Cultivar and Fungicide Evaluations for Cercospora Leaf Spot Control in Organic and Conventional Table Beet Production

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KEYWORDS. *Beta vulgaris* ssp. *vulgaris*, *Cercospora beticola*, disease resistance

ABSTRACT. Cercospora leaf spot (CLS), caused by the fungal pathogen *Cercospora beticola*, is the most destructive foliar disease of table beet (*Beta vulgaris* ssp. *vulgaris*) in Wisconsin, USA, and globally. Under conducive conditions, symptomatic lesions on the leaf expand and coalesce forming large necrotic areas that can ultimately lead to complete defoliation. This damage reduces productivity and threatens the ability to mechanically harvest. CLS damage also detracts from the visual appeal of fresh market bunched beets to such an extent that growers risk buyer rejection if CLS severity is observed to be greater than 5%. Fungicide use for CLS control is threatened by the emergence of resistant *C. beticola* strains, and the application of host resistance is constrained by limited knowledge of cultivar reaction to CLS in table beet. This study aimed to address the knowledge gaps of fungicide efficacy and cultivar reaction by conducting replicated field trials in multiple table beet growing environments across Wisconsin. Broad variation for resistance to CLS was observed among the 10 included cultivars. The mean area under disease progress curve (AUDPC) across environments for the most susceptible cultivar was 267% greater than the most resistant cultivar. Spearman correlations between environments for mean cultivar AUDPC value ranged from 0.71 to 0.99, revealing consistent cultivar CLS reactions across environments. Although susceptible cultivars surpassed 5% severity in all environments, the resistant cultivars remained below this threshold in six of the 10 environments. By comparison with resistant sugar beet (*Beta vulgaris* ssp. *vulgaris*) cultivars, however, all tested table beets appeared susceptible to CLS, highlighting the potential for a CLS breeding effort in table beet. Neither of the evaluated Organic Materials Review Institute–listed treatments were effective at limiting CLS disease progress, whereas both tested conventional fungicides significantly reduced disease severity over the nontreated plots. These findings may provide helpful guidance to table beet growers affected by CLS in Wisconsin and beyond.

Wisconsin is the leading producer of table beet (*Beta vulgaris* ssp. *vulgaris*) in the United States, growing ~30% of the country's annual supply [US Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2017]. Most of these beets are produced for processing into canned, steamed, and peeled products, and a variety of snack food items. Table beets also may be sold fresh, typically in bunches with foliage intact or bulked with foliage removed. As table beet consumption has increased in recent years, so too has production. Between 2012 and 2017, Wisconsin table beet acreage increased by 15% (USDA, NASS 2017). Although comparatively minor to the processing market, the fresh market is the fastest growing segment. The expansion of the fresh market has led to a diversification of production systems in Wisconsin. Although the processing market has historically depended on large-scale, conventional production, certified organic operations, varying in scale and crop diversity, are becoming more common (USDA, NASS 2020).

Shared by these production systems is the perennial challenge of controlling disease. Table beet is susceptible to a number of foliar diseases, none more pervasive and destructive than CLS, which is caused by the fungal pathogen *Cercospora beticola* (Delahaut and Stevenson 2004; Sharma et al. 2022). CLS symptoms begin as small, round lesions on the leaf surface and, under conducive conditions of high temperatures (27 to 32 °C day, >17 °C night) and relative humidity (>90%), these lesions multiply, expand, and coalesce, forming large necrotic areas (Rangel et al. 2020). Aside from marked losses in productivity, table beet mechanical harvesters common to large-scale production systems rely on healthy foliage to effectively lift beets from the soil. Severely diseased foliage can preclude mechanical harvest, resulting in crop abandonment (Harveson et al. 2009; Pethybridge et al. 2017a).

Leaf lesions and necrotic tissue have the additional consequence of detracting from the visual appeal of fresh market bunched beets. Strict market standards for bunched beet foliar damage defined by the USDA dictate that no more than 5% of leaf tissue may show disease symptoms (USDA, Agricultural Marketing Service 2016). Failure to meet this stan-

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
73.0778	fl oz/acre	$mL \cdot ha^{-1}$	0.0137
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
9.3540	gal/acre	$L \cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
2.2417	ton(s)/acre	$Mg \cdot ha^{-1}$	0.4461
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

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dard could force growers to sell their beets as bulked roots, thereby foregoing the economic premium associated with bunching as well as incurring additional post-harvest handling and expense (Goldman and Navazio 2003; Sharma et al. 2022). Although CLS epidemics occur regularly in Wisconsin, the disease is expected to become more prevalent under future climate change scenarios in which Wisconsin is predicted to experience conditions more favorable for CLS; notably, increased precipitation through summer as well as higher temperatures (Wisconsin Initiative on Climate Change Impacts 2021).

Management strategies to address CLS in table beet benefit from extensive CLS research conducted in a close relative and alternative host, the sugar beet (*Beta vulgaris* ssp. *vulgaris*) (Lartey et al. 2010). In particular, timely application of fungicides and the use of disease-resistant cultivars are broadly leveraged in sugar beet production to mitigate CLS damage (Vogel et al. 2018). Table beet cultivar resistance to CLS has been evaluated in Florida (Raid et al. 2013a, 2013b), South Carolina (Keinath et al. 2022), and New York, USA (Pethybridge et al. 2017a). In each of these trials, variation for CLS resistance among the cultivars was observed, suggesting that cultivar choice could be an important strategy for controlling CLS in table beet. However, with the exception of the cultivar Bull's Blood, which consistently ranked highly for CLS resistance, cultivar rankings between trials varied considerably, highlighting the importance of location-specific evaluations.

Despite evident variation among table beet cultivars for CLS resistance, grower flexibility to change cultivar may be limited due to strict processor and market demands (Pethybridge et al. 2019a). Crop protection may then rely substantially on the use of prophylactic fungicide applications, as is common in conventional production systems. However, this strategy is threatened by the development of *C. beticola* strains resistant to two major fungicide classes traditionally important to CLS control. Strains resistant to azoxystrobin of the quinone outside inhibitors group [Fungicide Resistance Action Committee (FRAC) group 11] have been reported in New York (FRAC 2022; Pethybridge et al. 2019a; Vaghefi et al. 2016). In addition, resistance to demethylation inhibitors [DMIs (FRAC group 3)] is prevalent in *C. beticola* isolates from sugar beet fields, foreshadowing the future of DMIs in table beet (Lartey et al. 2010). In a survey of New York's *C. beticola* population, 0.7% of isolates were found to exhibit reduced sensitivity to propiconazole, a group 3 fungicide (Pethybridge et al. 2019a).

New formulations to aid in CLS control are critically needed. The recently released product, pydiflumetofen + fludioxonil [Miravis Prime; Syngenta, Greensboro, NC, USA (FRAC groups 7 and 12)], was found to significantly reduce CLS progress compared with propiconazole in a New York table beet trial (Pethybridge et al. 2020a). Other similar trials provide evidence for significant reductions in CLS disease progress with regular applications of copper octanoate combined with the microbial biopesticide, *Bacillus amyloliquefaciens* D747 [Double Nickel; Certis USA, Columbia, MD, USA (FRAC group 44)] (Keinath et al. 2022; Pethybridge et al. 2017b, 2019b, 2022). For unknown reasons, the combination of these two products as a single treatment results in significantly improved disease control over separate applications (Pethybridge et al. 2017b). A second microbial biopesticide, *Bacillus mycoides* isolate J [Lifegard, Certis USA (FRAC group P06)], evaluated in two separate field trials, failed to significantly reduce disease severity over the nontreated control (Bloomingdale and Wilbur 2021; Pethybridge et al. 2017b). Pethybridge et al. (2017b) observed, however, that the treatment increased foliage dry weight by 60% over control plots, perhaps extending the viability of mechanical harvest. Contrary to findings of limited control, there is evidence from field and controlled environment studies that treatment with *B. mycoides* isolate J significantly reduces disease severity over nontreated controls (Bargabus et al. 2003; Pethybridge et al. 2020b, 2022). The latter two treatments mentioned here may be of interest to conventional producers as they represent atypical FRAC groups, which could help to diversify spray rotations. In addition, these two treatments are Organic Materials Review Institute (OMRI) approved and therefore available for use in certified organic operations.

