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Horticultural Characteristics and Susceptibility of Table Beet Cultivars to *Cercospora* Leaf Spot in New York

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SUMMARY. Table beet (*Beta vulgaris* ssp. *vulgaris*) production in New York is increasing for direct sale, use in value-added products, or processing. One of the most important diseases affecting table beet is cercospora leaf spot (CLS) caused by the fungus *Cercospora beticola*. CLS causes lesions on leaves that coalesce and leads to premature defoliation. The presence of CLS may cause buyer rejection at fresh markets. Defoliation from CLS may also result in crop loss because of the inability to harvest with top-pulling machinery. The susceptibility of popular table beet cultivars (Boldor, Detroit, Falcon, Merlin, Rhonda, Ruby Queen, and Touchstone Gold) to CLS was tested using *C. beticola* isolates representative of the New York population. Two trials were conducted by inoculating 6-week-old plants in the misting chamber. A small-plot replicated field trial was also conducted to examine horticultural characteristics of the cultivars. In the misting chamber trials, disease progress measured by the area under the disease progress stairs (AUDPS) was not significantly different between the red cultivars, Detroit and Ruby Queen, and was significantly higher in 'Boldor' than the other yellow cultivar Touchstone Gold. In the field trial, the number of CLS lesions per leaf at the final disease assessment and AUDPS were significantly lower in cultivar Ruby Queen than others and not significantly different between the yellow cultivars. The dry weight of roots was not significantly different among cultivars at first harvest (77 days after planting). At 112 days after planting, the dry weight of roots was significantly higher in cultivar Detroit than Rhonda and Boldor. Leaf blade length and the length:width ratio were cultivar-dependent, which may facilitate selection for specific fresh markets. Significant associations between canopy reflectance in the near infrared (IR) (830 nm), dry weight of foliage, and number of CLS lesions per leaf suggested that this technique may have utility for remote assessment of these variables in table beet research. Implications of these findings for the management of CLS in table beet are discussed.

The New York table beet industry currently supplies ~30,000 tons annually and is the second largest producer for the processing and fresh markets in the United States (U.S. Department of Agriculture, 2014). In New York, table beets are produced for the fresh market in diverse systems ranging from small, diversified farms to broad-acre fields.

Production across the northeastern United States is increasing as a result of the resurgence in popularity driven by demand for table beet in value-added products (i.e., juices) because of the enhanced perception of the health benefits of consumption (Clifford et al., 2015).

For the fresh market, table beets may be sold with foliage intact or

separated from roots. Profitability in table beet production is, therefore, a direct function of the number of marketable units (roots, foliage, or both) per length of row and the uniformity of root sizes for sale into specific markets (Hipp, 1977; Kikkert et al., 2010; Warne, 1948, 1953). For example, higher in-row plant densities increase the proportion of plants with smaller root diameters in globe-shaped cultivars but are inversely correlated with total root yield (Benjamin, 1987; Benjamin et al., 1985; Tyler et al., 1982). Similarly, agronomic characteristics such as row width, in-row populations, and harvest date also have a significant impact on disease incidence but adjustments often lead to economic detriments to growers (Kikkert et al., 2010).

The quality of foliage and roots are major determinants of profitability, with the presence of disease leading to consumer rejection at fresh markets. Diseases that deleteriously affect table beet production include root decay (Abawi et al., 1986; Shah and Stivers-Young, 2004) and foliar diseases (Franc, 2010). Maintenance of healthy leaves is critical to facilitate mechanized harvest, which is conducted in broad-acre fields by top-pulling machinery that removes the roots from the ground and separates the tops, which are left in the field. The use of top-pulling machinery reduces the need for mineral or other inorganic foreign contaminants to be separated at the factory, which is often problematic with conventional digger harvesters (J.L. Johnson, personal communication). In New York, CLS caused by the fungus *Cercospora beticola* is the most important foliar disease affecting table beet production. Symptoms begin as small gray spots on the leaves that coalesce and cause defoliation (Franc, 2010). For the fresh market, the presence of CLS lesions on leaves may lead to rejection. The disease is also important in sugar beet (*Beta vulgaris* ssp. *vulgaris*) and *C. beticola* isolates are known to infect either host (Jacobsen and Franc, 2009; Ruppel, 1986).

