Canopy Temperature as a Correlative Measure for Assessing Host Response to Septoria tritici Blotch of Wheat

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ABSTRACT

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The relationships between canopy temperature measured by an infrared thermometer and the response to Septoria tritici blotch of 43, 31, and 33 cultivars of bread, durum, and triticale, respectively, were evaluated during 3 years in the field. Measurements of canopy temperatures at midday and the percent of pycnidia coverage were taken in *Septoria*-infected plots and in fungicide-protected plots on several dates after anthesis. Canopy temperatures increased with the increase in disease coverage and with the decrease in green leaf area. When canopy temperatures were recorded before maturity, and when cultivars varied in disease coverage, the correlations between the two variables ranged from $r = 0.48$ ($P = 0.01$) to $r = 0.74$ ($P = 0.01$), depending on year and date. The association between canopy temperature and disease coverage generally improved when evaluated within cultivars of similar phenology and maturity. Canopy temperatures were positively correlated with the area under the *Septoria* progress curve and with losses in kernel weight. Infrared thermometry of *Septoria*-infected wheat canopies can be used as a measure for estimating differences in cultivars' response to Septoria tritici blotch.

Septoria tritici blotch, incited in wheat by the fungus *Mycosphaerella graminicola* (Fuckel) Schroeter (anamorph: *Septoria tritici* Rob. ex Desm.), may impose severe limitations on wheat yields in several parts of the world (3,4). Under severe epidemics, some vulnerable wheat cultivars may suffer 30–50% reductions in yield, resulting in shriveled grains (3).

Morphological traits (plant height and canopy architecture), physiological traits (photoperiod and vernalization requirements), and growth habit all influence the expression of symptoms (chlorosis, necrosis, and pycnidial production). Differentiation in cultivar response to the pathogen is usually based on quantitative assessment of symptoms.

Leaf tissue necrosis and pycnidia coverage were linearly correlated with losses in yield components (3,6). Gaunt (6) argued that green leaf area, rather than diseased leaf tissues, should be used to estimate yield losses. Wheat cultivars of similar phenology may express differential yield responses under similar apparent disease severity and progress (19). Wheat cultivars may differ in the ability to endure (tolerate) severe epidemics without sustaining significant losses in yield, when compared with vulnerable (nontolerant) cultivars (19).

The measurement of transpirational cooling of leaves by remote infrared thermal sensing of crop canopies allowed the development of methodologies for assessing crop water stress for irrigation scheduling (8,9,14). The use of an infrared thermometer has been proposed as a tool in screening plant breeding materials for drought resistance (1,2,5,7,16).

Infrared canopy temperature measurement was also suggested for assessing biotic stresses (10–13,17,18). Reflectance measurements assessed by a multispectral radiometer and visual assessment of disease severity of peanut rust (*Puccinia arachidis*) and late leaf spot (*Cercosporidium personatum* (Berk. & Curtis) Deighton) were highly correlated for all gradients measured (10). Incidence, defoliation, and radiometer method systems provided the most accurate and precise estimates of leaf spot severity and also had the highest correlation with peanut yield (11). Highly significant positive correlations were obtained between percent of reflection of solar radiation and mean spot blotch (*Helminthosporium sativum* Pammel, King, & Bakke) and scald (*Rhynchosporium secalis* (Oudem.) J. Davis) on the upper three leaves of barley (12,13). Canopy temperature was initially reduced in diseased, as compared with nondiseased, plants as a consequence of an increase in transpiration in the diseased (e.g., rust) plants. However, this trend was reversed with the progression of infection (17), when canopy temperatures rose as a

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consequence of progressive leaf death. It was, therefore, hypothesized that the variation among wheat breeding germ plasm differing in response to Septoria tritici blotch could be assessed by the measurement of canopy temperature under disease epiphytotics.

MATERIALS AND METHODS

At the Bet-Dagan Experimental Farm, 43 and 31 cultivars of bread spring wheat (*Triticum aestivum* L.), durum (*T. durum* Desf.), and triticale (× *triticosecale*) were tested during 1985 and 1986, respectively. In 1987, 33 bread spring wheat and durum wheat cultivars were tested at Kibbutz Saad. Cultivars were chosen for their receptivity to *S. tritici* and their response in yield components to the disease.