Both organic and conventional table beet growers reliably suffer from CLS damage every summer in Wisconsin. There is evidence that both cultivar choice and fungicide applications could aid in mitigating disease severity; however, cultivar resistance to CLS has not been evaluated in Wisconsin nor has the efficacy of new and promising fungicide formulations. This work aimed to address these knowledge gaps by conducting field evaluations of cultivar resistance and fungicide efficacy in representative table beet growing environments across the state.

Materials and methods

CULTIVAR TRIAL. A cultivar trial was conducted to evaluate cultivar reaction to CLS in representative table

Table 1. Table beet and sugar beet cultivars and associated characteristics selected for Cercospora leaf spot (CLS) resistance evaluation in Wisconsin, USA, during the 2021 and 2022 seasons.

Cultivar	Seed type	Root color	Time to maturity (d)	Reported CLS resistance	Seed source[i]
Boro	Hybrid	Red	50	No data	HMOS
Blushing not Bashful	OP[ii]	White	58–65	No data	UWM
Bull's Blood	OP	Red	60	High	HMOS
Early Wonder Tall Top	OP	Red	55	Moderate	HMOS
Evansville Orbit	OP	Pink	No data	No data	UWM
Red Ace	Hybrid	Red	50	Moderate	JSS
Rhonda	Hybrid	Red	60	Low	HMOS
Ruby Queen	OP	Red	55	Moderate	SS
Shiraz	OP	Red	60	No data	HMOS
Touchstone Gold	OP	Yellow	55	Moderate	JSS
EL50 (sugar beet)	OP	White	No data	High	MSU
F1042 (sugar beet)	OP	White	No data	Low	MSU
BTS 9986 (sugar beet)	Hybrid	White	No data	High	Betaseed

[i] HMOS = High Mowing Organic Seeds, Walcott, VT, USA; UWM = University of Wisconsin-Madison, Madison, WI, USA; JSS = Johnny's Selected Seeds, Winslow, ME, USA; SS = Stokes Seeds, Holland, MI, USA; MSU = Michigan State University, East Lansing, MI, USA; Betaseed, Shakopee, MN, USA.

[ii] Open-pollinated.

Table 2. **Agronomic practices of host farms Tipi Produce (Evansville, WI, USA), West Madison Agriculture Research Station [WMARS (Verona, WI, USA)], Arlington Research Station [ARS (Arlington, WI, USA)], Kudick Farms (Denmark, WI, USA), and Driftless Organics [Driftless O (Soldier's Grove, WI, USA)] before Cercospora leaf spot disease trials designed to evaluate the efficacy of fungicides and disease reaction of 10 table beet cultivars during the 2021 and 2022 seasons in Wisconsin, USA.**

Location	Yr	Fertilizer[i]	Weed management	Prior crop[ii]
Tipi Produce	2021	None	Cultivation	Swiss chard
	2022	0.2 ton/acre 5N–1.7P–4.2K–9Ca	Cultivation	Radish and Turnip
WMARS	2021	None	Cultivation	Alfalfa
	2022	None	Cultivation	Alfalfa
ARS	2021	None	S-metolachlor + Ethofumesate	Winter wheat
	2022	None	S-metolachlor + Ethofumesate	NA[iii]
Kudick Farms	2021	6 tons/acre manure	S-metolachlor + Ethofumesate	Soybean
	2022	10 tons/acre manure	S-metolachlor + Ethofumesate	Soybean
Driftless O	2021	10 tons/acre compost	Cultivation	Potato

[i] 5N–1.7P–4.2K–9Ca (ReVita Pro; Ohio Earth Food Inc., Hartville, OH, USA); 1 ton/acre = 2.2417 mg·ha^{-1}.

[ii] Swiss chard (*Beta vulgaris* ssp. *vulgaris*), radish (*Raphanus sativus*), turnip (*Brassica rapa* ssp. *rapa*), alfalfa (*Medicago sativa*), winter wheat (*Triticum aestivum*), soybean (*Glycine max*), potato (*Solanum tuberosum*).

[iii] Field was fallow during 2021.

beet environments of Wisconsin during Summer 2021 and 2022. Ten cultivars were selected for evaluation based on 1) previously reported susceptibility or resistance to CLS and 2) anecdotal popularity among area farmers (Table 1). Trials conducted in 2022 also included a resistant and susceptible sugar beet cultivar. All cultivar trials were structured as a randomized complete block design (RCBD) with four blocks per trial. Cultivars were evaluated at five locations in 2021 and four locations in 2022. Three of these locations were certified organic, including West Madison Agriculture Research Station [WMARS, Verona, WI, USA (lat. 43°04′12.6″N, long. 89°32′50.7″W)], Tipi Produce [Evansville, WI, USA (lat. 42°44′19.4″N, long. 89°17′24.2″W)], and Driftless Organics [Soldier's Grove, WI, USA (lat. 43°23′12.2″N, long. 90°55′11.4″W)] and two were conventional—Arlington Research Station [ARS, Arlington, WI, USA (lat. 43°19′22.7″N, long. 89°20′34.4″W)] and Kudick Farms [Denmark, WI, USA (lat. 44°22′16.6″N, long. 87°48′11.5″W)]. Fields were prepared for planting using host farm equipment and practices (Table 2). Fertilizer decisions, including whether to apply fertilizer, type of fertilizer, and quantity to use, were made by host farmers and reflected typical table beet production practices at the site. At Tipi Produce 2021, WMARS, and ARS, no additional fertilizer was applied as it was expected that the soil retained sufficient fertilizer from the prior crop. Liquid manure was knife-injected in the fall at Kudick Farms; compost was spring broadcast at Driftless Organics 2021; and at Tipi Produce 2022, 5N–1.7P–4.2K–9Ca fertilizer was broadcast before planting (ReVita Pro; Ohio Earth Food Inc., Hartville, OH, USA). Each cultivar was planted from seed using a continuous drill seeder (Planet Junior; Cole Planter Co, Albany, GA, USA) to a 12-ft row. Trials were planted during the months of May and June and, in 2021, the cultivar trial was planted twice at WMARS and Tipi Produce (Table 3). Three to 4 weeks after planting, each row was thinned manually to a target density of 8 to 10 plants/ft.