Cercospora beticola produces conidiospores that are dispersed short distances by wind, rain, or both (Franc, 2010). However, the mechanisms by which the fungus is dispersed between fields remain elusive as the sexual form of *C. beticola* has not been

identified. *Cercospora beticola* populations from table beet fields in New York have an equal distribution of the two mating type alleles and high genotypic diversity (Vaghefi et al., 2016, 2017a, 2017b) consistent with observations suggestive of the presence of cryptic sex in populations on sugar beet (Bolton et al., 2012; Groenewald et al., 2006, 2008).

The fungus may overwinter on plant debris as pseudostromata and in soil which may initiate epidemics by splash dispersal of inoculum to leaves (Franc, 2010; Khan et al., 2008), and in sugar beet, soilborne inoculum has been shown to remain viable for up to 22 months in North Dakota (Khan et al., 2008) and 3 years in Israel (Solel, 1970). Studies in New York have demonstrated that *C. beticola* populations on table beet and swiss chard (*B. vulgaris* ssp. *vulgaris*) are sympatric suggesting either of these hosts may serve as inoculum for each other when in close proximity (Vaghefi et al., 2017b). The role of infected weeds as alternative hosts for initiating epidemics in sugar beet fields has also been suggested (McKay and Pool, 1918; Vestal, 1933).

In conventional table beet production, CLS is controlled by prophylactic fungicide application (Pethybridge et al., 2016). However, a high frequency of *C. beticola* isolates that are resistant to fungicides threatens the durability of disease management strategies. For example, 40% of the *C. beticola* population in New York was reported as resistant to the quinone outside inhibitor fungicide, azoxystrobin (Vaghefi et al., 2016). In the CLS-sugar beet pathosystem, reports of resistance to multiple fungicide modes of action restrict tactical control options for growers (e.g., Georgopoulos and Dovas, 1973; Giannopolitis, 1978; Kirk et al.,

2012; Ruppel, 1975; Weiland and Halloin, 2001). A significant variation in CLS susceptibility between sugar beet cultivars has been identified enabling the use of resistant cultivars as a sentinel part of the integrated disease management strategy (Skaracis and Biancardi, 2000; Smith and Martin, 1978; Smith and Ruppel, 1974). To date, there has been less emphasis on CLS susceptibility in table beet breeding in comparison with desirable horticultural characteristics for the fresh market such as root shape and size, and color (Goldman and Navazio, 2003). In addition to disease response, the processing table beet industry has strict market preferences on root sizes and preservation quality standards translating to limited potential to use less susceptible cultivars (Kikkert et al., 2010).

The objective of this study was to evaluate the susceptibility of popular table beet cultivars to local (New York) *C. beticola* populations and horticultural characteristics of interest to fresh market growers. A secondary objective was to investigate the potential of near IR canopy reflectance to remotely assess table beet health. This information is vital for the implementation of durable disease management strategies for CLS in table beet in New York.

Materials and methods

MISTING CHAMBER TRIALS. Two trials were conducted in a misting chamber facility to assess the susceptibility of seven locally popular table beet cultivars [‘Boldor’, ‘Detroit’, ‘Falcon’, ‘Merlin’, ‘Rhonda’, ‘Ruby Queen’, and ‘Touchstone Gold’ (Table 1)] to infection by *C. beticola*. The experimental design of each trial was a completely randomized block including 10 plants of each cultivar

inoculated with a *C. beticola* isolate representative of the dominant clade present in New York [Tb14–085 (Vaghefi et al., 2016)]. All cultivars were grown from seed in the greenhouse, and inoculations were conducted on 6-week-old plants with 7–10 true leaves. Conidial inoculum was prepared according to the protocol of Secor and Rivera (2012) with minor modifications. In brief, 10 mL of sterile distilled water was added to 2-week-old cultures of Tb14–085 on potato dextrose agar (PDA; Hardy Diagnostics, Santa Maria, CA). Mycelia were gently scraped from the plate with a sterile spatula and 500 µL of the suspension was transferred and spread over petri plates containing clarified V8 (CV8) agar [10% (v/v) clarified V8 juice (Campbell’s Soup Co., Camden, NJ), 0.5% (w/v) calcium carbonate (CaCO₃), 2% agar]. These plates were left to dry for 1 h under sterile conditions and incubated at room temperature and exposed to a 12-h white fluorescent light photoperiod for 6 d to induce sporulation (Calpouzos and Stallknecht, 1965). To prepare the conidial inoculum, 5 mL of sterile distilled water was added to each of the CV8 plates. Conidia were dislodged by gentle scraping with a sterile spatula, and the suspension was passed through two layers of sterile cheesecloth and vortexed for 10 s. Conidial concentrations were quantified using a hemocytometer and adjusted to a final concentration of 10⁴ spores/mL and 0.01% (v/v) polysorbate 20 (Tween-20; Bio-Rad, Hercules, CA).

