The Role of Solar Radiation, Especially Ultraviolet, in the Mortality of Fungal Spores

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ABSTRACT

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Spores of *Peronospora tabacina, Uromyces phaseoli*, and *Alternaria solani* were exposed in the field either to full sunlight or were partially protected from the sun by a leaf, cheesecloth, or an ultraviolet filter. The fungicidal effect of long wavelength (above 290 nm) UV radiation on mortality increased from *A. solani* to *U. phaseoli* to *P. tabacina*. Sporangia of *P. tabacina* survived better when attached to sporangiophores than when detached. Temperature was an important factor in mortality of detached, but not of attached, sporangia of *P. tabacina*. Spores of *A. solani* were killed after 5 days of exposure to a total of about 5.5 $MJ \cdot m^{-2}$ of long wavelength UV radiation. Their mortality was not affected by temperature. Spores of *U. phaseoli* were more susceptible to UV than those of *A. solani* and their mortality was also affected by temperature. In both cases, more spores survived in samples shaded by cheesecloth, by a leaf, or protected by UV filters than in samples exposed directly to sunlight. The fact that the temperature in samples under the UV filters was higher than in samples exposed directly to sunlight, indicates that UV radiation rather than increased temperature was the main factor causing mortality. Compared to data published on survival of spores of *P. tabacina, U. phaseoli*, and *A. solani* in the laboratory, exposure to sunlight shortened their longevity by 6 to 30 times. It was concluded that solar radiation in general, and its UV portion in particular, is a major factor in mortality. Doses of long wavelength UV needed to kill spores in the open were about 10^3 times greater than the dosage of short wavelength (254 nm) UV radiation required to kill them in the laboratory.

Additional key word: epidemiology.

Dispersal of inoculum has been studied widely but survival of the dispersed spores has not. As succinctly stated by Waggoner (21) "all the words about the aerial dispersal of plant pathogens are wasted if the propagules are dead on arrival." Most studies on survival have been done in the laboratory and have concerned the effects of temperature, humidity, and germicidal short-wavelength (250–270 nm) ultraviolet (UV) radiation (13,17,18). These short wavelengths are practically absent in radiation reaching the earth's surface. Although long wavelength UV (above 290 nm) is present in sunlight, it has a much smaller effect on spore mortality than germicidal UV (4). Therefore, it is not clear whether ultraviolet radiation is a significant factor in the survival of fungi in nature.

Numerous observations have pointed to increased development of diseases in cloudy versus sunny weather (e.g., 20), lower intensity of solar radiation (e.g., 15), and in sites shaded during part of the day (e.g., 11). Duration of sunshine and the level of cloudiness have been incorporated into disease forecasting criteria (19,20). However, sunny weather is associated with increased temperatures and decreased humidity, and the relative inhibition of diseases in such weather may result from a combination of several factors. It is also not clear whether such an inhibition results from the effect of the environmental factors on survival of inoculum or from inhibition of other stages of the pathogen's life cycle. Caesar and Pearson (5) found that sunlight, and its UV portion in particular, diminished survival of ascospores of *Sclerotinia sclerotiorum* but considered temperature to be the main factor in mortality. Bashi and Aylor (2) found that solar radiation (SR) was a dominant factor in survival of detached sporangia of *Peronospora destructor* and *P. tabacina*. However, downy mildew pathogens are, in general, more sensitive to environmental conditions than many others. The question remains whether SR may effectively suppress the survival of species that are generally resistant to extremes of temperature and humidity. It is also unclear whether the effect of SR is directly exerted on the pathogen or acts through increasing temperature. This indirect action of SR has been suggested in the potato late blight system in hot semidesert conditions (15) but is less likely in temperate climates, especially for fungi resistant to high temperatures.

In this work we studied the effect of solar radiation, its UV portion, and temperature on survival of detached and attached spores of three fungal species that differ in their survival potential in general and susceptibility to high temperatures in particular. The species tested were the relatively sensitive *Peronospora tabacina* Adam (1,8), the relatively resistant *Uromyces phaseoli* (Reb.) Wint. var. *typica* Arthur (16), and the extremely resistant *Alternaria solani* (Ell and Mart.) Sor. (14).