FUNGICIDE TRIAL. Fungicide trials were conducted to evaluate CLS control of new and promising fungicide formulations. The fungicide trials occurred at the same locations and were sown with the same planting equipment as the cultivar trials (Table 3). Cultivar Ruby Queen was used in all 2021 trials and for conventional trials in 2022. The 2022 organic trials were sown to cultivar Early Wonder Tall Top in the hopes of increasing disease symptoms, as preliminary data from 2021

Table 3. **Details of cultivar and fungicide trials conducted to evaluate table beet cultivar reaction to and fungicide efficacy against Cercospora leaf spot disease in Wisconsin, USA, during Summer 2021 and 2022.**

		Trials (no.)		Planting date		
Yr	Location[i]	Cultivar	Fungicide	Cultivar	Fungicide	Fungicide applications (d after planting)
2021	Tipi Produce	2	2	20 May	20 May	28, 41, 51, 64
				11 Jun	11 Jun	22, 32, 42, 55, 66
	WMARS	2	2	13 May	13 May	28, 41, 51, 62
				10 Jun	10 Jun	29, 40, 52, 65
	ARS	1	1	14 Jun	14 Jun	29, 57
	Kudick Farms	1	1	15 Jun	15 Jun	27, 56
	Driftless Organics	1	1	17 Jun	17 Jun	32, 48, 58, 68
2022	Tipi Produce	1	1	23 May	23 May	28, 39, 49, 60, 71, 83
	WMARS	1	1	23 May	23 May	23, 34, 45, 57, 71, 81
	ARS	1	1	31 May	31 May	38, 62
	Kudick Farms	1	1	2 Jun	1 Jun	35, 61

[i] Tipi Produce (Evansville, WI, USA), West Madison Agriculture Research Station [WMARS (Verona, WI, USA)], Arlington Research Station [ARS (Arlington, WI, USA)], Kudick Farms (Denmark, WI, USA), Driftless Organics (Soldier's Grove, WI, USA).

suggested this cultivar to be more disease susceptible than Ruby Queen. The experimental design was a RCBD with four blocks per trial. Each block contained three experimental plots of two 12-ft rows sown 1.5 ft apart. Experimental plots were separated by equally sized plots of 'Bull's Blood', providing a 3-ft buffer between treated rows. As most organic table beet production in Wisconsin targets the fresh market, experimental plots on organic farms were thinned to a density of 8 to 10 plants/ft to reflect typical fresh market production density. Similarly, as most table beets produced conventionally in Wisconsin are grown for processing, conventional plots were not thinned to reflect the higher target densities (16 to 22 plants/ft) of these growing environments.

Fungicide treatments at the organic locations included the OMRI-approved products *B. mycoides* isolate J (Lifegard WG, Certis USA), a tank mix of *B. amyloliquefaciens* strain D747 (Double Nickel LC, Certis USA) and copper octanoate (Cueva, Certis USA), and a nontreated control. *B. mycoides* isolate J was applied at a rate of 1.1 oz/acre; *B. amyloliquefaciens* was applied at 31.5 fl oz/acre; copper octanoate was applied at 63.4 fl oz/acre. The conventional treatments included propiconazole (Tilt, Syngenta), pydiflumetofen + fludioxonil (Miravis Prime, Syngenta), and a nontreated control. Propiconazole was applied at a rate of 4.0 fl oz/acre; pydiflumetofen + fludioxonil was applied at 6.8 fl oz/acre. All pesticides were applied with a carbon dioxide-pressurized sprayer (21.9 gal/acre) equipped with a two-nozzle boom (model SS; R&D Sprayers, Opelousas, LA, USA). The nozzles were set 19 inches apart and flat spray tips (VisiFlo; TeeJet Technologies, Wheaton, IL, USA) were used throughout the experiment. OMRI-approved fungicides were prepared on-site and applied within 1 h of mixing. Conventional fungicides were mixed under a laboratory hood the morning of spraying.

A calendar spray schedule was followed for all fungicide applications (Table 3). The treatment schedule for conventional and OMRI-approved products began at the four- to six-leaf stage. Conventional fungicides were applied twice at each conventional location in accordance with the propiconazole label prohibiting more than two consecutive applications and, at the organic locations, applications occurred every 10 to 14 d following the initial spray, weather permitting, until harvest. This interval was followed in accordance with the label guidelines for copper octanoate requiring 10 d between treatments. In 2021, the first and second plantings at Tipi Produce received five treatments throughout the season; the first and second plantings at WMARS, as well as the trial at Driftless Organics, received four treatments. In 2022, trials at Tipi Produce and WMARS received six treatments each throughout the season.

Trial maintenance. In-season weed management at all locations and over both years was conducted by hand, excluding pre-emergent herbicide applications at ARS and Kudick Farms in 2021 and 2022. Supplemental irrigation was applied on one occasion in early Jun 2021 at WMARS owing to unusually dry conditions. Supplemental irrigation was also applied, as necessary, via drip tape to all trials conducted at Tipi Produce owing to the high proportion of sand in the soil at this location.

Inoculation. All 2021 trials, including both cultivar and fungicide, relied on natural *C. beticola* infection. In 2022, the WMARS and ARS cultivar and fungicide trials were inoculated on 13 and 26 Jul following the procedure of Pethybridge et al. (2019a). The inoculum suspension included two isolates collected from table beet fields in New York (Tb14–047 and Tb14–085). In brief, mycelia were added to liquid clarified V8 broth and allowed to incubate for 3 weeks on an orbital shaker at 100 rpm. A hemocytometer was used to evaluate the concentration of mycelial fragments for each inoculum suspension. The concentration of the first application was estimated to be 2.2×10^4 cfu/mL and the second was 4.3×10^4 cfu/mL. Viability of mycelia was tested by serial dilution (10^2 to 10^5) on water agar 24 h after plating. Polysorbate-20 (Tween 20; Sigma-Aldrich, St. Louis, MO, USA) was added to the inoculum suspension (0.01% v/v) and applied to each row using a 1-L hand-pump sprayer at 20.1 gal/acre (Solo Inc., Newport News, VA, USA).

Evaluations. Disease assessments for the cultivar and fungicide trials began between 23 and 45 d after planting (DAP) and continued at regular intervals until harvest. Each trial was evaluated a minimum of four times and an average of five times. CLS severity was quantified by observing percent disease affected area on 10 arbitrarily selected leaves per row in the cultivar trial, and 20 arbitrarily selected leaves per plot in the fungicide trial. The iPad (eighth generation; Apple Inc., Cupertino, CA, USA) application, *Estimate*, was used to aid in data collection (Del Ponte et al. 2019; Pethybridge and Nelson 2017). The integrated table beet–specific CLS standard area diagrams were referenced for accuracy and a linear ordinal scale, including 12 categories—0%, 100%, and intermediate intervals of 10%—was used to rate individual leaves.

Recognizing the similarity between CLS lesions and other table beet foliar diseases, including Alternaria leaf spot (*Alternaria* sp.), Phoma leaf spot (*Phoma betae*), Ramularia leaf spot (*Ramularia beticola*), and bacterial leaf spot (*Pseudomonas syringae* pv. *aptata*), diagnostic tests of lesions were conducted during the 2021 and 2022 seasons (Harveson et al. 2009). Leaf samples were placed in an incubation chamber to induce sporulation for 2 to 3 d followed by microscopic observation. On any given observation day, a minimum of four leaves were selected for evaluation and a single lesion from each leaf was subjected to microscopic inspection. The presence or absence of conidia characteristic of CLS within an observed lesion was noted for each leaf sample. In 2021, each location was assessed for presence of *C. beticola* at least once and, in 2022, each location was assessed at least twice. At harvest, the inner 2 m of each row (cultivar) or plot (fungicide) were removed. The foliage from each row or plot was cut at the crown, oven dried for 4 d at 55 °C, and weighed. The fresh roots from each row or plot were counted and weighed. The count of fresh roots served as a measure of within-row plant density and was collected as a potential covariate to disease severity.