Ten plants were placed in individual transparent plastic bags in centrally controlled misting chambers (New York State Agricultural Experiment Station, Geneva, NY) with a 14-h photoperiod at 25 ± 4 °C. Each plant received ≈12 mL of

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.574	fl oz	µL	3.3814 × 10 ⁻⁵
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
93.0102	oz/ft	g·m ⁻¹	0.0108
1.1692	pt/acre	L·ha ⁻¹	0.8553
0.9072	ton(s)	Mg	1.1023
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Table 1. Characteristics of the popular table beet cultivars in New York included in this study for quantifying susceptibility to cercospora leaf spot and variation in horticultural characteristics.

Cultivar (seed type) ^z	Color	Root shape	Primary use	Time to maturity (d) ^y
Boldor (OP)	Yellow	Globe	Fresh market	55
Detroit (OP)	Red	Globe	Fresh market	59–70
Falcon (hybrid)	Red	Blocky	Fresh market	80–85
Merlin (hybrid)	Red	Globe	Fresh market	48
Rhonda (hybrid)	Red	Globe	Fresh market	65–70
Ruby Queen (OP)	Red	Globe	Processing	55
Touchstone Gold	Yellow	Globe	Fresh market	85–90

^zOP = open pollinated.^yFrom planting by seed to maturity for harvest.

inoculum using a hand sprayer. The bags were closed for 48 h to increase relative humidity for infection. Ten plants of each cultivar were noninoculated controls and placed in individual plastic bags and received an equal volume of sterile distilled water + 0.01% (v/v) polysorbate 20. The misting apparatus was operated for 2–3 h daily delivering a fine mist of water at 25 °C resulting in 90% to 100% relative humidity. The entire trial was conducted twice.

Disease severity was assessed by counting the number of CLS lesions on each plant and calculating the average number per leaf. Disease assessments were conducted at 6, 10, 13, and 17 d after inoculation (DAI) and used to interpolate epidemic progress as the AUDPS (Simko and Piepho, 2012). The effect of cultivars on the average number of CLS lesions per leaf at 17 DAI and AUDPS was quantified using generalized linear modeling in Genstat (version 17.1; VSN International, Hemel Hempstead, UK). Results of the two trials were analyzed separately as exploratory data analysis identified significant differences in the means between the datasets from each trial using the Anderson–Darling goodness-of-fit test (Anderson and Darling, 1954), and nonhomogeneous variances using the Fisher *F*-test (Markowski and Markowski, 1990). Significant differences between cultivars within trials were separated using least significant differences ($P = 0.05$).

FIELD TRIAL. A small-plot, replicated trial was conducted to further assess CLS susceptibility and evaluate horticultural characteristics between the table beet cultivars at Geneva, NY, in 2016. The experimental design was a completely randomized block with five replications of each cultivar

(Table 1). The crop was planted on 22 June with a Monosem vacuum planter at a rate of 17 seeds/ft with 30 inches between rows (Monosem, Edwardsville, KS). Before planting, 10N–4.4P–8.3K fertilizer (Phelps Supply, Phelps, NY) at 300 lb/acre was broadcast and incorporated with shallow tillage using a tractor-mounted coulter mulcher. Additional 10N–4.4P–8.3K fertilizer at 350 lb/acre was banded at planting and 1.5 pt/acre of s-metolachlor herbicide (Dual Magnum[®]; Syngenta Corp., Greensboro, NC) was applied the day after planting (DAP). The entire trial area also received supplementary nitrogen (22% as urea, 50 lb/acre) in a side-dressed application 28 DAP. Irrigation was applied using overhead sprinklers as required for optimal plant growth. In-season weed management was conducted by hand and mechanical cultivation between rows. Each plot was 20 ft long and two rows wide. Plots within rows were separated by 4 ft of bare ground. Plots between rows were separated by two rows planted to the processing industry-standard cultivar Ruby Queen.