MATERIALS AND METHODS

Field trials with *P. tabacina*. *Peronospora tabacina* was maintained on 10-wk-old tobacco plants (*Nicotiana tabacum* L. 'Connecticut Broadleaf'). The plants, grown in a greenhouse, were inoculated and kept first in dew chambers for 24 hr at 20 C, then in a growth chamber at 20 ±1 C and a 14-hr photoperiod, until chlorotic-necrotic lesions developed. Plants with lesions were placed in dew chambers and sporangia were produced within 24 hr. Plants with sporangia were removed from the dew chambers and left in a room for 1 hr to dry the leaves before exposing the sporangia to factors affecting their survival. Drying the leaves did not induce a visible decrease of the numbers of sporangia present.

All or some of the following treatments were applied: sporangia exposed directly to the sun (S treatment), sporangia shielded from direct sun by four layers of cheesecloth (CH treatment), sporangia shielded from direct sun by a tobacco leaf (L treatment), and sporangia protected from the UV content of direct sunlight by barrier filters (F treatment). The UV filters were lenses of UV spectacles (Catalogue no. 11-403; Fisher Scientific Co., Pittsburgh, PA 15219) that transmit zero percent UV in the range from 210 to 405 nm. These treatments were made either with sporangia still attached to their sporangiophores or with sporangia detached and transferred onto 47-mm-diameter membrane filters by gently touching the sporangia-laden leaves with the filters.

To eliminate shading by other leaves, only one leaf with sporangia was left on each test plant. The sporangia, which form primarily on the abaxial leaf surface, were exposed to the S treatment by fixing the leaves in an inverted position. For

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sporangia protected from sunlight by the L treatment, sporangia-bearing leaves were left right side up. To secure the maximum dose of irradiation, the leaf surface was held in a fixed position approximately perpendicular to the sun's rays. The position of leaves was frequently corrected as the position of the sun changed. Protection of sporangia by the CH treatment or by the F treatment was achieved as follows. The bottom part of a 15 × 55-mm plastic petri dish was cut to form a 15-mm-high cylinder 55 mm in diameter. Holes were made in the cylinder to allow ventilation, and a cheesecloth or UV filter was attached to one end. The tobacco leaf was inverted, and the cylinder was clamped on the side facing the sun. The exposures to sunlight were made from 1100 to 1400 hours during 9 days in August–September 1983 and were considered as nine replicates of the same experiment.

Mortality of spores was estimated according to the proportion of spores that failed to germinate after termination of exposures to environmental conditions. The detached sporangia on membrane filters were transferred to petri dishes filled with water agar for germination testing. In tests with attached sporangia, these were transferred onto membrane filters and incubated as were the others. Controls for differences in initial germination were sporangia on membrane filters placed on water agar in petri dishes without any exposure to radiation. According to our experience with *P. tabacina*, as well as *A. solani* and *U. phaseoli*, the loss of germinability is a proper indicator of the death of spores. The possibility of dormancy for these spores was not observed by us, and, as far as we are aware, has not been reported in the literature. Germinating sporangia were counted in samples of 400 per treatment after 18 hr of incubation at 20 C in the dark.

Field trials with *U. phaseoli* and *A. solani*. Twelve-day old bean plants (*Phaseolus vulgaris* L. 'Pinto') were inoculated with urediospores of *U. phaseoli*. Newly formed urediospores were collected 10 days later, stored at −15 C, and used when needed. For exposure to sunlight, urediospores were dropped onto membrane filters through a set of two sieves, as described by Imhoff et al (9). This method prevented clumps of spores from settling on the filters. All tests were done with detached urediospores. Membrane filters with spores were attached to 12 × 36-cm plastic screens stretched over wooden frames. Some samples received the S treatment. Other samples either received the CH treatment, the F treatment, or were attached to 12 × 12-cm screens and frames and received the L treatment, as described for *P. tabacina*. All samples were oriented perpendicular to the sun's rays and their alignment was periodically corrected during 8–9.5 hr of exposure. During these periods, other samples of spores were kept in dark incubators at 30, 35, and 40 C. After exposure, the spores were transferred to water agar and incubated for 16 hr at 20 C in darkness. The controls for differences in initial germination consisted of spores transferred to water agar for germination without exposure to radiation. Evaluation of mortality was done by counting the percentage of germinating spores in samples of 400 per treatment. The experiment was repeated on 12 different days.

