Survival of *Phytophthora infestans* in Potato Stem Lesions at High Temperatures and Implications for Disease Forecasting

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ABSTRACT

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The ability of *Phytophthora infestans* to produce sporangia in 7-day-old lesions in potato stems after exposure to constant temperatures of 30–40 C was examined. Constant 30 C temperature had no effect, but 32.5 C was lethal to some sporangia, and the rate of mortality increased with higher temperatures. The relationship between diminished survival and duration of temperature exposure was found, by regression analysis, to be best expressed by a negative exponent over time and varying with temperature. However, survival at 40 C appeared to decline linearly with time. These data indicate that the provision of BLITECAST (a computerized late blight forecasting system) that cancels infection periods when temperatures the following day are 30 C or above may need modification if the system is used in hot climates.

Additional key words: epidemiology

BLITECAST, a computerized system for forecasting potato late blight, has been successfully used commercially by The Pennsylvania State University throughout the northeastern United States since 1972 (4). Clearly, the system's structure and component criteria are satisfactory for that region; it realistically assesses the risk of epidemic losses. However, some evidence suggests that the system may be inaccurate in hot regions. Maximum temperature of 30 C or above on a day cancels all BLITECAST severity values registered for the previous day. In Israel (8), however, late blight progressed when daytime temperatures were 30–40 C; the viability of the pathogen (*Phytophthora infestans* Mont. de Bary) in 12-hr-old lesions was reduced by exposure to 30 C and above, but sporangial dispersal was greater on hot dry days than on cool humid days. Increased dispersal could explain the greater epidemic progress during daytime temperatures of 30–40 C. The workers in Israel (8) suggested that the rate of epidemic development in periods of elevated daytime temperatures depends on the net outcome between increased dispersal and decreased survival, and they found that epidemic progress ceases when daytime temperatures reach about 40 C.

To forecast late blight progress reliably in regions with high daytime temperatures, it is desirable to have quantitative information on the effects of temperature on survival of *P. infestans*. The present study was undertaken to provide information on the effects of high temperatures on survival of *P. infestans* in stem lesions. Stem lesions are a major source of persistent inoculum and are thought (2,8) to play an important role in epidemics. The temperature sensitivity of *P. infestans* in stem lesions undoubtedly affects progress of late blight epidemic in hot weather.

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MATERIALS AND METHODS

Production of stem lesions. Potatoes (*Solanum tuberosum* L. 'Kennebec') were grown in 25-cm-diameter plastic pots in a greenhouse (13–24 C). Two tubers were planted per pot and an average of 18 stems allowed to develop. Stems were inoculated after 8–12 wk growth.

The isolate of *P. infestans* used was identified as race 1,2,3,4 and was cultured from the potato cultivar Abnaki by R. J. Young of The University of West Virginia. It was maintained by routine transfer on lima bean agar (3) at 14-day intervals. Suspensions of zoospores and sporangia were injected by hypodermic syringe into the central stem cavity in an internode. An initial puncture was made about 2 cm from each injection point to permit inoculum to flow into the stem cavity. One inoculation was made per stem of each test plant. Necrotic lesions appeared 3–4 days after inoculation. Lesion growth ceased 6–7 days after

Table 1. Linear regression models for the survival (S)[a] of *Phytophthora infestans* in 7-day-old potato stem lesions in relation to the duration of exposure (t, in hours) to constant high temperatures

Temperature (C)	Regression model	Coefficient of determination (%)
30	$\log_{10} S = 2.0 + 0.01 \log_{10} t$	0.0
32.5	$\log_{10} S = 2.0 - 0.30 \log_{10} t$	90.8
35	$\log_{10} S = 1.9 - 0.76 \log_{10} t$	93.5
37.5	$\log_{10} S = 2.1 - 1.00 \log_{10} t$	98.6
40	$S = 89.6 - 9.26\ t$	71.0

[a]S = Sporangia production is expressed as a percentage of check lesions that were not exposed to high constant temperature.

Table 2. Effect of constant high temperatures on the survival of *Phytophthora infestans* in potato stem lesions[a]

Temperature (C)	Hours required to reduce production of sporangia by:	
	50%	95%
30	No effect	No effect
32.5	10	long
35	2	41
37.5	2	23
40	4	9

[a]Reduction in capacity to produce sporangia was used as the measure of the effect of high temperatures on *P. infestans* stem lesions.

