Report submitted to the Pennsylvania Vegetable Marketing and Research Program
Pennsylvania Vegetable Growers Association
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TITLE: Coupling host resistance with the evaluation of biofungicides for the management of common foliar diseases of tomatoes and cucurbits in Pennsylvania.

PRINCIPLE INVESTIGATOR:

Beth K. Gugino, Dept. of Plant Pathology and Environmental Microbiology, The Pennsylvania State University, University Park, PA 16802; (814) 865-7328; bkgugino@psu.edu.

INTRODUCTION:

Biofungicides and OMRI-approved products, whether based on microbial or biochemical active ingredients, are a primary tool for vegetable disease management in organic production and are becoming increasing used more frequently as a part of conventional fungicide programs. This is partly due reduced environmental and human safety risk as well as increased production flexibility in terms of reduced REIs and PHIs, potential market opportunities and significant industry marketing. In addition, due to the expedited EPA registration process, an increasing number are becoming available each year and marketed in trade magazines. For example, in the October 2017 issue of American Vegetable Grower, five of the seven pest management advertisements were for biopesticides. In university trials, product efficacy is often evaluated on highly susceptible cultivars under augmented conditions to promote high disease pressure as an “acid” test. Under these conditions when disease development is assessed regularly throughout the season, biofungicides, in general, are most effective when disease pressure is low and then fail later in the season when it is high. In typical product efficacy trials, the use of biofungicides or OMRI-registered products are less frequently leveraged with the use of host resistance; a scenario where they are most likely to be effective. Thus, we coupled host resistance with the evaluation of conventional fungicide programs augmented with biofungicide/OMRI-approved products for the management of powdery mildew on pumpkin, downy mildew on cucumber, early blight on tomato in Pennsylvania. Although established, unfortunately, due to the extreme wet weather this past season usable data was not obtained from the tomato late blight trial. However, for the other three trials, a description of the establishment, maintenance, data collection, results and analysis can be found below. All trials were conducted at The Pennsylvania State University Russell E. Larson Agricultural Research Center in Pennsylvania Furnace, PA in Centre County.

METHODS AND RESULTS FOR EACH TRIAL:

PUMPKIN POWDERY MILDEW TRIAL

Methods: The field was plowed and fertilizer (N-P-K; 19-19-19 at 395 lb/A and 0-0-60 at 75 lb/A based on soil test results) was broadcast and incorporated on 18 May. Nineteen raised beds with 1.5-mil black-plastic mulch and a single row of drip-irrigation tape were formed in early Jun. Raised beds were 48-in. wide and 6-in. high and were laid on 13-ft centers. For each set of three rows, the center row was an untreated guard row and the two outer rows were treatment rows. On 14 Jun, pumpkin cvs. Howden (susceptible) and Bayhorse Gold (moderately resistant) were direct-seeded in designated plots, two seeds per hole, spaced 36-in. apart, one row per bed. Plants were thinned to one plant per hole or missing plants were replaced with transplants in early Jul so that each plot consisted of six plants. Plots were single rows, 20-ft long and separated by 22-ft of bare plastic. Fungicide treatments were replicated four times and arranged in a randomized complete block design with five treatments being applied to cv. Howden and a subset of four of the same treatments being applied to cv. Bayhorse Gold for a comparison of host resistance. Cucumber beetle was managed with an application of Admire 2F applied with a Solo backpack sprayer (mixed 5 ml/1gal then drench applied 5 fl oz/plant) on 20 Jun. Weeds were managed with an application of Medal EC (1.33 pt/A) plus Profine 75DF (0.5 oz/A) on 7 Jun along with supplemental hand weeding. Plots were fertigated regularly (N-P-K; 20-20-20 at 7 lb/A) and at increasing intervals as the crop matured. Fungicide applications were made using a tractor mounted, R & D CO_2-powered sprayer with an offset-boom traveling 2 mph and calibrated to deliver 42 gpa at 32 psi at the tank through six TX-18 hollow-cone nozzles on 20-in. centers on 29 Jul and 7, 16, 23 and 29 Aug for a total of five treatment applications. Natural inoculum was relied upon and symptoms were first observed on 26 Jul. Powdery mildew severity was rated on a continuous scale of 0 to 100% based on the percentage of upper and lower leaf surface (rated separately) showing powdery mildew symptoms on six leaves per plot on 10, 19, 16 Aug and 2 Sep. Area under the disease progress curve (AUDPC) was calculated at the end of the season and then the data converted to percent control relative to the untreated treatment (data presented below). Downy mildew was observed and confirmed in the trial on 5 Aug and the entire trial was maintenance sprayed with a rotation of Ranman (2.5 oz/A on 7 and 24 Aug) and Tanos (8 oz/A on 15 Aug). Rainfall totals (in.) were 2.06, 10.2, and 7.22 for 14 to 30 Jun, Jul, and Aug, respectively. Data was analyzed separately by cultivar using an analysis of variance and treatment means separated using Fisher's Least Significant Difference test (SAS v. 9.4, SAS Institute, Cary, NC).