Conidia of *A. solani* were produced on filter papers as described elsewhere (12). Filter papers with spores were dried, stored at 2 C, and used when needed. For S treatment, spores of *A. solani* were transferred to membrane filters with a camel's-hair brush. All other techniques were as described for *U. phaseoli*.

Mortality following exposure for 1–5 days was tested for *A. solani* and *U. phaseoli* with several sets of spore samples exposed to the same treatments. After each day, one set of samples was removed from further exposures and tested for germination. Other sets were stored overnight at 2 C, then exposed for the next day outdoors and to high temperatures in the laboratory.

Meteorological measurements in the field. The temperature of the membrane filter with spores or leaf surface was determined with an Omega 871 digital thermometer with a type K thermocouple (Omega Engineering Inc. Stamford, CT 06907). The sum of hourly measurements (*P. tabacina*) or two-hourly measurements (other species) was divided by the number of hours and given as mean temperature for the exposure period.

SR in watts per square meter was measured with a pyranometer (LI 200SB, LI-COR Inc., Lincoln, NE 68504). The long wavelength (above 290 nm) UV component of SR was measured in watts per square meter with a UV radiometer (Eppley Labs Inc., Newport, RI 02840). Irradiance measurements were made at a station located about 11 km from the experimental site. The same environmental conditions prevailed at both sites. Most experiments were done on days with high barometric pressure with either none or few clouds of the cumulus type. Alto-stratus and (rarely) stratus clouds extending over both sites reduced radiation on some days. Both SR and UV sensors were oriented to measure the irradiance on a horizontal surface. The output of the sensors was sampled at 10-sec intervals, averaged for 1 hr, and recorded by a data logger. The measurements were converted to irradiances on a surface perpendicular to the sun by using the mathematical methods described in detail by Gates (7). Irradiances on surfaces protected by a UV filter, a tobacco leaf, or four layers of cheesecloth were measured with the Eppley and LI-COR radiometers and calculated according to formulae based on attenuation of UV and SR by these materials. The F, L, and CH treatments reduced SR by 10, 72, and 70%, and UV by 100, 99, and 98%, respectively.

Laboratory experiments. Attached and/or detached spores of *A. solani*, *U. phaseoli*, and *P. tabacina* were irradiated at constant temperature with short wavelength (254 nm) UV radiation from a 15-W germicidal lamp (model G15T8; General Electric). Irradiance was 5.2 $W \cdot m^{-2}$ (measured with the J-225 meter from Ultra-violet Products Inc., San Gabriel, CA).

Analysis of data. For experiments done on different days with different batches of spores, the initial germination varied. To facilitate comparison of experiments, we equated the initial germination of spores to 100% and calculated the values of the other treatments accordingly. Analysis of variance and Duncan's new multiple range test were used to detect significant differences between treatments. In addition, relationships between survival of spores and doses of radiation were calculated by using linear regression analyses for the single-day tests.

RESULTS

Exposure to sunlight. *Single-day tests.* The mean temperature and dose (irradiance × time) for all days of exposure in various treatments are given in Table 1 in rows called "8-hr exposure" (*A. solani* and *U. phaseoli*) and "3-hr exposure" (*P. tabacina*). For each fungus, the lowest and highest temperatures were in samples that received the L and F treatments, respectively. Doses of UV were reduced to trace amounts by the leaf and cheesecloth and to zero by the filter. Doses of SR were reduced by about 70% by the leaf and cheesecloth and by only about 10% by the filter.

Fig. 1 shows results obtained with the L, F, and S treatments. Initial germination was equated to 100% and the percentage of germination of sporangia in the treatments were calculated on the 100% basis. The CH treatments and samples exposed in dark incubators to 30, 35, and 40 C are not included. Spores of *A. solani* were the most resistant and sporangia of *P. tabacina* were least resistant to SR. With *A. solani*, only full sun increased mortality significantly. No significant differences existed between other treatments, or between treatments not included in Fig. 1 (viz., control samples, those that received CH treatment, and those kept in darkness in the laboratory at up to 40 C).

Urediospores of *U. phaseoli* were moderately resistant. Again, only treatment S decreased survival significantly. No significant differences were found between controls and L treatments, or between controls and the F treatment despite the much higher surface temperatures created by the UV filters. In the laboratory, however, the survival of samples exposed to 40 C was slightly, but significantly, lower than that of the controls.