Experimental design. A split-plot design was adopted in all trials. Infection by *S. tritici* was compared with uninfected, fungicide-protected treatments in main plots. Three applications of propiconazole (125 g a.i/ha) were given at 21-day intervals, starting when flag leaf was just visible (growth stage 40), at a rate of 100 L/ha at 1.5 psi with a motor-driven knapsack sprayer to which a boom was attached. Cultivars were sown as subtreatments in four replicates (blocks). Each plot was 2 × 5 m, planted at 15-cm row spacing.

Inoculation and assessment. Septoria tritici blotch epidemics were incited by weekly sprays of the canopy with a suspension of 10^7 conidia per milliliter of a mixture of five virulent Israeli isolates of *S. tritici*. Each isolate was grown separately in a liquid sucrose (3%) and yeast extract (0.5%) medium and rotated for 4–6 days at 18 C before application. Application of conidial suspension was initiated at the emergence of flag minus-2 leaf stage and terminated at the end of the milk stage of the late-maturing cultivars. Each plot received 150 ml of inoculum per inoculation. Inoculation was performed with a low-volume, low-pressure, Ulva 8 sprayer (Micron Co., Bromyard, England) during rainy days or dewy nights.

Assessment of percent of pycnidia and green leaf area on the four uppermost leaves was performed on 10 randomly selected plants per plot on each recording date. In all trials, recording started when the ear emerged to one-half of its length (growth stage 55) in the early maturing cultivars, and continued at about 10-day intervals. The last records were taken when grain filling reached early milk stage (growth stage 73) in the late-maturing cultivars. Mean pycnidial coverage and percent of green leaf area for the three to four recording intervals from midanthesis (growth stage 65) and 30 days afterwards were used for calculation of the area under progress curves for all cultivars, thus allowing the comparison between cultivars differing in maturity.

Canopy temperature. Measurements were performed within 0–4 days of the date of disease assessment. Temperature measurements were made as follows: two in 1985, four in 1986, and one in 1987. Measurements of foliage temperature were made about 1 hr after solar noon with a hand-held Everest Model 110 infrared thermometer (Everest Interscience Co., Fullerton, CA) with a 3-degree field of view, a spectral pass-band between 8 and 14 micron wavelength, a resolution of ±0.1 C, and a practical accuracy of ±0.5 C. The target area diameter was 55–65 cm in the center of the wheat plot. Air temperatures on all dates of measurement in the 3-yr trial ranged from 19.1 to 26.3 C.

Analysis of data. Area under the *Septoria* progress curve (AUSPC) was calculated for the 30 days past anthesis for each plot. Canopy temperature readings were standardized by calculation of the temperature of each plot in a block as the percent of the mean temperature of all plots in that block. All plots were combine-harvested and kernel weight was determined for evaluation of the effect of the disease on this yield component.

RESULTS AND DISCUSSION

High pycnidia coverages were recorded on the susceptible wheat cultivars in all-year trials. Area under the *Septoria* progress curve differed greatly among cultivars. However, for the most susceptible (e.g., Barkai) and the most

Table 1. Simple correlations across cultivars between canopy temperature (as percent of the block mean) in *Septoria*-infected plots and percent disease coverage, percent green leaf area in infected and control plots, days to anthesis, area under the *Septoria* progress curve, and percent kernel weight loss due to disease

Year	DAE[a]	Disease coverage[b] (%)	Green leaf area (infected) (%)	Green leaf area (control)[c] (%)	Days to anthesis	AUSPC[d]	Kernel weight loss (%)
1985	107	0.48**[e]	−0.51**	−0.42**	−0.49**	0.48**	0.39**
	145	0.57**	−0.39**	−0.26 ns[f]	−0.39**	0.53**	0.54**
1986	107	0.71**	−0.71**	−0.56**	−0.52**	0.53**	0.35 ns
	115	0.65**	−0.63**	−0.51**	−0.32**	0.52**	0.23 ns
	132	0.51**	−0.41*	−0.43*	−0.43*	0.40*	0.03 ns
	145	−0.05 ns	−0.28 ns	−0.38*	−0.51**	0.51**	0.40*
1987	130	0.74**	...	...	0.83**	0.62**	0.59**

[a]Days after emergence.
[b]Mean pycnidia coverage on the four uppermost leaves.
[c]Uninfected, fungicide-protected treatment (three applications with propiconazole).
[d]Area under *Septoria* progress curve for the 30-day interval past anthesis.
[e]* = Significant at $P = 0.05$ and ** = significant at 0.01.
[f]Not significant.