The entire trial area was inoculated with a mycelial suspension containing eight *C. beticola* isolates representative of the New York population (Tb14-047, Tb14-070, Tb14-081, Tb14-113, Tb14-116, Tb14-118, Tb14-146, and Tb14-154; Vaghefi et al., 2016). Individual liquid cultures of each isolate were established by transferring mycelia into CV8 broth [10% (v/v) clarified V8 juice, 0.5% (w/v) CaCO₃]. After 14 d, the mycelia of each isolate was collected and filtered through two layers of cheesecloth. The mycelia were then dispersed in sterile distilled water in a blender (Waring Commercial, Torrington, CT) at low speed for

30 s and again filtered through sterile cheesecloth. The number of mycelial fragments per milliliter of suspension was counted using a hemocytometer, and the concentration was adjusted to about 10⁶ fragments/mL. The inoculum was diluted 10 times with sterile distilled water before applying to plants in the field, including 0.01% (v/v) polysorbate 20, with a backpack sprayer at a volume of 28 gal/acre. To estimate the colony-forming units (cfu) in the inoculum, 1 mL of the mycelial suspension was serially diluted (10–10⁶) in sterile distilled water, and 100 µL was spread on CV8 plates. Three replicate plates were used for each concentration and incubated at room temperature exposed to a 12-h photoperiod of white light. After 3 d, the number of colonies was counted on each plate and quantified. The first inoculation was conducted on 9 Aug. (48 DAP) with 3.6 × 10³ CFU/mL, followed by 1.6 × 10⁴ CFU/mL on 17 Aug. (56 DAP). The second inoculation was conducted to ensure disease development following dry conditions after the first inoculation.

DISEASE ASSESSMENT. Plant density (number of plants/foot) and CLS severity were assessed before the first inoculation [8 Aug. (47 DAP)] and at regular intervals [24 Aug. (63 DAP), 28 Aug. (67 DAP), 31 Aug. (70 DAP), 5 Sept. (75 DAP), 9 Sept. (79 DAP), and 23 Sept. (93 DAP)] until harvest. Plant density was assessed by counting the number of plants in two, 3.2-ft lengths beginning at an arbitrarily located position within each row of the plots. An individual leaf was defined as the sampling unit for assessment of CLS severity. CLS lesions were counted on each of the 10 arbitrarily selected leaves of similar age from different

plants within each of the two rows ($n = 20$ plants/plot). The temporal disease progress was then depicted within each plot by calculating AUDPS based on the average number of CLS lesions per leaf (Simko and Piepho, 2012).

CANOPY REFLECTANCE. A hand-held, multispectral radiometer (MSR5; CropScan, Rochester, MN) equipped with five narrow wavelength band sensors (485, 560, 660, 830, and 1650 nm) was used to measure spectral reflectance from the plots. Canopy reflectance was measured the day before the first inoculation, and then postinoculation on 24 Aug. (63 DAP), 5 Sept. (75 DAP), 9 Sept. (79 DAP), 23 Sept. (93 DAP), and 11 Oct. (regrowth after defoliation; 111 DAP). The radiometer was positioned 6.6 ft above the soil and a spirit level mounted to the support pole was used to ensure it was positioned at the appropriate angle and height. The support pole was placed 5 and 15 ft from the end of each plot in the middle of the rows. Canopy reflectance was therefore measured from an area that was 3.2 ft in diameter. Percentage reflectance readings were obtained between 1200 and 1400 HR. Reflectance was calculated as a percentage of the voltage for the reflected radiation divided by the voltage for the incident radiation of each corresponding wavelength. Two readings were obtained for each plot, which were averaged.

YIELD AND OTHER HORTICULTURAL CHARACTERISTICS. Plants were removed by hand from 3.2-ft row lengths on 7 Sept. (77 DAP) and 12 Oct. (112 DAP). The second harvest was conducted following defoliation to quantify cultivar differences in regrowth ability. In-ground storage into late autumn is often used to facilitate processing schedules and by fresh market growers to extend product sales. At each harvest, the total number of plants removed per unit row length was counted, and tops were removed from the roots and weighed separately following washing. Fresh and dry weights of the foliage and roots were recorded. The dry weight of the foliage was calculated by placing $\approx 20\%$ of the sample at 149 °F for 48 h. The dry weight of the roots was calculated after the subsample was left to dry in the same conditions for 120 h. At the first

harvest (77 DAP), 30 leaves were randomly selected from each plot for measuring blade length and width (at the midpoint) with a ruler, and the average length to width ratio was calculated. The shoulder diameter of 20 randomly selected roots from each plot was measured using digital calipers. The number of immature roots (less than 0.5 inch in diameter) in the subsample was also recorded.