Detached sporangia of *P. tabacina* were the most sensitive and germination was reduced significantly by all treatments. The high temperature under the UV filter (Table 1) seemed to affect mortality. Nevertheless, the S treatment samples with average temperatures of 32.1 C, but exposed to full effects of UV, germinated much less than the F treatment samples protected from UV but heated up to 37.3 C (Table 1). Attached sporangia of *P. tabacina* survived significantly better than detached ones. With

attached sporangia, no significant differences were found between controls and the L and F treatments and only survival of sporangia directly exposed to the sun (S) was reduced significantly. Thus, under conditions of our trials, we did not find effects of temperature on survival of attached sporangia.

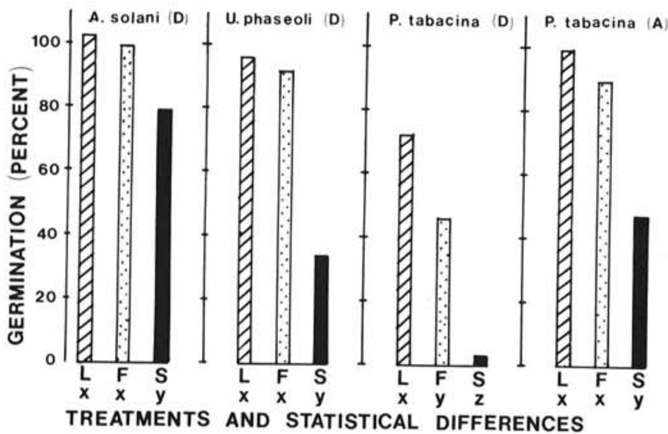

Fig. 1. Survival of detached (D) spores of *Alternaria solani* and *Uromyces phaseoli* exposed to sunlight for 8 hr. The letter S indicates samples exposed directly to sun, and F and L indicate samples protected from direct sunlight by UV filter and a tobacco leaf, respectively. Survival of attached (A) and detached (D) sporangia of *Peronospora tabacina* similarly exposed to sunlight for 3 hr. The data represented are the means of 11, 12, and 9 daily exposures for *A. solani*, *U. phaseoli*, and *P. tabacina*, respectively. Controls were spores incubated on water agar without previous exposure to sun. Their rate of germination was equated to 100% and the percentage of germination in other treatments was calculated accordingly. Treatments referenced by the same letter (x, y, or z) are not significantly ($P = 0.05$) different.

Linear regression analysis for 1-day tests indicated a relationship between mortality and dose of long wavelength UV radiation for all fungi tested, but the degree of correlation varied. The regression was best for *U. phaseoli* ($r^2 = 0.87$), intermediate for *A. solani* ($r^2 = 0.62$), and poorest for *P. tabacina* ($r^2 = 0.41$ for detached and $r^2 = 0.30$ for attached sporangia). In all cases, the slopes of the regression lines were significant. Mortality was very poorly correlated ($r^2 < 0.1$) with temperature in every case. The results of the several-day tests presented below indicate that the relationship between mortality and UV is probably nonlinear and we must be cautious in interpreting the results of linear regression analysis. Therefore, we have not presented the values of the slopes and intercepts but only use the regression analysis as a measure (along with Fig. 1) of the effect of UV on mortality.

Several-day tests. The average temperatures and doses of radiation for *A. solani* and *U. phaseoli* exposed for several days are shown in Table 2. The daily radiation and temperatures were higher in the trials with *U. phaseoli* which were made in mid-August than for the trials with *A. solani* which were made in October. Fig. 2A shows results obtained with *A. solani* exposed to various treatments for a total of 40 hr (8 hr/day for 5 days). Only in treatment S was survival of spores reduced significantly. Despite higher temperatures under the UV filters, treatment F and samples exposed daily to high temperatures in the laboratory were not affected.

Spores of *Uromyces phaseoli* were exposed for 9.5 hr/day for 4 days (38 hr total). Germinability of the S treatment samples declined to near zero after a 2-day (19 hr) exposure. Survival in samples exposed to 40 C in the laboratory also was reduced significantly, as was survival in the F, L, and CH treatments (Fig. 2B, CH treatment not included).