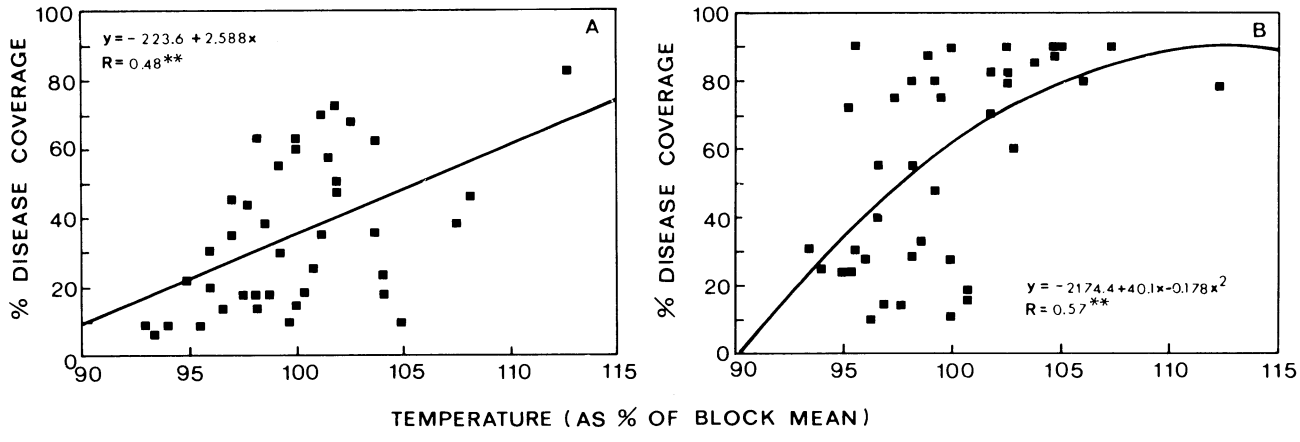

Fig. 1. The association across 43 cultivars between percent of disease coverage and canopy temperature (as percent of the block mean) in Septoria tritici blotch infected plots in a 1985 trial. At **(A)** 107 days after seedling emergence and **(B)** 145 days after seedling emergence.

resistant (e.g., Kvz-K4500.L.A.4) cultivars, differences in AUSPC were consistent over the years.

The relationship between canopy temperature (as percent of the block mean) and the parameters (mean pycnidia coverage on the four uppermost leaves; green leaf area in infected plots; green leaf area in uninfected, fungicide-protected control plots; days to anthesis; AUSPC; and percent loss in kernel weight due to disease) for several dates in the 3-yr trials is presented in Table 1.

In all the years of the study, canopy temperatures were positively correlated with percent of disease coverage across variable germ plasm. Although temperature measurement represented a transient situation for a given date of observation, the correlations (r) between canopy temperature for 107 and 145 days after emergence (DAE) across 43 cultivars in 1985 and disease coverage were 0.48 ($P = 0.01$) and 0.57 ($P = 0.01$), respectively (Fig. 1A,B). Similar correlations were found between canopy temperature and AUSPC ($r = 0.48$, $P = 0.01$ and $r = 0.53$, $P = 0.01$) for the same year (Table 1). Partition of data into early flowering (95–115 DAE) and late-flowering (116–130 DAE) cultivars improved the within-group correlations between canopy temperature and disease coverage. For example, the respective correlation coefficients for the early flowering group on 107 days was $r = 0.71$ ($P = 0.01$), compared with $r = 0.48$ ($P = 0.01$) for the pooled data (Fig. 1A). High correlations were obtained for 3 recording days (107, 115, and 132) in 1986 ($r = 0.71$, $P = 0.01$; $r = 0.65$, $P = 0.01$; and $r = 0.51$, $P = 0.01$, respectively). The association between canopy temperature and percent of disease coverage became stronger when evaluated within a group of cultivars of similar phenology. For example, the correlation coefficient between canopy temperature and percent of disease coverage across early cultivars only (anthesis 95–115 DAE) was 0.81 ($P = 0.01$), compared with 0.71 ($P = 0.01$) for all cultivars on the first assessment date. The correlation between temperature and percent of disease coverage for 145 days in this year was low and not significant. Similarly, low correlations were found for percent of green leaf area for that date. Apparently, the lack of correlation between canopy temperature and disease coverage on the last date (145 days) and the overall tendency of these correlations to weaken with time resulted, at least partly, from the progression of leaf senescence in all cultivars. The correlation across cultivars between canopy temperature and percent of disease coverage at 130 DAE in 1987 (a date at which all cultivars varied in the amount of percent of disease and green leaf area in infected plots) was as good as ($r = 0.72$, $P = 0.01$) (Fig. 2), or better than, the correlations obtained on a similar day in 1985 and 1986. The early maturing wheat cultivars, when compared with the late-maturing ones, tended to harbor high pycnidia coverage and sustain higher canopy temperatures (Fig. 2). The association between canopy temperature and disease coverage appeared to be relatively better in the late-maturing than in the early maturing cultivars (Fig. 2). The different behavior of the two groups of cultivars may be due to the natural plant senescence at the measurement date in the early maturing cultivars.