Data analysis. All data were analyzed using the statistical software, R (version 4.2.2, R Core Team 2022). CLS incidence was calculated for each observation day as a percentage based on presence or absence of *C. beticola* within evaluated lesions. Locally estimated scatterplot smoothing regressions were fitted to these data for the 2021 and 2022 seasons using the ggplot2 package in R. To calculate the AUDPC for each row/plot, first, disease severity assessments of individual leaves taken on each evaluation day at each trial were averaged to represent the disease severity of the entire row or plot (Madden et al. 2007). These data were then used to calculate the AUDPC for each row/plot with the agricolae package in R. Trials that failed to exceed a mean disease severity of 5% considering all cultivars (cultivar trial) or nontreated control plots (fungicide trial) at harvest were excluded from further analysis. For the cultivar trial, after single trial analysis, a multitrial analysis was conducted using the following linear fixed effects model, $Y_{ijkl} = \mu + e_i + b(e)_{j(i)} + g_k + ge_{ik} + \epsilon_{ijkl}$, where μ represents the overall mean of all rows in all trials, e_i is the effect of trial i, $b(e)_{j(i)}$ is the effect of block j nested within trial i, g_k is the effect of cultivar k, ge_{ik} is the interaction of cultivar k with trial i, and ϵ_{ijkl} is the experimental error. To meet model assumptions, the response variables, AUDPC and foliage dry weight, were square root transformed before conducting an analysis of variance (ANOVA). ANOVA was conducted using R to investigate the significance of main effects and the interaction effect on the response variable in question. A significant interaction effect was further investigated to determine the nature of the interaction (crossover or magnitude) by calculating Spearman rank correlations of average trait values between trials (trait values averaged for each treatment across blocks within the trial) and between years (trait values averaged for each treatment across blocks within a year). Means of significant main effects were separated by Tukey's honestly significant difference post hoc tests at $P = 0.05$ using the emmeans package in R. Broad-sense heritability estimates for AUDPC, plant density, root fresh weight, and foliage dry weight were conducted using the lme4 package in R. All predictor variables in the model provided previously were considered random effects. Variance components were extracted for each trait and heritability was calculated as

$$H^2 = \frac{\sigma^2 g}{\sigma^2 g + \left({}^{\sigma^2 ge}\!/_{t} \right) + \left({}^{\sigma^2 \epsilon}\!/_{(tr)} \right)},$$

where $\sigma^2 g$ is the cultivar variance; $\sigma^2 ge$ is the cultivar × trial interaction variance, hereafter referred to as the cultivar × environment interaction; $\sigma^2 \epsilon$ is the error variance; t is the number of trials; and r is the number of replications per trial (Fehr 1987).

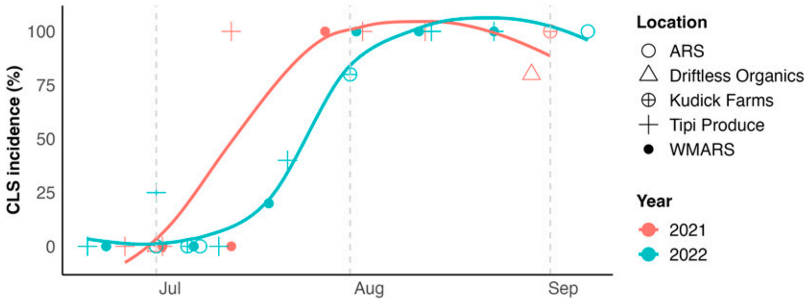

Fig. 1. Locally estimated scatterplot smoothing regressions fitted to Cercospora leaf spot diagnostic evaluations of table beet foliage from trials planted at Arlington Research Station [ARS (Arlington, WI, USA)], Driftless Organics (Soldier's Grove, WI, USA), Kudick Farms (Denmark, WI, USA), Tipi Produce (Evansville, WI, USA), and West Madison Agriculture Research Station [WMARS (Verona, WI, USA)] during the 2021 (n = 11) and 2022 (n = 17) seasons. Each data point represents a minimum of four evaluated lesions and each lesion originated from a separate leaf. Vertical dashed lines indicate the first day of each month.

Results

Diagnostic evaluations. All lesions assessed during Jun 2021 and 2022, and most lesions assessed during early Jul 2021 and 2022, did not contain morphological structures consistent with *C. beticola*. Rather, *Alternaria alternata* was commonly observed in many of these lesions. The presence of *C. beticola* was first observed at Tipi Produce on 13 Jul 2021 and 1 Jul 2022. Evaluations at all other locations in August and September of both years revealed *C. beticola* to be the primary pathogen (Fig. 1).

Cultivar trial. Despite thinning to a target density, significant differences among cultivars for plant density were identified in seven of the 10 trials ($P < 0.05$). Although *C. beticola* was confirmed as the dominant disease organism in all trials, mean CLS disease severity at harvest ranged widely across trials. From least severe to most severe, the trials ranked as follows: ARS 2021 (3%), WMARS 2021 second planting (6%), Driftless Organics 2021 (7%), Kudick Farms 2021 (10%), WMARS 2021 first planting (10%), Tipi Produce 2022 (17%), Kudick Farms 2022 (24%), Tipi Produce 2021 first planting (46%), Tipi Produce 2021 second planting (53%), ARS 2022 (61%), and WMARS 2022 (63%). Considering trials with a mean disease severity at harvest above 5%, all single trial analyses revealed significant differences in CLS resistance among table beet cultivars ($P < 0.001$). The cultivars with the lowest AUDPC values in each trial were consistently Bull's Blood, Blushing not Bashful, and Touchstone Gold. Conversely, high AUDPC values were consistently observed for the cultivars Rhonda, Red Ace, and Boro relative to other cultivars evaluated in the same trial (Fig. 2).

Multitrial analysis identified significant main and cultivar × environment interaction effects, affecting all traits (Table 4). For each trait, the mean square was largest for the main effect of environment, followed by the main effect of cultivar. The mean square values for the interaction of cultivar × environment were considerably lower than the main effects across all traits, consistent with an interaction pattern of magnitude. Further investigations found Spearman correlations (r_s) between 2021 and 2022 for mean cultivar trait values to be moderate to high ($0.60 \le r_s \le 0.94$, $P < 0.05$). Spearman correlations between environments for mean cultivar trait values ranged considerably for plant density ($-0.48 \le r_s \le 0.83$), root fresh weight ($0.05 \le r_s \le 0.92$), and foliage dry weight ($-0.14 \le r_s \le 0.93$); however, moderate median correlation values were observed for all of these traits (median r_s = 0.58, 0.61, and 0.49, respectively). Considering disease resistance, Spearman correlations between environments and between years for mean cultivar

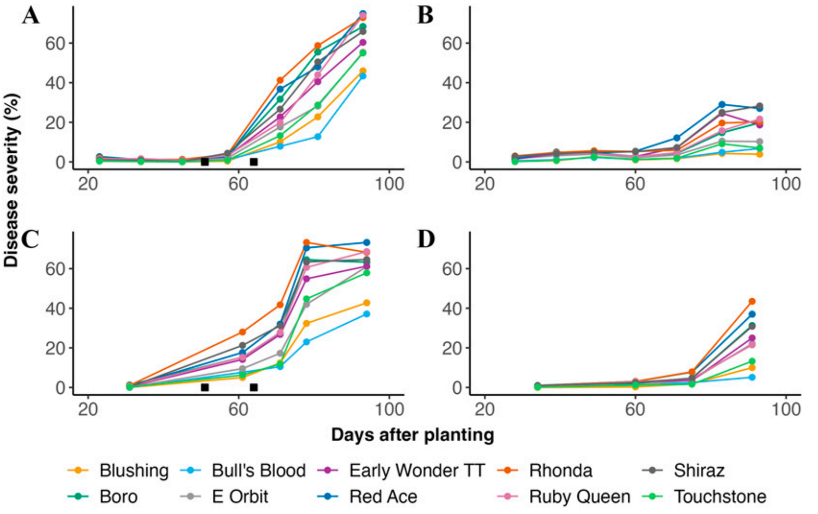

Fig. 2. Temporal progress of Cercospora leaf spot disease of 10 table beet cultivars evaluated at four replicated field trials in Wisconsin, USA during the 2022 season. Locations included (A) West Madison Agriculture Research Station [WMARS (Verona, WI, USA)], (B) Tipi Produce (Evansville, WI, USA), (C) Arlington Research Station [ARS (Arlington, WI, USA)], and (D) Kudick Farms (Denmark, WI, USA). All locations were subject to natural inoculation. Trials at WMARS and ARS received supplemental inoculation with cultured *Cercospora beticola* (timing of inoculation is indicated by black squares along the x-axis).