Germinability of the samples of spores from the "several-day tests" experiments and of *P. tabacina* from the "single-day exposure" are plotted against UV doses (Fig. 3A) and show

TABLE 1. Average temperature and accumulative doses of solar radiation (SR) and the ultraviolet (UV) part of SR measured or calculated in experimental treatment[a] to measure the mortality of fungal spores during single-day tests

Fungus	Temperature[b] (C) in treatments:				SR[c] (dose in $MJ \cdot m^{-2}$) in treatments:				UV[c] (dose in $MJ \cdot m^{-2}$) in treatments:			
	S	L	F	CH	S	L	F	CH	S	L	F	CH
A. solani	34.5	31.2	36.1	33.6	(15.5) 18.6	5.2	16.7	5.6	(1.1) 1.3	0.01	0	0.02
U. phaseoli	34.8	31.0	36.5	34.3	(17.2) 20.1	5.6	18.1	6.0	(1.2) 1.4	0.01	0	0.02
P. tabacina	32.1	29.3	37.3		(6.6) 8.6	2.4	7.8		(0.4) 0.5	0.003	0	

[a]Treatments: S for samples directly exposed to sun, L for samples under the leaf, F for samples under a UV filter, and CH for samples shaded by four layers of cheesecloth.

[b]For calculation of mean temperatures see section Materials and Methods.

[c]Dosages of SR and UV in $MJ \cdot m^{-2}$ (ie, irradiance times length of exposure specific for each fungus). *Alternaria solani* and *Uromyces phaseoli* spores were exposed for 8 hr/day and repeated on 11 and 12 days, respectively, and *Peronospora tabacina* spores were exposed for 3 hr/day and repeated on 9 days. SR and UV data in parentheses are those measured with sensors oriented to measure irradiance on a horizontal surface. SR and UV data without parentheses are those calculated for samples of spores kept perpendicular to the sun.

TABLE 2. Average temperature and accumulative doses of solar radiation (SR) and the ultraviolet (UV) part of SR measured or calculated in experimental treatment[a] to measure the mortality of fungal spores during several-day tests

Fungus	Days	Temperature[a] (C) in treatments				SR[c] (dose in $MJ \cdot m^{-2}$) in treatments				UV[c] (dose in $MJ \cdot m^{-2}$) in treatments			
		S	L	F	CH	S	L	F	CH	S	L	F	CH
A. solani	1	32.5	28.8	35.8		(4.1) 7.1	2.0	6.4		(0.2) 0.4	0.04	0	
	2	32.1	28.2	34.9		(16.0) 26.6	7.4	24.0		(0.9) 1.6	0.05	0	
	3	28.2	26.3	29.6		(21.1) 34.6	9.7	31.0		(1.1) 2.0	0.06	0	
	4	30.1	25.8	32.2		(36.5) 60.6	17.0	54.5		(2.1) 3.7	0.08	0	
	5	25.0	23.4	29.0		(54.3) 87.3	24.5	78.6		(3.1) 5.5	0.11	0	
U. phaseoli	1	33.7	27.3	35.4	33.0	(19.9) 25.9	7.2	23.3	7.8	(1.3) 1.7	0.01	0	0.02
	2	34.0	28.9	36.7	32.5	(40.5) 52.6	14.7	47.3	15.7	(2.6) 3.4	0.02	0	0.05
	3	35.7	27.9	40.0	34.3	(58.9) 77.1	21.6	69.4	23.1	(3.8) 5.0	0.03	0	0.1
	4	34.5	26.8	37.4	33.3	(78.9) 103.6	29.0	93.3	31.1	(5.1) 6.7	0.05	0	0.1

[a]Treatments: S for samples directly exposed to sun, L for samples under the leaf, F for samples under a UV filter, and CH for samples under four layers of cheesecloth.

[b]For calculation of mean temperatures see section Materials and Methods.

[c]Dosages of solar radiation (SR) and UV in $MJ \cdot m^{-2}$ (ie, irradiance times length of exposure of each sample). *Alternaria solani* spores were exposed for 8-hr in each of 5 days, and *Uromyces phaseoli* spores were exposed for 9.5-hr in each of 4 days. SR and UV data in parentheses are those measured with sensors oriented to measure irradiance on a horizontal surface. SR and UV data without parentheses are those calculated for samples of spores kept perpendicular to sun.

increased sensitivity to UV doses from *A. solani* to *U. phaseoli* and attached and detached sporangia of *P. tabacina*. The curves presented are hand-drawn fits to the data.