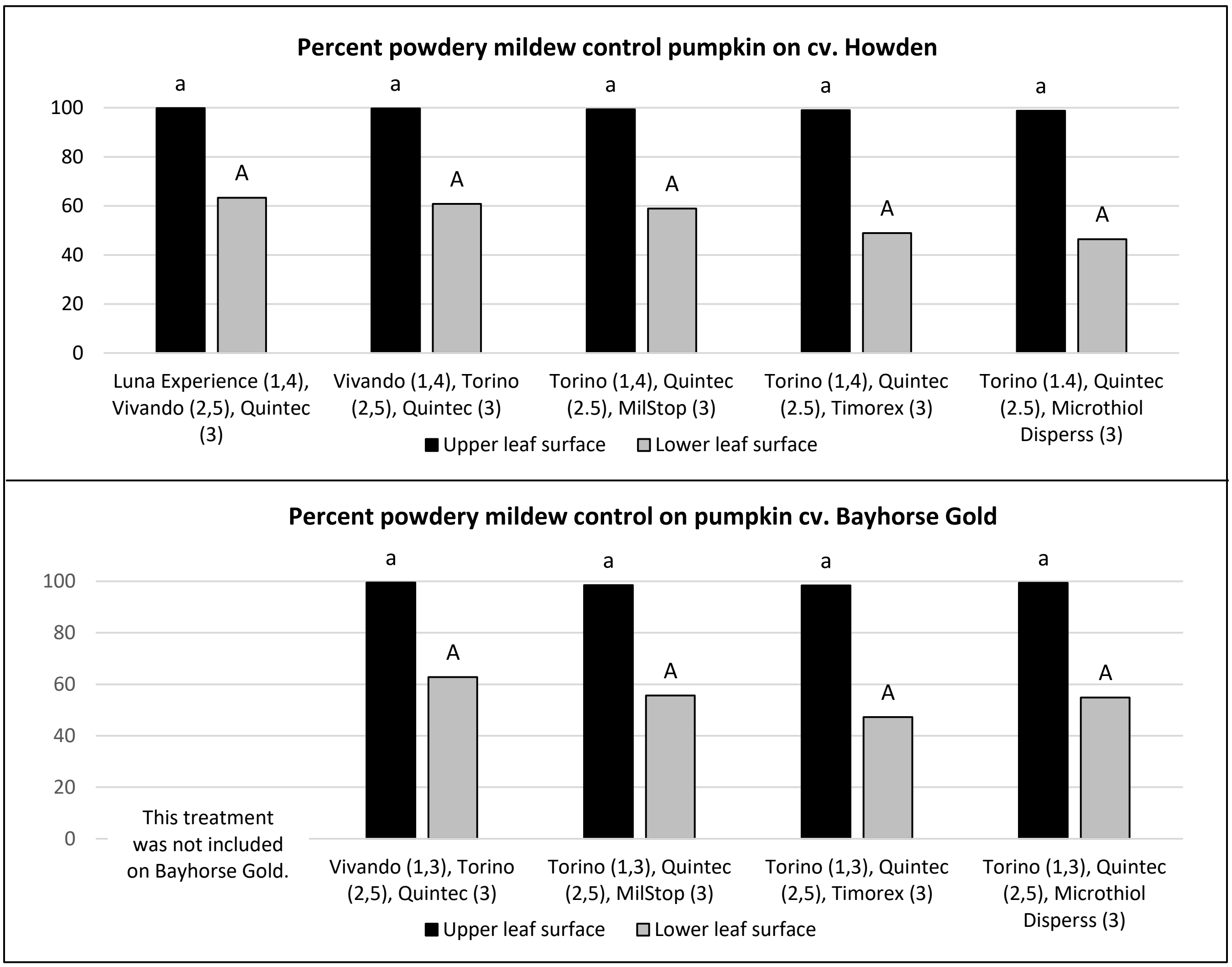

Figure 1. All fungicides were applied at the highest label rate. Luna Experience, Vivando, and Torino were tank-mixed with Bravo Weather Stik (2.0 pt/A) plus Induce (0.125% v/v) when applied. The numbers in parentheses indicate the following fungicide applications dates: 1 = 29 Jul; 2 = 7 Aug; 3 = 16 Aug; 4 = 23 Aug and 5 = 19 Aug. As indicated by the letters at the top of the bars, there was no significant differences in the level of disease control obtained on the upper leaf surface (black bars; lower case letters) and lower leaf surface (gray bars; upper case letters) across treatments for either pumpkin cultivar ($P < 0.05$). There was also no difference in disease severity between the cultivars (data not shown).

Results: Disease pressure was severe, with the untreated control plots in both cultivars reaching near 100% disease severity by the end of the trial. All treatments significantly reduced powdery mildew symptoms on both the upper and lower leaf surface, regardless of the cultivar planted. In this trial, replacing the application of Quintec (a.i. quinoxyfen), a targeted powdery mildew specific fungicide, in the fungicide program with a biofungicide/OMRI-approved fungicide Microthiol Disperss (a.i. sulfur from United Phosphorus, Inc.), Timorex Act (a.i. tea tree oil from STK Stockton Group) or MilStop (a.i. potassium bicarbonate from BioWorks, Inc.) were equally as effective as the fungicide programs only consisting of targeted powdery mildew fungicides. However, within individual fungicide treatments there was not an added benefit of host resistance on helping to manage powdery mildew on either the upper ($P = 0.2477$) or lower ($P = 0.7973$) leaf surface using a paired T-test. This was likely due to the favorable weather conditions this past season.