In all trials, the correlations between canopy temperature and AUSPC were

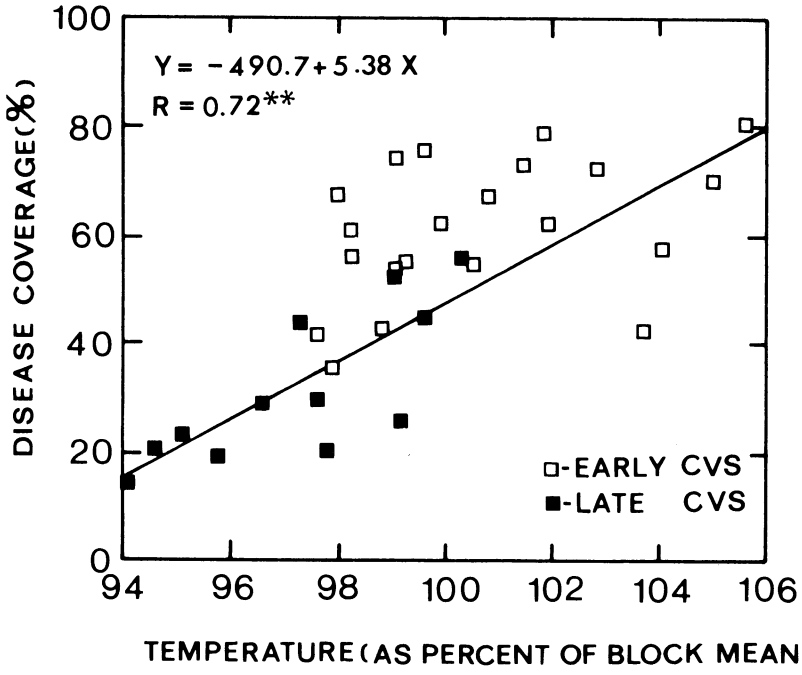

Fig. 2. The association across 33 cultivars between percent of disease coverage and canopy temperature (as percent of the block mean) in Septoria tritici blotch infected plots at 130 days after emergence in 1987. Late-maturing cultivars (■) (anthesis at 86–115 days after emergence) and early maturing cultivars (□) (anthesis at 73–85 days after emergence).