DATA ANALYSIS. The effect of cultivar on the number of CLS lesions per leaf, temporal disease progress (AUDPS), canopy reflectance at 830 nm, and yield components (dry weight of foliage and roots at each of the two harvests, and average leaf and root dimensions at 77 DAP) were assessed using generalized linear models. The 830 nm wavelength was selected as canopy reflectance within the near IR region has been demonstrated as a good predictor of plant health (Nilsson, 1995). Means were separated with Fisher's protected least significant difference test ($P = 0.05$). Pearson's correlation coefficient was used to analyze the associations between the number of CLS lesions per leaf, AUDPS, canopy reflectance at 830 nm, and the dry weight of foliage. All analyses were conducted within the statistical software, Genstat (version 17.1).

Results and discussion

Significant differences in CLS susceptibility and desirable horticultural

characteristics between table beet cultivars grown in New York were found. In the misting chamber trials, the average number of CLS lesions per leaf across cultivars at 17 DAI was 13.1 and 19.9 in trials 1 and 2, respectively, and a significant cultivar $\times$ trial interaction was identified (Table 2). No CLS lesions were observed in any of the noninoculated control plants in either trial. In both trials, AUDPS in cultivar Touchstone Gold was significantly lower than in the other yellow cultivar, Boldor. In trial 1, the number of CLS lesions per leaf in cultivar Merlin was significantly lower than the other cultivars with the exception of 'Rhonda' and 'Detroit'. In trial 2, the cultivars were of similar susceptibility with the exception of 'Touchstone Gold', which was not significantly different from 'Rhonda', 'Falcon', and 'Detroit'. When evaluating epidemic progress, the interaction between trials was also significant as AUDPS average values were 63% higher in the second trial compared with the first (Table 2). In trial 1, AUDPS in cultivars Rhonda and Merlin was not significantly different between each other but reduced by 48.5% and 33.9%, respectively, compared with 'Bolder'. Moreover, AUDPS in cultivar Rhonda was not significantly different from 'Touchstone Gold'. AUDPS was not significantly different between the red cultivars, Detroit, Falcon, and Ruby Queen. In trial 2, AUDPS was similar across cultivars with no significant

Table 2. The effect of table beet cultivar on severity of cercospora leaf spot (CLS) following inoculation with *Cercospora beticola* isolate Tb14-085 in two trials conducted in the misting chamber.

Cultivar	CLS lesions (no./leaf) ^z		AUDPS ^y	
	Trial 1	Trial 2	Trial 1	Trial 2
Boldor	17.4 a ^x	28 a	147.1 a	282.3 a
Detroit	12.2 bc	16.6 ab	117 bc	151.8 cd
Falcon	14.9 ab	16.5 ab	141.1 ab	220 b
Merlin	10.5 bc	23.8 a	75.7 e	177.4 bc
Rhonda	8.7 c	18.2 ab	88.4 de	187.5 bc
Ruby Queen	14.5 ab	27.1 a	126.4 abc	195.4 bc
Touchstone Gold	13.8 ab	9.3 b	112.2 cd	106.8 d
LSD ^x	4.4	11.6	27.2	51.1
F	1.56	1.43	2.01	2.22
P	0.005	0.024	<0.001	<0.001
CV (%) ^w	14.1	22.2	12.1	12.5

^zAverage number of CLS lesions per leaf 17 d after inoculation. Total number of leaves varied between 7 and 10 leaves/plant.

^yArea under the disease progress stairs (Simko and Piepho, 2012).

^xMeans followed by the same letter within a column are not significantly different by a least significant difference (LSD) test at $P \leq 0.05$.

^wCoefficient of variation.

differences between 'Detroit', 'Merlin', 'Rhonda', and 'Ruby Queen' (Table 2).