CUCUMBER DOWNY MILDEW TRIAL

Methods: The field was plowed and fertilizer (N-P-K; 11-52-0 at 145 lb/A and 46-0-0 at 130 lb/A based on soil test results) was broadcast and incorporated on 15 and 18 May. Nineteen raised beds with 1.5-mil black-plastic mulch and a single row of drip-irrigation tape were formed in early Jun. Raised beds were 48-in. wide and 6-in. high and were laid on 9-ft centers. For each set of three rows, the center row was an untreated guard row and the two outer rows were treatment rows. On 7 Jun, cvs. Darlington (susceptible) and DMR 264 (resistant) were direct seeded, two seeds per hole, spaced 24-in. apart, one row per bed in designated treatment plots. Guard rows were directed seeded with cv. Straight Eight (susceptible). Plots were single rows, 16-ft long and separated by 8-ft bare plastic buffer. Fungicide treatments were replicated four times and arranged in a split-plot randomized complete block design with cultivar as the whole-plot and fungicide treatment as the sub-plot. Plots were thinned to one plant per hole or missing plants replaced with transplants in late Jun so that each plot consisted of six plants. Cucumber beetles were managed with an application of Admire 2F applied with a Solo backpack sprayer (mixed 5 ml/1gal then drench applied 5.0 fl oz/plant) on 14 Jun and Baythroid (2.8 fl oz/A) was applied on 10 Aug. Weeds were managed with an application of Profine 75DF (1 oz/A) plus Prefar (6 qt/A) on 29 May that was activated with 0.5 in. of overhead irrigation on 1 Jun. On 6 Jun, Round-up (1.5 pt/A) was applied between the plastic and supplemental hand weeding was conducted throughout the season. Plots were fertigated regularly (N-P-K; 20-20-20 at 7 lb/A) and at increasing intervals as the crop matured. Fungicide applications were made using a tractor mounted, R&D CO_2 powered offset-boom sprayer traveling 2 mph and calibrated to deliver 42 gal/A at 32 psi at the tank through six TX-18 hollow-cone nozzles on 20-in. centers on 16 and 26 Jul, 6, 15 and 23 Aug for a total of five applications. Natural inoculum was relied upon and symptoms were first observed on 8 Aug. Downy mildew severity was rated on a continuous scale of 0 to 100% based on the percentage of the leaf surface showing symptoms across the whole plot on 9, 16, 19 and 26 Aug. That data was used to calculate the area under the disease progress curve which was then converted to percent control achieved relative to the untreated treatment (data presented below). Rainfall totals (in.) were 4.49, 10.20 and 6.84 for 7 to 30 Jun, Jul, and 1 to 26 Aug, respectively. Data was analyzed using PROC GLM which indicated a significant cultivar by fungicide treatment interaction ($P < 0.0001$) in additional to significant main effects (cultivar $P = 0.0002$; treatment $P < 0.0001$), so fungicide treatments were analyzed separately within cultivar using an analysis of variance and treatment means separated using Fisher's Least Significant Difference test (SAS v. 9.4, SAS Institute, Cary, NC).

Results: Disease pressure was severe, with the untreated control plots of cv. Darlington reaching nearly 100% disease severity by the end of the trial. In contrast, very little to no downy mildew developed on cv. DMR 264 regardless of whether receiving fungicide treatments (no data shown due to low disease incidence). DMR 264 is a new next generation downy mildew resistant cucumber cultivar from Dr. Michael Mazourek's breeding program from Cornell University and is sold by Commonwealth Seeds. It has also performed well in trials conducted at the University of Massachusetts. Foliar symptoms of angular leaf spot were observed early in the season and foliar anthracnose was observed later in the season on both cultivars, however, neither disease was significant enough to impact downy mildew ratings or necessitate a maintenance fungicide spray.

Fungicide programs that consist of targeted downy mildew fungicides applied in a rotation to manage for fungicide resistance using FRAC codes and tank-mixed with Bravo Weather Stik (unless already in the pre-mix) were most effective at managing cucumber downy mildew. Further tank mixing with the biofungicide LifeGard (a.i. *Bacillus mycoides* isolate J from Certis USA) or the biostimulate Keylate Colbalt (a.i. 4% nitrogen and 5% cobalt from Stoller) did not provide any disease management benefit. Substituting Zonix (a.i. rhamnolipid surfactant from Jeneil Biosurfactant Company) or Stargus (a.i. *Bacillus amyloliquefaciens* strain F727 from Marrone Bio Innovations) from the targeted downy mildew fungicide Zampro significantly reduced downy mildew control by approximately 28 and 53%, respectively.