AUDPC values were notably high (environments: $0.71 \leq r_s \leq 0.99$, $P < 0.01$; years: $r_s = 0.94$, $P < 0.001$) (Fig. 3). These correlations confirmed the interaction effect to be primarily driven by shifts in magnitude, permitting further analyses to focus only on the main effects.

Averaged across all environments, AUDPC values were lowest for ‘Bull’s Blood’ and ‘Blushing not Bashful’, and highest for ‘Rhonda’ and ‘Red Ace’ (Table 5). The mean AUDPC value for ‘Rhonda’ was higher than ‘Blushing not Bashful’ by 230% and higher than ‘Bull’s Blood’ by 267%. Significant cultivar variation for AUDPC was not reflective of cultivar differences in biomass production. Many of the most CLS-susceptible cultivars were also some of the most productive at accumulating root biomass (e.g., Rhonda, Red Ace, Boro). Conversely, the higher CLS resistance of ‘Bull’s Blood’ and ‘Touchstone Gold’ was accompanied by low root biomass productivity. Cultivars Blushing not Bashful and Evansville Orbit were notable for good to moderate CLS resistance without the evident root productivity penalty observed in Bull’s Blood and Touchstone Gold. Similarly, despite high susceptibility to CLS, Early Wonder Tall Top and Shiraz produced the most foliage relative to other cultivars, whereas the CLS-resistant cultivars Bull’s Blood and Touchstone Gold were some of the least productive producers of foliage. Consistent with CLS reaction, susceptible cultivars Boro and Rhonda accumulated little foliar biomass, and resistant cultivar Blushing not Bashful generated moderate amounts of foliage (Table 5).

CLS-resistant sugar beets were more resistant than any table beet cultivar included in this study. In the moderate disease pressure environments of Tipi Produce 2022 and Kudick Farms 2022, the resistant sugar beet cultivars EL50 and BTS 9986 accumulated the lowest mean AUDPC values (102 and 7, respectively) relative to table beets evaluated in the same environments, but were not significantly different from the mean AUDPC values of the most resistant table beet cultivar in the trial [131 ($P = 0.54$) and 109 ($P = 0.12$), respectively]. Considering the high disease pressure environments of WMARS 2022 and ARS 2022, the mean AUDPC values of the most resistant table beet cultivars were 519 and 803. By contrast, the mean AUDPC values of the resistant sugar beets evaluated in these environments were 70 and 58, representing substantial decreases over the most resistant table beet cultivars ($P < 0.001$). A comparison of the disease progress curves between the table beet cultivars and resistant sugar beets evaluated in the environments of WMARS 2022 and ARS 2022 illustrates the distinct disease reactions between these groups (Fig. 4). In addition, the susceptible sugar beet cultivar, F1042, demonstrated significantly improved resistance over the mean AUDPC value of all table beet cultivars in the environments of Tipi Produce 2022 ($P = 0.03$) and Kudick Farms 2022 ($P = 0.05$), moderate significance for improved resistance in ARS 2022 ($P = 0.09$), and no evidence for improvement in WMARS 2022 ($P = 0.71$).

FUNGICIDE TRIAL. Nontreated plot mean disease severity at harvest varied among trials. From least severe to most severe, the trials ranked as follows: ARS 2021 (4%), WMARS 2021 second planting (4%), Kudick Farms 2021 (7%), WMARS 2021 first planting (7%), Driftless Organics 2021 (8%), Tipi Produce 2022 (25%), Kudick Farms 2022 (29%), Tipi Produce 2021 first planting (53%), Tipi Produce 2021 second planting (56%), WMARS 2022 (68%), ARS 2022 (70%). Single trial analysis, considering only those trials for which mean disease severity of the nontreated plots at harvest surpassed 5%, revealed significant differences in plant density at Driftless Organics 2021 ($P = 0.01$).

Table 4. Mean squares from the analysis of variance results for Cercospora leaf spot disease reaction collected from a panel of 10 table beet cultivars evaluated in multiple Wisconsin, USA, environments.

		Mean square			
Source of variation	*df*	AUDPC[i]	Plant density	Root fresh wt	Foliage dry wt
Environment (E)	9	3702 ***[ii]	3284 ***	94 ***	482 ***
Cultivar (C)	9	933 ***	669 ***	35 ***	73 ***
Block	30	8 **	116 ***	1 NS	8 ***
C × E	81	14 ***	72 **	2 ***	5 *
Error	270	4	47	1	4

[i] Area under disease progress curve.

[ii] NS, *, **, *** nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

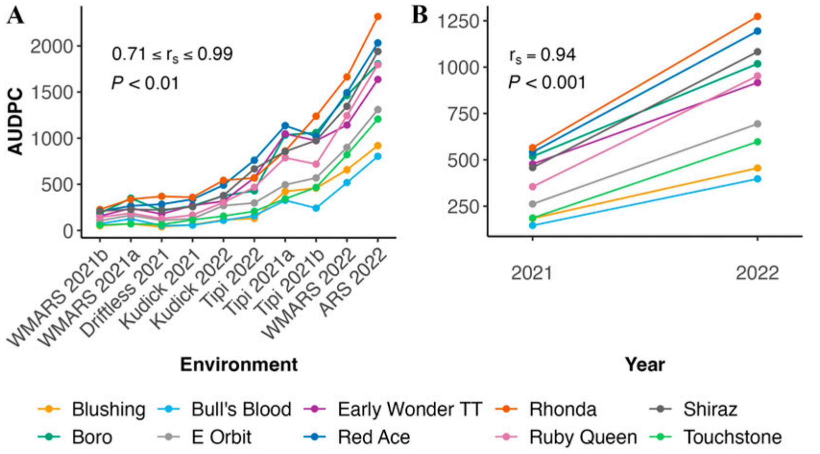

Fig. 3. Rank change in mean area under disease progress curve (AUDPC) for 10 table beet cultivars evaluated for Cercospora leaf spot disease reaction across (A) environments West Madison Agriculture Research Station 2021 and 2022 [WMARS (Verona, WI, USA)], Driftless Organics 2021 (Soldier's Grove, WI, USA), Kudick Farms 2021 and 2022 (Denmark, WI, USA), Tipi Produce 2021 and 2022 (Evansville, WI, USA), and Arlington Research Station 2022 [ARS (Arlington, WI, USA)], and (B) across 2 years. Environments are ordered from least to most disease severe with "a" and "b" referring to first and second plantings in a given environment, respectively. Cultivar AUDPC values were averaged across (A) blocks in each trial and across (B) blocks in each year. Spearman rank correlations (r_s) for mean cultivar AUDPC between environments (range) and years are provided, as are associated *P* values.

No other trials were found to differ significantly for plant density. Regarding biomass production of root and foliage, no significant differences were identified in any trial for dry weight of foliage and only at WMARS 2022 was a significant difference among treatments for fresh weight of roots identified ($P = 0.02$).

Efficacy of OMRI fungicides. No significant differences in the AUDPC between fungicide-treated and nontreated plots were identified in five of the six organic trials. Overlapping disease progress curves of the nontreated and treated plots throughout the season illustrate this lack of difference in disease reaction (Fig. 5). Only at WMARS 2022 was a significant treatment effect observed [$P < 0.001$ (Table 6)]. Post hoc analyses revealed that both of the fungicide treatments significantly reduced AUDPC compared with nontreated plots and treatment with copper octanoate + *B. amyloliquefaciens* D747 significantly reduced AUDPC compared with treatment with *B. mycoides* isolate J ($P < 0.01$). The significant effect of fungicide treatment on AUDPC was reflected in significant root weight differences among the treatments ($P = 0.02$); however, no significant difference was evident among treatments for dry foliar weight ($P = 0.08$). At harvest, mean disease severity of plots receiving fungicide treatment at WMARS 2022 was 63% for *B. mycoides* isolate J and 57% for copper octanoate + *B. amyloliquefaciens* D747, as compared with 68% for the nontreated plots.