In the field trial, the number of CLS lesions per leaf at the final assessment was significantly lower in cultivar Ruby Queen than other cultivars, and not significantly different between 'Detroit', 'Falcon', 'Rhonda', and 'Merlin' (Table 3). For example, the number of CLS lesions in cultivar Ruby Queen was 43.3% lower compared with 'Falcon'. The number of lesions was not significantly different between either of the yellow cultivars, Boldor and Touchstone Gold (Figs. 1 and 2). Disease progress was also

significantly lower in 'Ruby Queen' than other cultivars and 41.6% lower in 'Ruby Queen' than 'Rhonda'. Moreover, AUDPS in 'Rhonda' was significantly higher than the other red cultivars. For example, AUDPS in cultivar Rhonda was higher by 23.7%, 13.9%, 34.7%, and 71.4% compared with 'Detroit', 'Falcon', 'Merlin', and 'Ruby Queen', respectively. AUDPS between the yellow cultivars was not significantly different but was on average 21.5% lower than in 'Rhonda' (Table 3).

Cultivar differences in CLS susceptibility when comparing the

number of CLS lesions per leaf and AUDPS may reflect variation in disease progression on a leaf scale, which has also been suggested in sugar beet (Skaracis and Biancardi, 2000). For example, in cultivar Ruby Queen lesions remained small and discrete, but in 'Touchstone Gold' and 'Boldor', lesions expanded and coalesced leading to increased disease severity. Averaged over 30 leaves, lesion size was also significantly ($P = 0.01$) greater in 'Rhonda' and 'Falcon' (mean = 3.6 cm, SD = 0.6 cm) than in 'Ruby Queen' (mean = 1.1 cm, SD = 0.3 cm). Minor variation in cultivar

Table 3. Table beet cultivar susceptibility to cercospora leaf spot (CLS) and effect of cultivar on the fresh and dry weight of foliage and average leaf dimensions tested in a small-plot, replicated trial conducted at Geneva, NY in 2016.

Cultivar	CLS lesions (no./leaf) ^z	AUDPS ^y	Foliage fresh wt (g·m ⁻¹) ^x		Foliage dry wt (g·m ⁻¹)		Leaf length (cm) ^x	Leaf width (cm)	Leaf length : width ratio
			77 DAP ^x	112 DAP	77 DAP	112 DAP	112 DAP	112 DAP	112 DAP
Boldor	93 ab ^w	1,943 bc	2,100	572 d	242.1	128.9 c	15.5 ab	9.7	1.6 bc
Detroit	84 ab	1,914 bc	1,844	732 b	254.9	212.1 a	17.5 a	8.6	2.1 a
Falcon	97 a	2,078 b	2,136	640 c	246.9	153.9 bc	13.7 c	9.7	1.5 c
Merlin	96 a	1,758 c	2,680	636 c	314.9	154.5 bc	14.7 bc	8.9	1.7 bc
Rhonda	92 ab	2,368 a	1,952	588 d	238.9	142.0 c	12.9 c	7.4	1.8 b
Ruby Queen	55 c	1,382 d	2,596	868 a	267.1	195.9 ab	14.9 bc	9.1	1.8 b
Touchstone Gold	80 b	1,956 bc	2,420	636 c	315.8	162.2 abc	16.3 ab	8.9	1.9 a
LSD ^w	16	283	—	45	—	52.2	2.3	—	0.2
F	7.4	9.6	0.9	4.23	2.11	5.72	4.4	2.1	7.7
P	<0.001	<0.001	0.102 (ns)	0.045	0.089 (ns)	0.037	0.004	0.098 (ns)	<0.001
CV (%) ^v	14.2	11.3	42.1	21.2	37.9	24.3	10.9	12.6	8.6

^zAverage number of CLS lesions per leaf at 93 d after planting.

^yArea under the disease progress stairs (Simko and Piepho, 2012).

^x1 g·m⁻¹ = 0.0108 oz/ft, DAP = days after planting, 1 cm = 0.3937 inch.

^wMeans followed by the same letter within a column are not significantly different by a least significant difference (LSD) test at $P \leq 0.05$.

^vCoefficient of variation.

Fig. 1. Temporal progression of cercospora leaf spot (CLS) epidemics according to the cultivar in a replicated field trial conducted at Geneva, NY, in 2016. (A) Yellow cultivars (Touchstone Gold and Boldor) compared with processing cultivar standard (Ruby Queen); (B) Ruby Queen compared with other red cultivars, Detroit, Rhonda, Falcon, and Merlin; error bars = SE.