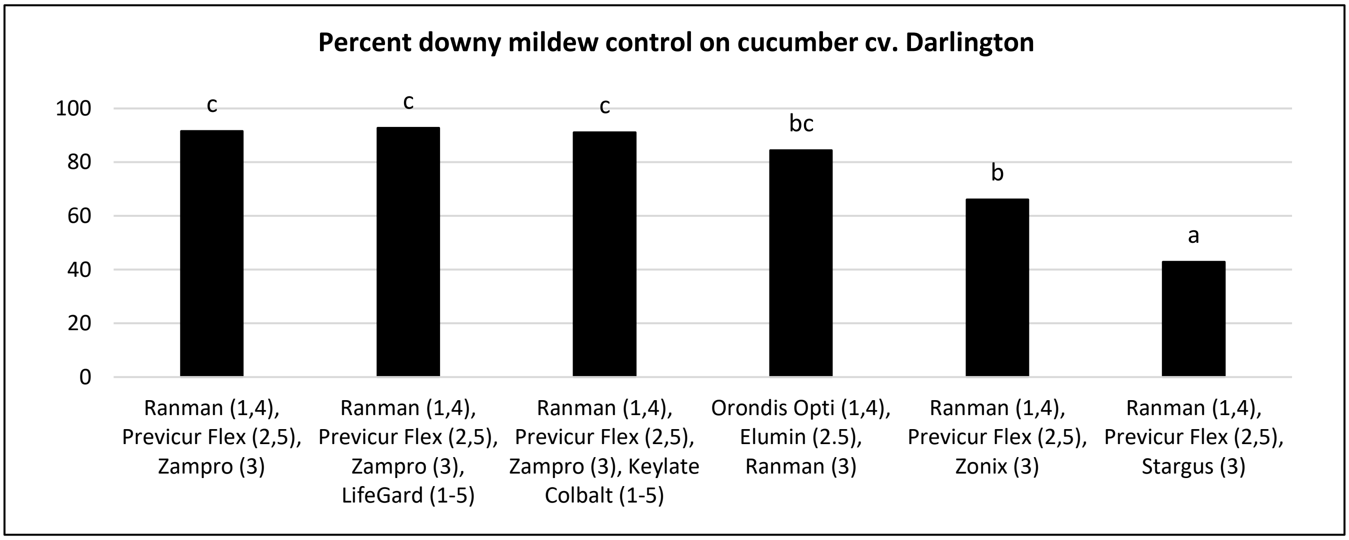

Figure 2. All fungicides were applied at the highest label rate. When applied Ranman, Previcur Flex and Zampro were tank-mixed with Bravo Weather Stik (2.0 pt/A) and Ranman, Zampro, and Orondis Opti were also applied with Silwet L-77 (0.125% v/v). The numbers in parentheses reflect the following fungicide applications dates: 1 = 16 Jul; 2 = 26 Jul; 3 = 6 Aug; 4 = 15 Aug and 5 = 23 Aug. Bars with different letters at the top indicate significant differences in the level of downy mildew disease control (P = 0.0006).