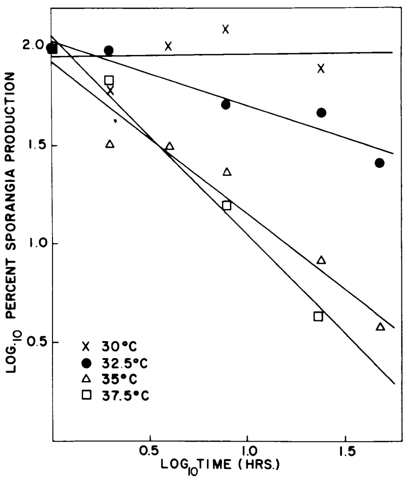

Fig. 1. Influence of constant ambient temperatures of 30–37.5 C on survival of *Phytophthora infestans* in 7-day-old potato stem lesions as measured by sporangia production from lesions after temperature exposure.

inoculation, though often some stem tissue distal to lesions collapsed after the seventh day. The length of lesions was relatively uniform (6–8 cm).

The plants were kept in the glasshouse for 7 days after inoculation before temperature treatments. Preliminary work had established that 7 days was necessary for lesions to reach their maximum capacity as inoculum sources.

Exposure to high temperatures. Seven days after inoculation the potted potato plants were exposed to constant air temperatures ranging from 30 to 40 C in a controlled environment cabinet. Relative humidity was 70–80% and lighting was on a cycle of 12 hr light and 12 hr dark. Each experimental exposure began with a light period. Pots were removed from the cabinet at intervals of 2–48 hr and returned to the greenhouse.

Survival of *P. infestans* in lesions. The ability of the stem lesions to produce sporangia relative to similar lesions not exposed to high temperatures was used to measure survival of *P. infestans* in lesions. Eighteen sections of stems, with one lesion for each temperature treatment, were excised and placed in moist chambers in a cyclic photoperiod incubator at 18–20 C for 18 hr to induce sporulation. The incubator was illuminated during the first 6 hr of this period; the remaining 12 hr were in darkness. After incubation, the lesions from each temperature treatment were bulked and washed in distilled water, and the number of sporangia produced per lesion was calculated from hemocytometer slide counts. Production of sporangia on temperature-exposed lesions was expressed as a percentage of production on nonexposed lesions.

The relationship of duration of exposure to percent sporangia production at each temperature was examined by regression analysis. Several data transformations were tested. The best regression models were used to estimate the duration of exposure to constant high temperatures needed to reduce production of sporangia by 50 and 95%.

RESULTS

Sporangial production of *P. infestans* in 7-day-old potato stem lesions was not affected by exposure to a constant temperature of 30 C but was progressively less with increasing temperatures above 32.5 C (Fig. 1). The equation $S = at^{-b}$ best explained the data at 32.5, 35, and 37.5 C, where S is the production of sporangia expressed as a percent of that from lesions not exposed to the high constant temperature, t is hours of exposure to the constant high temperature, a is a scaling factor and $-b$ is a negative exponent (Table 1, Fig. 1). All transformations tested were unsatisfactory at 40 C, with survival of *P. infestans* appearing to decline linearly with time (Table 1). Ten hours at 32.5 C were required to reduce production of sporangia from stem lesions by half, but the time needed for this reduction dropped sharply to 2 hr at 35 C. The time required to reduce production of sporangia by 95% was much longer, decreasing from 41 hr at 35 C to 9 hr at 40 C (Table 2).

DISCUSSION

The success of BLITECAST in the northeastern United States remains unquestioned. The benefits to commercial potato growers in reduced applications of fungicide sprays attest to the value of the program. The provision of BLITECAST that calls for the cancellation of severity values for the previous day when the maximum temperature exceeds 30 C is not important in the northeastern United States. The relatively rare occurrence of high temperatures in this region causes rare use of this provision. This, it now appears, is fortunate.

The success of BLITECAST has increased interest in its application to other potato-producing regions of the world. There is reason to be concerned that, if BLITECAST were used in a region of high temperatures, spray recommendations could be imperfect as a direct result of the cancellation of severity values during periods of high temperature (ie, greater than 30 C). Based on our findings and those of others (1,2,5–10), we have concluded that to continue the high temperature provision of the original BLITECAST is an unnecessary risk.

We urge those who now have FORTRAN programs of BLITECAST in the original Pennsylvania State University form to remove the provision for severity value cancellation by high temperature from the program. Anyone wishing assistance in this programming change should contact the second author of this paper.

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