Laboratory trials. Exposure of spores to short wavelength UV in the laboratory was used to determine the efficiency of the UV filters (with *P. tabacina*), to compare the relative susceptibility of all three pathogens at the same temperature (20 C), to compare the relative sensitivity of attached and detached spores (*P. tabacina*), to compare the relative sensitivity of dry and wet spores (*A. solani*) and to check the effect of various temperatures on irradiation efficiency. Different doses of UV were obtained by exposing spores for different periods from 0 (controls) to 60 min.

The effect of UV on spores was completely inhibited by UV filters. There were no differences in the subsequent germination of attached or detached sporangia of *P. tabacina* irradiated through the filters from 0 to 9.4 $KJ \cdot m^{-2}$. Compared to long wavelength UV (Fig. 3A), relatively low doses of short wavelength UV killed spores. Sensitivity to short wavelength UV increased from *A. solani* to *U. phaseoli* to *P. tabacina*. Again, attached sporangia of *P. tabacina* were more resistant than were detached sporangia. Urediospores of *U. phaseoli* showed no differences in reaction to UV from 0.3 to 4.7 $KJ \cdot m^{-2}$ when irradiated under ambient temperatures of 20, 30, and 40 C. About 95% of spores of *A. solani* germinated after being irradiated by 3.1 $KJ \cdot m^{-2}$ when dry. At the same doses, only 23.5% of these spores germinated when the time of irradiation coincided with the onset of wetting to induce germination. At the highest dose (9.4 $KJ \cdot m^{-2}$, the germination of dry and wet spores was 47.3 and 0%, respectively.