Fig. 2. *Cercospora* leaf spot (CLS) symptoms in table beet cultivars [(A) Boldor, (B) Rhonda, (C) Detroit, (D) Falcon, (E) Ruby Queen, (F) Touchstone Gold] following inoculation with *Cercospora beticola* isolates representative of the population in New York.

susceptibility rankings between trials in the misting chamber and field may be attributed to a range of factors. Temperature and relative humidity in the misting chamber trials were highly conducive to infection and disease development, whereas in the field, environmental conditions varied and included sporadic irrigation to promote disease spread. In all trials, plants were inoculated at similar leaf stages (42–48 DAP). The inoculum used for the misting chamber trials consisted of a single representative isolate, whereas the field trial

inoculum consisted of a mixture of isolates (Vaghefi et al., 2016). Variation in virulence between *C. beticola* isolates infecting sugar beet has been reported (Ruppel, 1972; Solel and Wahl, 1971). No information is available on variation in virulence between isolates on table beet in New York but may be substantial considering the high genotypic diversity within populations (Bolton et al., 2012; Groenewald et al., 2008; Moretti et al., 2004; Vaghefi et al., 2016, 2017a, 2017b).

Preliminary information on CLS susceptibility in table beet cultivars grown in New York indicated that ‘Touchstone Gold’ and the red cultivar Bull’s Blood were more resistant than ‘Early Wonder Tall Top’. This study relied upon naturally occurring inoculum and used disease severity to estimate disease progress rather than the number of lesions per leaf (Lange et al., 2015). By contrast, under high disease pressure resulting from homogeneously applied inoculum with isolates representative of the genetic diversity of the New York population

in the current study, the susceptibility of the yellow cultivars was similar to the selected red with the exception of 'Ruby Queen'. 'Ruby Queen' is the predominant cultivar used by the processing table beet industry in New York (J.L. Johnson, personal communication). Reduced susceptibility of 'Touchstone Gold' to CLS compared with 'Detroit' and 'Ruby Queen' has been reported in previous studies in Florida where the epidemic resulted from natural inoculum from an adjacent field and had generally low disease severity [$\leq 20.3\%$ (Raid et al., 2013a, 2013b)].

A significant negative association was described between canopy reflectance at 830 nm and AUDPS ($r = -0.36$, $P = 0.017$) and the number of CLS lesions per leaf at the final disease assessment ($r = -0.65$, $P < 0.001$). Conversely, there was a significant, positive linear relationship between canopy reflectance at 830 nm and the dry weight of foliage ($r = 0.56$, $P < 0.001$). The utility of canopy reflectance in the near IR as an alternative to quantifying CLS severity has also been tested in sugar beet (Steddom et al., 2005). In the CLS-sugar beet study, canopy near IR reflectance was measured using a device (MSR16, CropScan) similar to the MRS5. In sugar beet, this method improved the precision of CLS severity estimation (Steddom et al., 2005) compared with the use of the industry-standard Kleinwanzleber Saat-zucht diagrammatic scale on a plot basis (Kleinwanzleber

Saat-zucht Ag. Einbeck, 1970). In table beet, CLS severity has been assessed by counting lesions on multiple leaves to obtain an average on a plot scale (Abawi et al., 2005). The significant association between canopy reflectance at 830 nm and the dry weight of foliage also suggests this technique may be a reliable and rapid method for remote estimation of biomass and plant health in table beet research. The relationships between growth and yield and amount of intercepted radiation has been well documented (e.g., Nilsson, 1995) and used for plant health assessment in many agricultural crops (e.g., Kobayashi et al., 2001; Nutter, 1989; Pethybridge et al., 2008).

The significant cultivar differences in the number of CLS lesions per leaf did not translate to significant differences in the fresh and dry weights of foliage at 77 DAP (Table 3). Significant differences between cultivars in fresh and dry weights of foliage at 112 DAP were reflective of cultivar differences based on AUDPS. For example, the dry weight of foliage in cultivar Rhonda was 27.4% lower than in 'Ruby Queen', and was not significantly different to 'Detroit'. The dry weight of foliage at 112 DAP was not significantly different between the yellow cultivars (Touchstone Gold and Boldor), Falcon and Merlin (Table 3). Significant cultivar variation in the dry weight of foliage at 112 DAP was not reflective of differences in CLS susceptibility.