TOMATO EARLY BLIGHT TRIAL

Methods: The field was plowed and fertilizer (N-P-K, 46-0-0 at 180 lb/A and 11-52-0 at 155 lb/A based on soil test results) was broadcast and incorporated on 15 Jun. Tomato transplants cvs. Mountain Fresh Plus and BHN 964 were transplanted on 26 Jun. Planting was delayed multiple times due to prolonged wet field conditions. A starter fertilizer (N-P-K, 20-20-20 at 7 lb/A) along with Admire 2F (1.0 pt/A) was applied in the transplant water. Each plot was 12-ft-long and separated by a 5-ft break within the row and 5-ft between row centers. Untreated guard rows planted with cv. H4007 on 15 Jun (susceptible processing cultivar) separated each treatment row. Each plot was planted with eight transplants spaced 18-in. apart. Treatments were replicated four times and arranged in a split-plot randomized complete block design with cultivar as the whole plot and fungicide treatment as the subplot. Weeds were managed with an application of Medal EC (1.5 pt/A) and Tricor DF (0.33 lb/A) on 20 Jun. Plots were fertigated regularly (N-P-K, 20-20-20, 7.0 lb N/A) with a single row of drip irrigation tape was laid with the plastic and located just to the left of the plant. Fungicide applications were made using a tractor mounted, R & D CO_2-powered offset-boom sprayer traveling at 3 mph and calibrated to deliver 28 gal/A at 32 psi through three TX-18 hollow-cone nozzles on 27 Jul, 7, 16, 24, 30 Aug, and 6, 13 and 20 Sep for a total of eight fungicide applications. Several foliar late blight lesions resulting from natural inoculum were observed on 25 Aug, therefore the trial was maintenance sprayed with Curzate (5 oz/A) on 27 Aug, Ranman (2.75 oz/A) on 31 Aug and 14 Sep and Presidio (4 oz/A) on 7 Sep. This was the first observation of natural late blight on the research farm in several years. Maintenance sprays were made with a Solo backpack sprayer with a TX-18 hollow cone nozzle. On 30 Jul, the guard rows were inoculated with a mix of three Pennsylvania *Alternaria solani* isolates (1.75×10^4 spores/ml sprayed in three to four spots per 12 ft guard row using a hand-held Hudson sprayer). Supplemental water was delivered using overhead misters to extend the dew period and create more favorable conditions for disease progression. Foliar early blight severity was evaluated on 3, 8, 16, and 23 Sep by estimating the percent of symptomatic foliage across the whole plot. Area under the disease progress curve was calculated. Rainfall totals (in.) were 2.71, 10.20, 7.22, and 6.22 for 26 to 30 Jun, Jul, Aug and 1 to 23 Sep, respectively. Data was analyzed using PROC GLM which indicated a significant cultivar by fungicide treatment interaction ($P = 0.0006$) in additional to significant main effects (cultivar $P = 0.0366$; treatment $P < 0.0001$), so fungicide treatments were analyzed separately within cultivar using an analysis of variance and treatment means separated using Fisher's Least Significant Difference test (SAS v. 9.4, SAS Institute, Cary, NC).

Results: Disease severity developed slowly but did reach near 100% in the untreated control plots of both tomato cultivars by the end of the trial. All treatments significantly reduced early blight disease severity compared to the untreated controls for both cultivars. Replacing Bravo Weather Stik with the biofungicides LifeGard (a.i. *Bacillus mycoides* isolate J from Certis USA), Double Nickel (a.i. *Bacillus amyloliquefaciens* strain D747) or the OMRI-approved copper Champ (a.i. copper hydroxide from Nufarm Agricultural Products) reduced half of the number of chlorothalonil applications but did not reduce tomato early blight control on either Mountain Fresh Plus or BHN 964. It in not know why a completely different program rotating Fontelis and Regalia (a.i. *Reynoutria sachalinensis* extract from Marrone Bio Innovations) tank mixed with Kocide 3000 was equally effective on cv. Mountain Fresh Plus but not as effective on cv. BHN 964. In general disease severity was higher on cv. BHN 964 compared to Mountain Fresh Plus but this may be explained in part due to the difference in plant growth habit when the plants are not staked and tied.