Efficacy of conventional fungicides. Significant differences for AUDPC were observed among treatments in all three conventional environments ($P < 0.05$). The distinct disease progress curves between the treated and nontreated plots illustrate these differences (Fig. 6). Both propiconazole and pydiflumetofen + fludioxonil significantly reduced AUDPC compared with the nontreated plots ($P < 0.05$) in Kudick Farms 2021 and ARS 2022 (Table 7). In the environment of Kudick 2021, the major point of disease progress curve divergence between treated and nontreated plots occurred at 45 DAP (Fig. 6A). By 58 DAP the elevated disease severity of the nontreated plots had reduced to similar levels of the treated plots, perhaps suggesting fungicide control of early season *A. alternata* rather than *C. beticola*. No significant treatment effect was identified between propiconazole and the nontreated plots at Kudick Farms 2022 ($P = 0.08$), although pydiflumetofen + fludioxonil did exhibit significantly improved disease control over no fungicide application ($P = 0.03$). In all environments, no significant differences for AUDPC were identified between propiconazole and pydiflumetofen + fludioxonil (Kudick Farms 2021, $P = 0.99$; Kudick Farms 2022, $P = 0.77$; ARS 2022, $P = 0.99$). No significant differences for biomass production, either of root or foliage, were identified between treatments in any of the conventional environments.

Table 5. Table beet cultivar response to Cercospora leaf spot and the effect of cultivar on plant density, the fresh weight of roots, and the dry weight of foliage averaged across 10 field evaluations conducted in representative growing environments of Wisconsin, USA, during the 2021 and 2022 seasons.

Cultivar	AUDPC[i]	Plant density[ii]	Root fresh wt (kg)[ii]	Foliage dry wt (g)[ii]
Blushing not Bashful	223 a[iii]	31.3 bc	5.3 bc	295 bc
Boro	613 e	28.0 cd	6.4 a	235 e
Bull's Blood	201 a	26.1 d	3.0 e	259 cde
Early Wonder Tall Top	560 e	35.5 ab	5.8 ab	380 a
Evansville Orbit	361 c	29.6 cd	5.5 b	282 cd
Red Ace	698 f	37.4 a	5.5 b	271 cde
Rhonda	737 f	37.9 a	5.6 b	249 de
Ruby Queen	486 d	35.5 ab	4.8 cd	245 de
Shiraz	607 e	35.6 ab	5.2 bc	337 ab
Touchstone Gold	269 b	31.9 bc	4.4 d	242 de
CV (%)[iv]	94	37	38	48
H^2[v]	0.98	0.89	0.95	0.93

[i] Area under disease progress curve.

[ii] Data collected from the internal 2 m (6.56 ft) of each row; 1 kg = 2.2046 lb, 1 g = 0.0353 oz.

[iii] Means followed by the same letter within a column are not significantly different (Tukey honestly significant difference post hoc test at $P = 0.05$).

[iv] Coefficient of variation.

[v] Entry-mean broad-sense heritability.

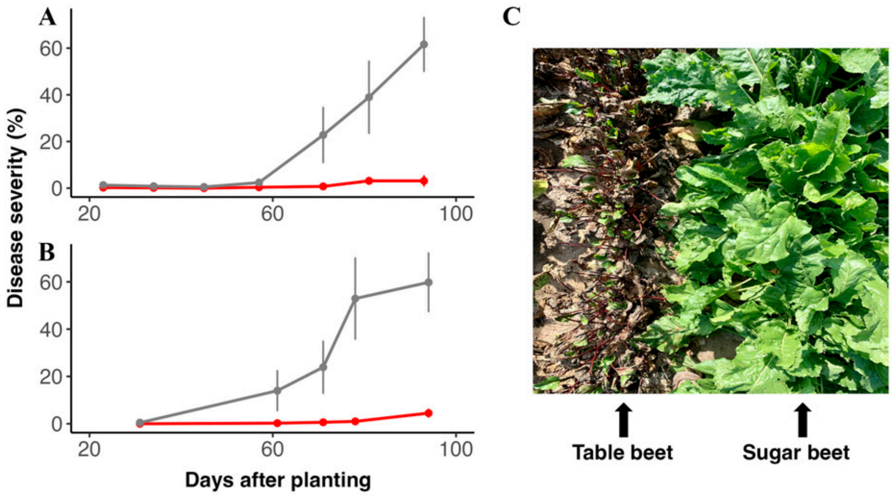

Fig. 4. Comparison of Cercospora leaf spot disease progression between the mean disease severity of resistant sugar beet cultivars (red lines) and the mean disease severity of 10 table beet cultivars (gray lines) at (A) West Madison Agriculture Research Station [sugar beet cultivar is EL50 (Verona, WI, USA)] and (B) Arlington Research Station [sugar beet cultivar is BTS 9986 (Arlington, WI, USA)] during the 2022 season; error bars = *SD*. (C) Visual comparison of resistance as observed at Arlington Research Station (78 d after planting) between table beet cultivar Rhonda (left) and sugar beet cultivar BTS 9986 (right).

Discussion

The disease progress curves experienced in most environments analyzed in this study followed a typical pattern of CLS infection. Some environments, however, experienced limited disease severity throughout the season, despite the confirmed presence of *C. beticola*. Presumably, conditions in these environments were not conducive to escalating infection. In high disease pressure environments, disease severity increased steadily after canopy closure and continued until defoliation. At defoliation, the disease progress curves for certain treatments appear to plateau and, in some cases, decline (Figs. 2C, 5A, and 5B). This phenomenon results from regrowth—the generation of new, often small, and initially disease-free foliage. Given the random nature of leaf sampling, the inevitable scoring of such regrowth has the potential to deflate the true observed disease status of the evaluated row or plot. Therefore, in such cases, it is expected that the disease severity of these treatments is, in fact, greater than reported. The phenotyping method used to evaluate disease severity in this study offers many advantages, including automatic transcription of data, standard area diagrams as visual aids for consistent rating, and efficiency. That said, it is likely that the observed plateau of disease progress curves in high disease environments may not have resulted had evaluations been made at the whole row or plot level, as the regrowth leaves were generally small and did little to improve the overall appearance of the row or plot.