Foliar biomass in fall was significantly higher in 'Detroit' than 'Rhonda' and 'Boldor'. Similarly, root biomass was significantly higher at 112 DAP in 'Detroit' and 'Ruby Queen' than 'Rhonda' and 'Boldor'. This suggests the former two cultivars may be more suitable for in-ground storage because of less deterioration (reduced biomass) to facilitate processing schedules and extend fresh product sales. The cultivars also differed significantly in leaf blade length and shape. For example, the leaf blade of 'Rhonda' was 26.1% shorter than 'Detroit' and did not significantly differ between the yellow cultivars nor 'Merlin' and 'Ruby Queen'. No significant differences were detected between cultivars in leaf width. Therefore, the significant differences between cultivars in leaf length led to effects on the length to width ratio (Table 3). This information may be important for fresh market growers considering the attractiveness of foliage for intact or separate sale in cultivar selection.

No significant differences were found among cultivars in the number of beets per unit row length at either harvest date. This is not surprising as CLS is not known to affect plant stand but was quantified as a potential covariate affecting foliar disease severity and horticultural characteristics. No significant differences were found among cultivars (Table 4). Root shoulder diameter and dry weight were not significantly different

Table 4. The effect of table beet cultivar on the number of roots per row length, dry weight of roots, the percentage of immature roots (< 0.5 inch shoulder diameter), and root shoulder diameter following inoculation with *Cercospora beticola* in a small-plot, replicated trial conducted at Geneva, NY, in 2016.

Cultivar	Beets (no./m) ^z		Root fresh wt (g·m ⁻¹) ^z		Root dry wt (g·m ⁻¹)		Immature roots (%)	Shoulder diam (cm) ^z
	77 DAP ^z	112 DAP	77 DAP	112 DAP	77 DAP	112 DAP	77 DAP	77 DAP
Boldor	66	59	1,196	1,113 cd	490.9	412.5 c	21	3.7
Detroit	43	46	1,904	1,721 a	1,020.5	677.8 a	13	4.3
Falcon	72	71	2,236	1,285 bc	1,241.9	492.5 bc	15	3.5
Merlin	66	61	2,164	1,149 bcd	1,098.6	463.5 bc	9	4.2
Rhonda	66	66	2,228	1,056 d	1,047.1	455.4 c	11	3.9
Ruby Queen	78	59	1,988	1,673 a	1,074.9	626.8 ab	13	3.6
Touchstone Gold	56	58	1,612	1,323 b	1,046.1	519.1 abc	22	3.4
LSD ^y	—	—	—	181	—	167	—	—
F	2.4	1.3	0.85	2.8	1.19	3.54	1.14	0.71
P	0.062 (ns)	0.299 (ns)	0.252 (ns)	0.043	0.341 (ns)	0.04	0.37 (ns)	0.65 (ns)
CV (%) ^x	25.5	25.7	52.1	21.2	58.3	24.3	67.5	22.2

^z1 beet/m = 0.3048 beet/ft, DAP = days after planting, 1 g·m⁻¹ = 0.0108 oz/ft, 1 cm = 0.3937 inch.

^yLSD = least significant difference ($P = 0.05$). Means followed by the same letter within a column are not significantly different.

^xCoefficient of variation.

between cultivars at 77 DAP. However, differences were detected at 112 DAP in root dry weight which were significantly higher in cultivar Detroit, than 'Rhonda' and 'Boldor'. The dry weight of roots was not significantly different among 'Boldor', 'Rhonda', and 'Touchstone Gold'. The average dry weight of roots at 112 DAP across cultivars was 47.5% lower than at first harvest (Table 4).

Conclusions

Popular table beet cultivars in New York included in this study were similarly susceptible to CLS when inoculated with local *C. beticola* isolates with the exception of the less susceptible 'Ruby Queen'. Significant positive associations between canopy reflectance at 830 nm and foliar biomass, and inversely the number of CLS lesions per leaf indicated this technique may have utility for remote estimation of these variables in table beet research. Significant cultivar differences were detected in foliar and root biomass upon in-ground storage to 112 DAP. Moreover, significant differences in leaf length and the length:width ratio may be informative for the selection of cultivars for fresh market sales in New York.

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