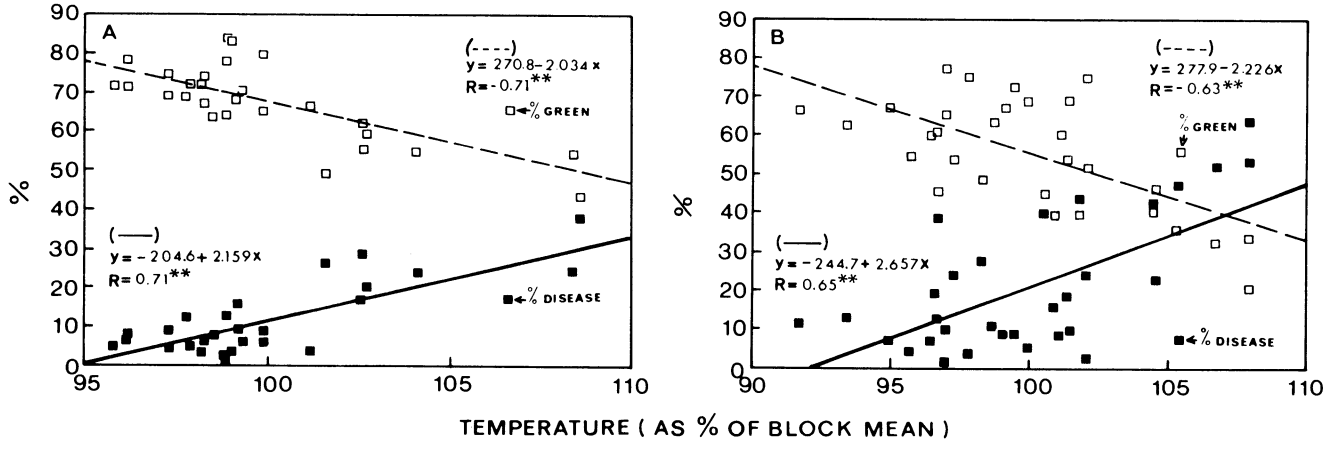

Fig. 3. The association across 31 cultivars between percent of disease coverage (■, dashed line), green leaf area in infected plots (□, solid line), and canopy temperature (as percent of the block mean) in Septoria tritici blotch infected plots in a 1986 trial. At **(A)** 107 days after seedling emergence and **(B)** 115 days after seedling emergence.

high, but slightly lower than percent of disease coverage. The use of the difference in temperature between *Septoria*-infected and uninfected control plots instead of canopy temperature in the infected plots did not improve the correlations.

Canopy temperature was negatively correlated with percent of green leaf area in infected plots (Table 1). The correlations between these two parameters in 1986 was reduced from $r = 0.71$ ($P = 0.01$) on 107 DAE to $r = 0.41$ ($P = 0.05$) on 132 DAE. The mean percent of green leaf area of all cultivars in the control plots decreased from 72.7% on the first date (107 days) to 19.4% at 145 DAE. Canopy temperatures in infected plots were negatively correlated with the green leaf area in these plots, with an $r = -0.71$ ($P = 0.01$) and $r = -0.63$ ($P = 0.01$) for 107 and 115 DAE, respectively (Fig. 3A,B). Canopy temperatures were positively correlated with percent of disease coverage on the same dates with correlation values of 0.71 ($P = 0.01$) and 0.65 ($P = 0.01$), respectively (Fig. 3A,B). It is of interest to note that the slope of the regression lines across cultivars for the relation of temperature-disease coverage and for temperature-green leaf area on each of the two dates was rather similar, though of a different sign, which indicates that in most cultivars the decrease in green leaf area in infected plots, especially in early recordings, is proportional to the increase in disease coverage. Canopy temperature, therefore, is an estimator of both disease coverage and green leaf area in infected plots. The rate of senescence and advanced necrotic host response to the pathogen strongly affects canopy greenness. Differences among cultivars in maturity and natural leaf senescence seem to be major intervening factors in assessing plant response by infrared thermometry in *Septoria*-infected accessions. It is apparent that infrared thermometry is sensitive to canopy greenness (11,15), irrespective of whether residual green leaf area results from lower disease coverage or lateness of maturity.

Loss of kernel weight under Septoria tritici blotch infection, which ranged in 1985 from 0 to 41.5% across cultivars, is a complex host response. It involves the effect of reduced viable leaf area by the disease during grain filling as well as the response to the disease in terms of stem reserve mobilization (16). Still, a significant positive association was revealed across all cultivars in 1985 on both 107 and 145 DAE between canopy temperature and percent of loss in kernel weight ($r = 0.39$, $P = 0.01$ and $r = 0.54$, $P = 0.01$, respectively) (Table 1). Only on the last date of measurement (145 DAE) was canopy temperature correlated with loss in kernel weight in the 1986 trial ($r = 0.40$, $P = 0.05$). The correlations between canopy temperature and percent of loss in kernel weight in 1987 were better ($r = 0.59$, $P = 0.01$) than any of those obtained in the previous years.

The results of this study suggest that infrared thermometry of *Septoria*-infected canopies of wheat can serve as a useful measure for predicting high residual green leaf area. Infrared thermometry cannot differentiate whether greenness results from low pycnidial coverage on cultivars of similar phenology or whether it is a result of a longer growth duration of a cultivar.

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