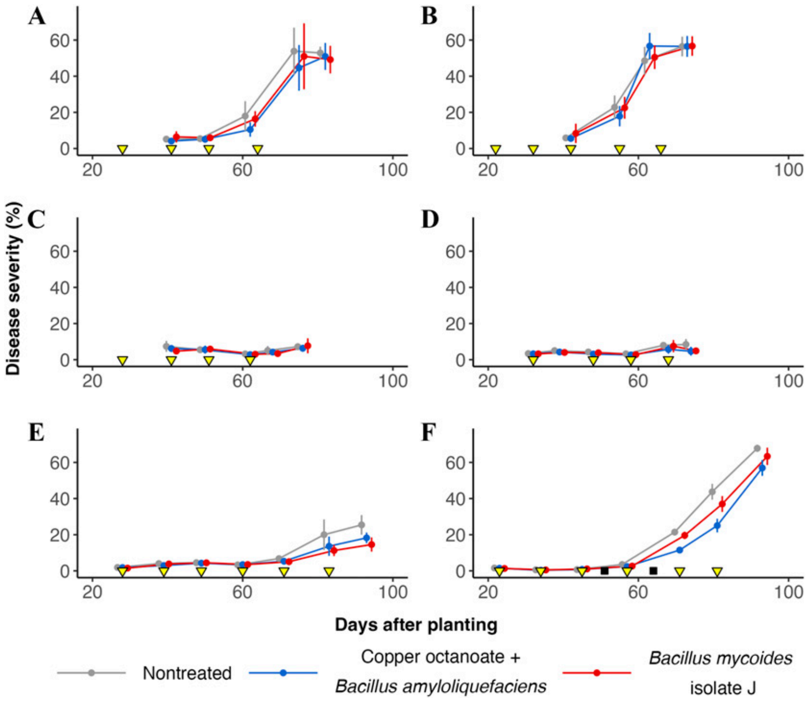

Fig. 5. Temporal progress of Cercospora leaf spot disease in table beet plots treated with Organic Materials Review Institute–listed products at six replicated field trials in Wisconsin, USA: (A) Tipi Produce 2021 first planting (Evansville, WI, USA), (B) Tipi Produce 2021 second planting, (C) West Madison Agriculture Research Station 2021 first planting [WMARS (Verona, WI, USA)], (D) Driftless Organics 2021 (Soldier's Grove, WI, USA), (E) Tipi Produce 2022, and (F) WMARS 2022 (black squares on x-axis indicate timing of inoculations). Yellow triangles on x-axis indicate timing of spray applications. Points are offset horizontally to visualize error bars (*SD*) and may not be on the actual measurement day.

The table beet cultivars evaluated in this study varied considerably in their reaction to CLS. In agreement with similar studies, Bull's Blood again demonstrated high CLS resistance relative to other table beet cultivars (Keinath et al. 2022; Raid et al. 2013a, 2013b). In addition, Blushing not Bashful, a recently released cultivar, was found to exhibit comparable levels of resistance to Bull's Blood in this study. Interestingly, Blushing not Bashful was selected from a base population formed by the cross of Bull's Blood and the cultivar Chioggia and, therefore, likely shares many of the same genetic defense mechanisms as Bull's Blood (Hanson et al. 2022; Maher and Goldman 2017). Conversely, this study found cultivars Rhonda and Red Ace to be highly susceptible to CLS.

The observed variation for CLS resistance in this study is sufficient to make a meaningful difference to farmers. Strict market standards for foliage of bunched beets limit acceptable symptomatic tissue to below 5%. In the moderate disease pressure environment of Kudick Farms 2022, 'Rhonda' passed

Table 6. Effect of Cercospora leaf spot disease on area under disease progress curve (AUDPC), plant density, fresh weight of roots, and dry weight of foliage for table beet plots treated with Organic Materials Review Institute–approved products at West Madison Agriculture Research Station (Verona, WI, USA) in 2022.

Treatment[i]	AUDPC	Plant density[ii]	Root fresh wt (kg)[ii]	Foliage dry wt (g)[ii]
Nontreated	1214 c	54	11.4 a	495
Bacillus mycoides isolate J	1082 b	54	13.0 b	582
Copper octanoate + *Bacillus amyloliquefaciens* D747	807 a	58	13.4 b	567
F	51.9	0.4	8.5	4.1
P	<0.001	0.68	0.02	0.08
CV (%)[iii]	18	13	9	13

[i] Means followed by the same letter within a column are not significantly different (Tukey honestly significant difference post hoc test at $P = 0.05$).

[ii] Data collected from the internal 2 m (6.56 ft) of each plot; 1 kg = 2.2046 lb, 1 g = 0.0353 oz.

[iii] Coefficient of variation.

this threshold at 66 DAP, whereas 'Bull's Blood' stayed below 5% damage for an additional 25 d (Fig. 7B). Similarly, at Tipi Produce 2022, 'Red Ace' exceeded 5% severity 27 d before 'Bull's Blood', and 'Blushing not Bashful' stayed below 5% severity for the entire trial (Fig. 7A). The choice of cultivar in these environments could mean the difference between market acceptance and rejection.

In the high disease pressure environment of WMARS 2022, however, the number of days between first and last cultivar to exceed 5% severity shortened considerably to 8 d (Fig. 7C). When disease pressure was high, the resistance of all evaluated table beet cultivars was ultimately overcome. The susceptibility of evaluated table beets to CLS became explicitly clear when compared against resistant sugar beet cultivars. The maximum disease severity experienced by sugar beet cultivar EL50 was 3% in WMARS 2022 compared against an average table beet maximum of 62%, and although sugar beet 'BTS 9986' never exceeded 5% severity in ARS 2022, the average table beet maximum severity was 60% (Fig. 3A and B).

Accomplishing similar levels of resistance in table beet may be possible by introgressing resistance alleles from sugar beet germplasm. The CLS resistance of 'BTS 9986' is purportedly determined by 'CR+'—a patent-protected trait (patent US10767191B1) developed by KWS (KWS SAAT SE & Co. KGaA, Einbech, Germany). As such, without a license, 'BTS 9986' cannot be considered for table beet improvement. Sugar beet cultivar EL50, however, was developed by the USDA-Agricultural Research Service (Beltsville, MD, USA) in collaboration with the Beet Sugar Development Foundation (Denver, CO, USA) and Michigan State University (East Lansing, MI, USA) as a germplasm resource, in part, for the improvement of CLS resistance (Lartey et al. 2010; Saunders et al. 1999). A backcross breeding design accompanied by phenotypic selection for CLS resistance may facilitate introgression of CLS resistance from 'EL50' into table beet germplasm (Bilgen et al. 1968). The success of such a program may depend on the nature of the genetic control of CLS resistance in table beet; a subject that has received little attention from researchers.

CLS resistance in sugar beet has historically been accompanied by a yield penalty in the presence of low disease conditions. In a promising advance, several recently released European cultivars appear to lack this yield penalty (Vogel et al. 2018). Regarding table beet, Bull's Blood exhibited a clear yield penalty in the cultivar trial, scoring considerably lower than any other cultivar for root biomass production. Alternatively, both 'Blushing not Bashful' and 'Evansville Orbit' demonstrated high to moderate CLS resistance while yielding well relative to other table beets in the trial. Overall, CLS did not appear to affect root development in this study, with many of the most susceptible cultivars yielding the most root biomass. This apparent contradiction was perhaps due to early planting in both years relative to epidemic onset. As the table beet root swells, growth plateaus as neighboring roots restrict further expansion. In this study, disease pressure increased at 50 to 60 DAP in many environments, providing sufficient time for root expansion before defoliation (Table 1). One may expect root biomass to be affected more severely if planting had occurred closer to epidemic onset.

Future breeding efforts and additional cultivar trials will benefit from the finding that CLS reaction does not appear to be subject to cultivar × environment interaction among the included Wisconsin environments. In this study's cultivar trial, the significant interaction effect appeared to be due almost entirely to magnitude shifts in cultivar disease response across

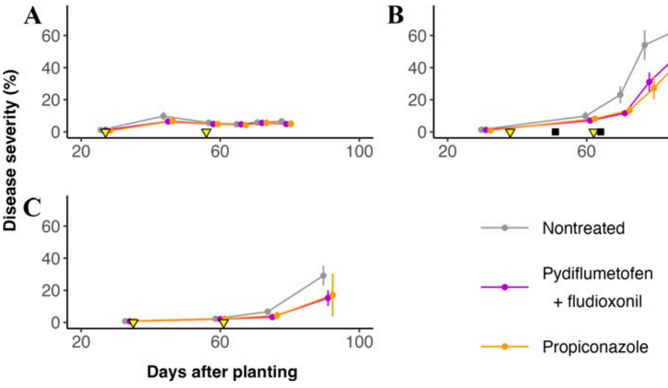

Fig. 6. Temporal progress of Cercospora leaf spot disease in table beet plots treated with conventional fungicides at three replicated field trials in Wisconsin, USA, including (A) Kudick Farms 2021 (Denmark, WI, USA), (B) Arlington Research Station 2022 [black squares on x-axis indicate timing of inoculations (Arlington, WI, USA)], and (C) Kudick Farms 2022 (Denmark, WI, USA). Yellow triangles on x-axis indicate timing of spray applications. Points are offset horizontally to visualize error bars (*SD*) and may not be on the actual measurement day.