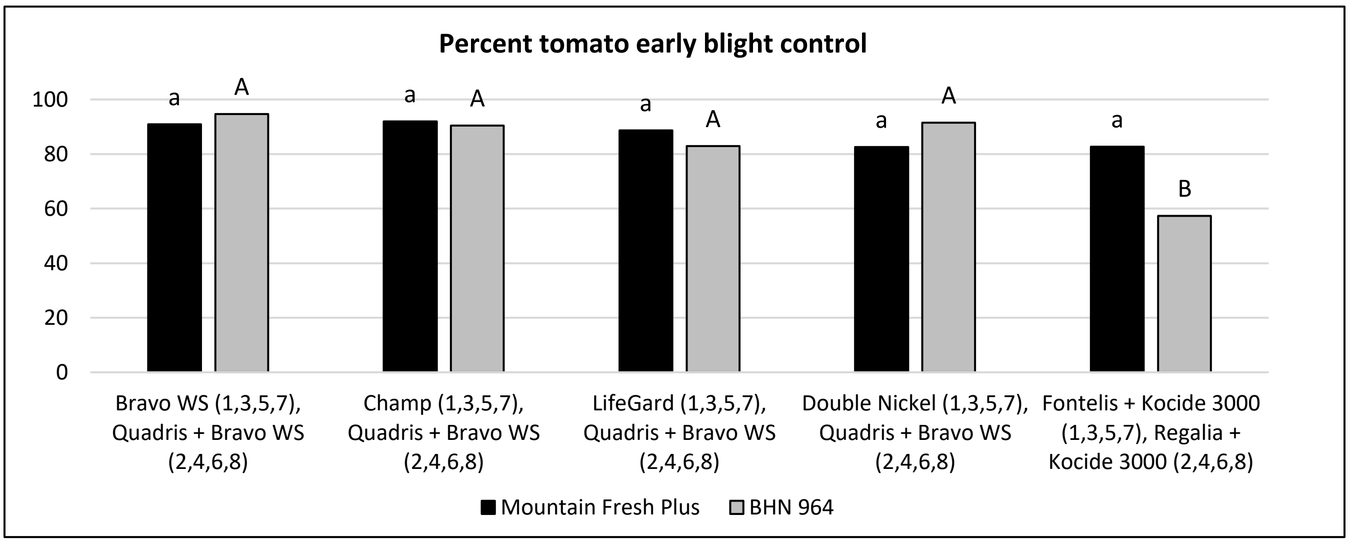

Figure 3. The fungicide rates are as follows: Bravo Weather Stik (Bravo WS 2 pt/A), Quadris (5 fl oz/A), Champ (3.2 lb/A), LifeGard (4.5 oz/100 gal), Double Nickel (3 lb/A), Fontelis (1 pt/A), Kocide 3000 (1 lb/A) and Regalia (4 qt/A). The numbers in parentheses reflect the following fungicide application dates: 1 = 29 Jul; 2 = 7 Aug; 3 = 16 Aug; 4 = 24 Aug; 5 = 30 Aug; 6 = 6 Sep; 7 = 13 Sep and 8 = 20 Sep. As indicated by the letters at the top of the bars, there was no significant differences in the level of disease control obtained on cv. Mountain Fresh plus regardless of treatment (lower case letters and black bars; $P = 0.4106$). The Fontelis/Regalia plus Kocide treatment was not as effective on cv. BHN 964 (upper case letters and gray bars; $P = 0.0021$).

CONCLUSION/SUMMARY:

Although these trials only reflect the results from one year, it is clear depending on the crop and disease, augmenting conventional fungicide programs with select biofungicides or OMRI-approved products can still provide the same or similar level of disease control as the conventional program. Except for cucumber downy mildew (cv. DMR 264), the additive effect of coupling with host resistance was less clear this season when disease pressure was high and the wet conditions favorable for disease development. Evaluating programs such as these over multiple field seasons is important. When evaluating the incorporation of new products into your own fungicide programs, it is important to not only review the research-based results available to help select the most promising biofungicides and OMRI-approved products but also consider conducting your own on-farm comparisons. The efficacy of fungicide programs can also be dependent on farm-specific factors so conducting a side-by-side comparison in conjunction with regular scouting to monitor disease development are important for successful disease management.

Biofungicide Project Budget:

Hourly wages for summer help to assist in conducting proposed field work for 12 wks at 24 to 25 hrs/wk at $11.00/hr. This includes a mandatory 2.5% wage increase since the project spans across two fiscal years	$ 3455
Fringe benefits (7.8%)	$ 255
Supplies to establish, maintain, and evaluate the replicated field trials	$ 2045
Travel (in-state)	$ 500
Total	**$ 6000**

Project Duration: April 1, 2018 to November 30, 2018

Signature: