FHB infection in malting barley.

MATERIALS AND METHODS

A field experiment was established at the Borderview Research Farm located in Alburgh, Vermont in the spring of 2021 to investigate the effects of cultivar resistance, fungicide efficacy, and 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 two cultivars evaluated were Robust, a 6-row malting barley that is a FHB susceptible variety, and ND Genesis, a 2-row malting barley with some resistance to FHB infection. 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 barley producers in the region. The previous crop planted at the site was silage corn and the soil type was Benson rocky silt loam (Table 1). Prior to planting, the trial area was disked and spike tooth harrowed. 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, 2021.

Location	Borderview Research Farm Alburgh, VT
Soil type	Benson rocky silt loam
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	26-Jul
Harvest area (ft)	5 x 20
Tillage operations	TerraDisc & spike tooth harrow

Fungicides evaluated in the 2021 spring barley fungicide trial included Caramba, ChampION, Miravis Ace, Prosaro and Regalia (Table 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. Caramba, Prosaro, and Regalia were applied at heading. ChampION was applied at heading, at 4-6 days post-heading, and both at heading and at 4-6 days post-heading. Treatments consisted of a combination of applications of two fungicides. For one dual treatment, Miravis Ace was applied at heading, followed by Prosaro four days after heading. In another 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 3). 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. 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	8-Jun
Genesis Heading Applications	15-Jun
Genesis Inoculated with *Fusarium*	15-Jun
Genesis Post-heading Applications	20-Jun
Robust 10.3 Feekes- Early Applications	9-Jun
Robust Heading Applications	16-Jun
Robust Inoculated with *Fusarium*	16-Jun
Robust Post-Heading Applications	20-Jun

On 15-Jul, when the barley reached the soft dough growth stage, FHB infection rates were assessed by clipping 60-100 randomly selected spikes 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 26-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 optimal test weight for barley is 48 lbs bu^{-1} or higher.

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 at the McMaster lab at Virginia Tech on an Agilent 6890N / 5975 GC/MS. This method has a detection range of from 0.025ppm – 15ppm.

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}
Regalia	65 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.

Regalia® (EPA # 85059-3) biological fungicides have a unique and complex mode of action, referred to as Induced Systemic Resistance (ISR), and carry a FRAC code of P5. ISR creates a defense response in the treated plants and stimulates additional biochemical pathways that strengthen the plant structure and act against the pathogen. When applied to crops, Regalia products activate ISR and induce the plants to produce specialized proteins and other compounds-phytoalexins, cell strengtheners, antioxidants, phenolics, and PR proteins-which are known to inhibit fungal and bacterial diseases and also improve plant health and vigor. This product is approved for use in organic production systems.

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 project results 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 (e.g. yield). Least Significant Differences (LSD's) at the 10% level of probability are shown. 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 in 9 out of 10 chances that there is a real difference between the two values. Treatments that were not significantly lower in performance than the highest value in a particular column are indicated with an asterisk. In the accompanying example, treatment A is significantly different from treatment C but not from treatment B. The difference between A and B is equal to 200, which is less than the LSD value of 300. This means that these treatments did not differ in yield. The difference between A and C is equal to 400, which is greater than the LSD value of 300. This means that the yields of these treatments were significantly different from one another.

Treatment	**Yield**
A	**2100***
B	1900*
C	1700
LSD	300

RESULTS

Seasonal precipitation and temperature recorded at a weather station at Borderview Research Farm are displayed below in Table 4. The growing season was warmer than normal overall, although the month of July was cooler than average. There were a surplus of growing degree days early in the season and a deficit in July, resulting in a season just 36 growing degree days above normal. There were 4.99 inches less precipitation than normal. Low precipitation through heading and flowering stages resulted in low fusarium infection rates and DON concentrations in the other grains trials at Borderview Research Farm in the 2021 growing season.

Table 4. Temperature and precipitation summary for Alburgh, VT, 2021.

Alburgh, VT	April	May	June	July
Average temperature (°F)	48.1	58.4	70.3	68.1
Departure from normal	2.52	-0.03	2.81	-4.31
Precipitation (inches)	3.52	0.66	3.06	2.92
Departure from normal	0.45	-3.10	-1.20	-1.14
Growing Degree Days (32-95°F)	497	818	1149	1119
Departure from normal	85	-1.0	86	-134

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, i.e., both varieties trialed responded similarly to treatments.

Impact of Fungicide and Timing

There were significant differences between treatments for harvest moisture, test weight, yield and DON concentrations (Table 6). Harvest metrics are shown in Table 5 and DON concentrations and FHB incidence and severity are shown in Table 6.

Harvest moisture was statistically different between treatments, but all treatments were over 14% and required drying down for storage. Test weights across the trial were lower than ideal. The Caramba treatment had the highest test weight at 44.6 lb bu^{-1}. Yields were good across the trial, ranging from 3475 lbs to 4488 lbs ac^{-1}. The highest yield was the Caramba treatment and the lowest yielding treatment was the *Fusarium* only treatment.

Table 5. Harvest quality by fungicide treatment and timing, Alburgh, VT, 2021.

Treatment	Timing	Harvest moisture	Test weight	Yield at 13.5% moisture
		%	lbs bu^{-1}	lbs ac^{-1}
Control	Heading	**14.2*** †	42.3	3852
Fusarium	Heading	14.9*	41.5	3475
Caramba	Heading	16.3	**44.6***	**4488***
ChampION	Heading	14.5	43.4*	4024*
ChampION	Post-heading	15.8	44.1*	4106*
ChampION	Heading & Post-heading	15.0	42.8	4023*
Miravis Ace	Feekes 10.3	14.7*	40.5	4007
Miravis Ace	Heading	15.4	43.8*	4129*
Miravice Ace	Post-heading	14.9*	42.2	3495
Miravis Ace, Caramba	Heading, Post-heading	15.8	42.7*	4048*
Miravis Ace, Prosaro	Heading, Post-heading	15.5	42.2	3951
Prosaro	Heading	14.6*	43.7*	3760
Regalia	Heading	15.3	43.3*	4334*
LSD (p=0.10) ‡		0.68	2.21	475
Trial mean		15.1	43.0	3982

† Within a column, treatments with an asterisk (*) was statistically similar to the top performer in **bold**.

‡ LSD- Least significant difference at p=0.10.

All treatments and timings, including the control and the *Fusarium* inoculated plots, had average DON concentrations below the 1 ppm threshold recommended by the FDA. It is important to note that although no treatments averaged above 1 ppm, several plots across several treatments tested above 1 ppm (as high as 1.72 ppm).

The highest DON concentrations in the trial were in the Regalia treatment (applied at heading) at 0.93 ppm. Similar to two other treatments above 0.7 ppm. The uninoculated control had the lowest DON concentrations at 0.17 ppm. Five treatments had DON concentrations statistically below those of the Fusarium only treatment that was inoculated but not treated with fungicide: Miravis Ace applied at heading, Miravis Ace applied post-heading, Miravis Ace at heading followed by Caramba post-heading, and Miravis Ace at heading followed by Prosaro post-heading.

The incidence and severity of Fusarium head blight infection was calculated for each plot. Incidence refers to the percentage of plants evaluated that were infected with FHB. Severity refers to the degree of infection of each head examined. The treatment of Miravis Ace at heading followed by Prosaro post-heading had lowest severity with less than 1% of the average barley head affected by FHB. This was similar to all other treatments, except the *Fusarium* only treatment which had FHB severity over 10%. The ChampION at heading treatment had the lowest FHB incidence with only 0.15% of barley spikes examined showing evidence of FHB infection. This was similar to all other treatments except the treatment Miravis Ace applied at heading and the *Fusarium* only treatment which had 1.97% and 2.33% incidence rates respectively.

Table 6. DON concentrations and FHB severity by fungicide treatment and timing, Alburgh, VT, 2021.

Treatment	Timing	DON	Average FHB severity	Incidence of FHB infected heads
		ppm	%	%
Control	Heading	**0.17***[†]	3.50*	0.97*
Fusarium	Heading	0.65	11.1	2.33
Caramba	Heading	0.49	3.21*	1.58*
ChampION	Heading	0.80	2.63*	**0.15***
ChampION	Post-heading	0.90	2.84*	1.44*
ChampION	Heading & Post-heading	0.63	4.38*	0.71*
Miravis Ace	Feekes 10.3	0.53	1.75*	0.38*
Miravis Ace	Heading	0.29*	1.75*	1.97
Miravis Ace	Post-heading	0.40	4.38	1.72*
Miravis Ace, Caramba	Heading, Post-heading	0.29*	3.06*	0.74*
Miravis Ace, Prosaro	Heading, Post-heading	0.33*	**0.88***	1.09*
Prosaro	Heading	0.66	1.88*	1.19*
Regalia	Heading	0.93	4.67*	1.60*
LSD (p=0.10) ‡		0.23	6.09	1.79
Trial Mean		0.53	4.01	1.24

†Treatments within a column with an asterisk (*) are statistically similar to the top performer in **bold**.

‡ LSD- Least significant difference.

Impact of Variety

Table 7. Harvest quality and FHB assessment by variety, Alburgh, VT, 2021.

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	%	%
NDGenesis	15.1	41.0	**4353**	0.61	4.36	2.01
Robust	15.1	**44.9**	3610	**0.45**	**3.66**	**0.46**
LSD (0.10) ‡	NS§	0.83	179	0.09	NS	0.01
Trial Mean	15.1	43.0	3982	0.53	4.01	1.24

The top performing treatment in each column is indicated in **bold.**

‡LSD - Least significant difference at p=0.10.

§NS - Not significant.

Both varieties had average moisture concentrations of 15.1% at harvest (Table 7). Robust had higher test weight by 3.8 lbs bu^{-1}. Genesis had higher yields by 743 lbs ac^{-1}. Interestingly, Robust had lower DON concentrations, FHB severity and incidence, although it is purported to be the more susceptible variety of the two (Table 7, Figure 1).

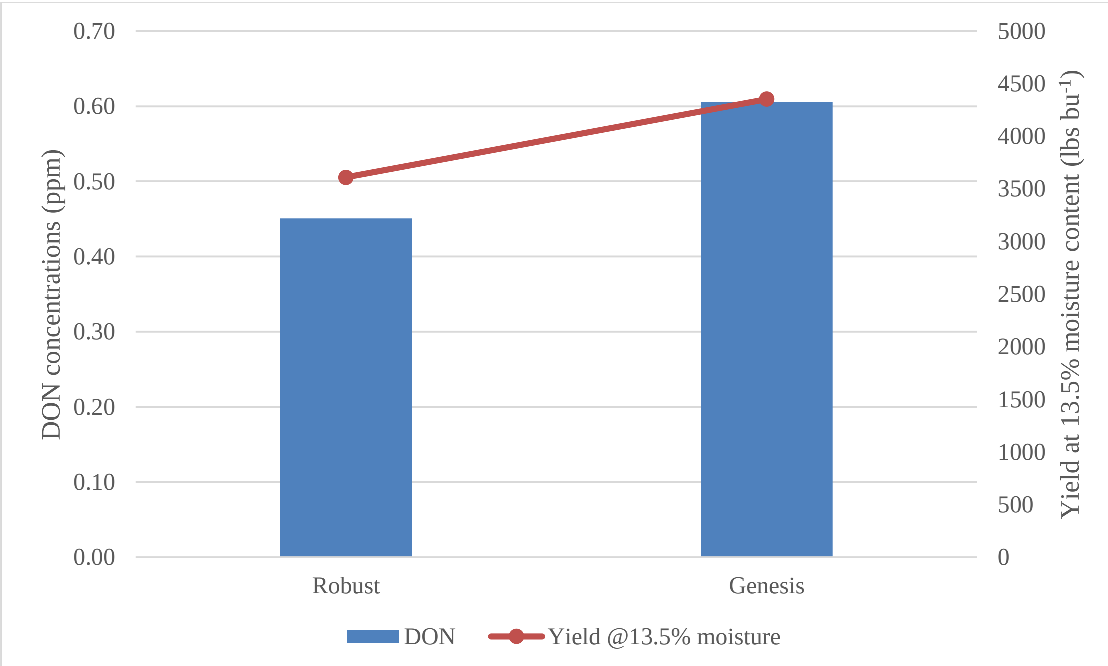

Figure 1. The impact of variety on barley yield and DON concentration.
Varieties with different letters varied significantly by DON concentration. No yields differed significantly by treatment.

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. Temperatures during heading were above the 30-year-average, and precipitation was below the 30-year average during the entire growing season. 2021 weather conditions permitted inoculation with *Fusarium* spores to result in infection levels that could allow comparative evaluation of the efficacy of fungicide treatments. All fungicide applications reduced FHB incidence and severity compared to the plots that were inoculated with *Fusarium* but not treated with fungicides. However, this did not correlate to their effectiveness at reducing concentrations of the DON vomitoxin in the harvested grain. Four treatments had DON concentrations statistically below those of the Fusarium only treatment that was inoculated but not treated with fungicide: Miravis Ace applied at heading, Miravis Ace applied post-heading, Miravis Ace at heading followed by Caramba post-heading, and Miravis Ace at heading followed by Prosaro post-heading. There was no statistical difference in outcomes between following a heading application of Miravis Ace with another fungicide and applying only Miravis Ace at heading without an additional fungicide application.

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

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