Table 7. Effect of Cercospora leaf spot disease on area under disease progress curve (AUDPC), plant density, fresh weight of roots, and dry weight of foliage for table beet plots treated with conventional fungicides at Arlington Research Station (Arlington, WI, USA) in 2022.

Treatment[i]	AUDPC	Plant density[ii]	Root fresh wt (kg)[ii]	Foliage dry wt (g)[ii]
Nontreated	1596 b	124	9.6	446
Propiconazole	1122 a	120	10.6	539
Pydiflumetofen + fludioxonil	1117 a	112	9.5	455
F	19.4	0.7	3.6	2.0
P	<0.01	0.52	0.09	0.21
CV (%)[iii]	21	18	9	19

[i] Means followed by the same letter within a column are not significantly different (Tukey honestly significant difference post hoc test; $P = 0.05$).

[ii] Data collected from the internal 2 m (6.56 ft) of each plot; 1 kg = 2.2046 lb, 1 g = 0.0353 oz.

[iii] Coefficient of variation.

locations, indicating that cultivar CLS rankings in one environment are highly repeatable in other environments. This pattern was consistent across organic and conventional farming systems, suggesting that cultivars bred for improved CLS resistance will benefit all table beet growers in Wisconsin. This finding may serve as a justification for future researchers operating in Wisconsin to initially concentrate CLS resistance improvement to a reduced set of environments. The favorably high heritability for cultivar AUDPC values observed in this study (entry-mean broad-sense heritability = 0.98) further supports the potential to reduce locations and/or replications in future CLS breeding work. This finding is especially relevant to researchers interested in designing an efficient selection scheme for the improvement of CLS resistance.

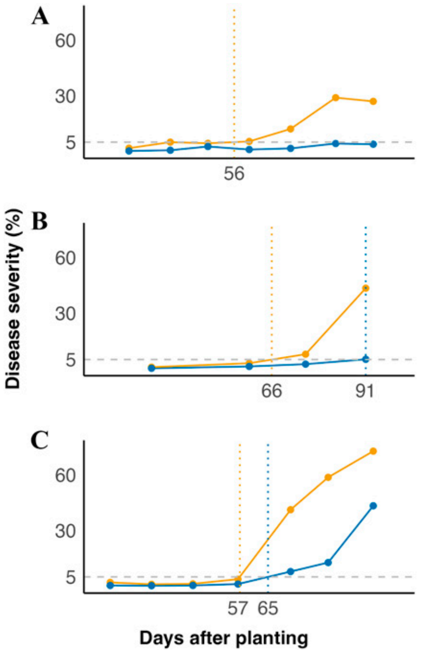

Fig. 7. Time (d after planting) to exceed the Cercospora leaf spot disease threshold of 5% severity for the most resistant (blue) and most susceptible (orange) table beet cultivar out of an evaluated panel of 10 cultivars in the locations of (A) Tipi Produce [resistant: 'Blushing not Bashful'; susceptible: 'Red Ace' (Evansville, WI, USA)], (B) Kudick Farms [resistant: 'Bull's Blood'; susceptible: 'Rhonda' (Denmark, WI, USA)], and (C) West Madison Agriculture Research Station [resistant: 'Bull's Blood'; susceptible: 'Rhonda' (Verona, WI, USA)] during Summer 2022. The dotted vertical lines correspond to the days after planting that the specified treatment—resistant cultivar in blue and susceptible cultivar in orange—crossed the 5% threshold.

OMRI-listed fungicides evaluated in this study were found to be largely ineffective at controlling CLS. No significant differences were identified between AUDPC values of treated and nontreated plots in any environments except for WMARS 2022. From one perspective, the significant treatment effect observed at WMARS 2022 does demonstrate fungicide efficacy. For reference, the AUDPC of copper octanoate + *B. amyloliquefaciens* D747 is not significantly different from the AUDPC of cultivar Touchstone Gold also measured at WMARS 2022, suggesting that treatment with this product is equivalent to changing cultivars from Early Wonder Tall Top to Touchstone Gold ($P = 0.80$). Combining copper octanoate + *B. amyloliquefaciens* D747 with a resistant cultivar may further reduce AUDPC.

From another perspective, the significant treatment effect at WMARS 2022 may not demonstrate fungicide efficacy. Treatment with *B. mycoides* isolate J extended the length of time beneath a threshold of 5% severity by 1 d over no treatment and copper octanoate + *B. amyloliquefaciens* D747 provided 3 d additional—results that, from a practical perspective, make little difference to the grower (Fig. 5F). Furthermore, the initial rate-limiting effect of the treatments was neutralized by harvest, as the disease progress curves of the nontreated and treated plots converge. These results may not justify the additional time and potential economic investment in spray equipment required to regularly treat throughout the season.

Both conventional fungicide treatments evaluated in this study appear to have limited epidemic progress. Lower AUDPC values of the treated plots along with the evident rate-reducing effect following treatment are promising findings. These findings do not provide evidence for resistance to propiconazole among *C. beticola* strains in Wisconsin. Failing to provide evidence for resistance, however, should not be confused with no resistance. The presence of resistant strains could be tested only in the noninoculated environments of Kudick Farms 2021 and 2022, as the isolates used in ARS 2022 were both known to be sensitive to propiconazole (Pethybridge SJ, personal communication). The limited environments tested, coupled with the low to moderate disease severity experienced in these environments, means propiconazole resistance in Wisconsin is still an outstanding question.

Although propiconazole and pydiflumetofen + fludioxonil demonstrated improved disease control over no treatment, ultimately all plots succumbed to the disease at ARS 2022. At harvest, there were no significant differences for disease severity among treated and nontreated plots ($P = 0.24$). If one measure of fungicide efficacy is the maintenance of healthy foliage to facilitate mechanized harvest, these treatments failed, as no differences were observed in dry foliar weight between treated and nontreated plots at harvest. This observation raises the critical question of optimal fungicide application timing. Pethybridge et al. (2020a) found propiconazole and pydiflumetofen + fludioxonil to be most effective when applied before symptom onset and during a period of high risk, as defined by relative humidity and temperature. This study successfully applied fungicides before symptom onset; however, the available weather-monitoring tools were not sufficiently reliable to determine periods of high risk. Perhaps with decision support tools to help guide fungicide application timing, the maintenance of healthy foliage may be extended. Such decision support tools, in the form of forecasting models, have been developed for CLS in Michigan, North Dakota, and New York, USA (Khan et al. 2007; Pethybridge et al. 2020a; Tedford et al. 2019). Creating similar tools for Wisconsin table beet producers could be beneficial.

The results from this study's cultivar trial confirm that cultivar choice can be leveraged to mitigate CLS damage in Wisconsin. Cultivars Bull's Blood and Blushing not Bashful were the most resistant table beets tested, whereas Rhonda and Red Ace were the most susceptible. CLS-resistant sugar beets proved highly resistant relative to the evaluated table beets and provided an optimistic vision for similar levels of resistance in table beet. As for fungicide treatments, the evaluated OMRI-listed products were not effective at controlling CLS in this study, and both conventional fungicides did measurably limit CLS progress. The effectiveness of fungicide treatments in general, however, may be improved by providing tools that assist growers in deciding when to apply fungicides. The authors hope that the findings from this work will provide useful guidance to table beet growers affected by CLS.

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