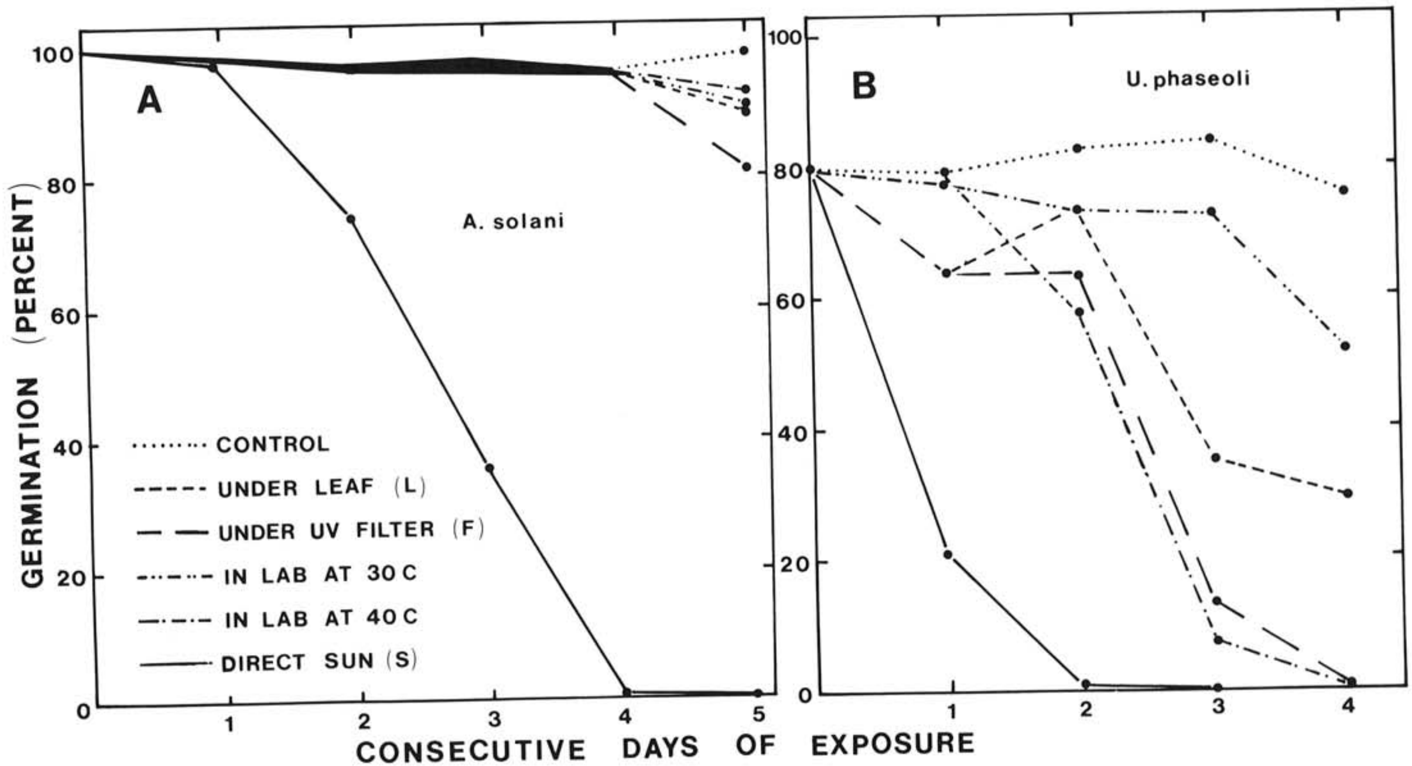

Fig. 2. Survival of detached spores exposed to the sun in the open or to high temperatures in the laboratory. **A,** Spores of *Alternaria solani* exposed for 8 hr/day for 5 successive days; **B,** spores of *Uromyces phaseoli* exposed for 9.5 hr/day for 4 successive days. Data given are actual values without equating controls to 100%.

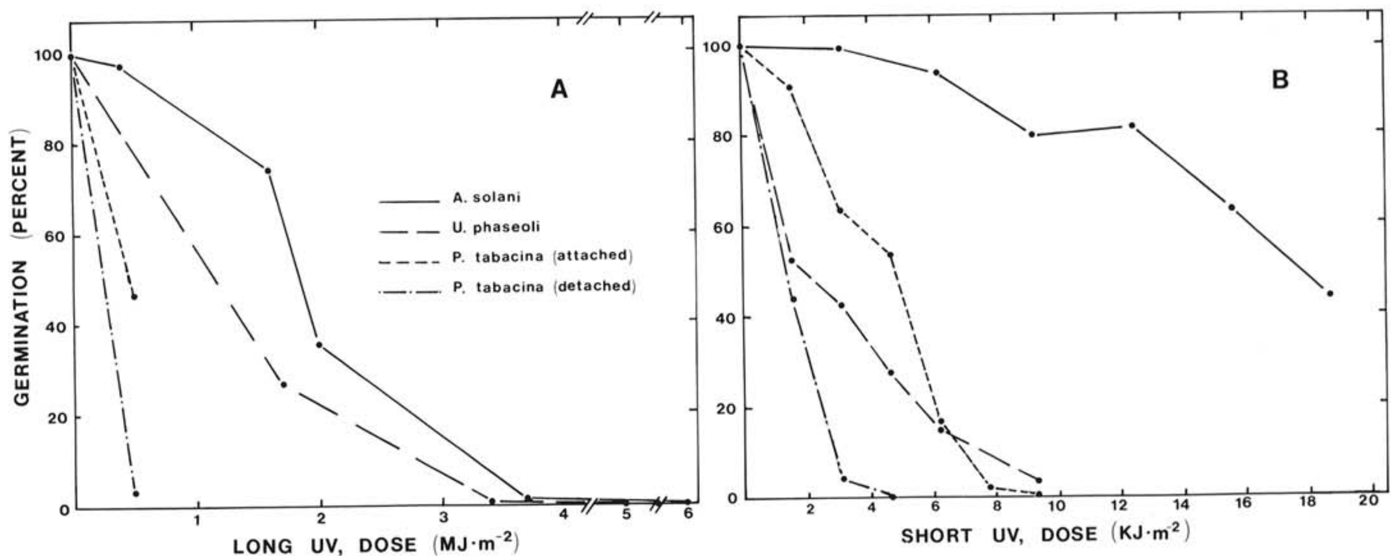

Fig. 3. Survival of *Alternaria solani, Uromyces phaseoli*, and *Peronospora tabacina* plotted against doses of UV radiation. **A,** Long wavelength UV (above 290 nm) present during the days of exposure in the field, and **B,** short wavelength UV (254 nm) applied in the laboratory.

DISCUSSION

The knowledge that sunshine affects plant disease has rarely been attributed to its direct effect on the survival of spores; exceptions include *Exobasidium vexans* on tea (6,20), *Peronospora destructor* on onions, and *P. tabacina* on tobacco (2). These pathogens are generally sensitive to other environmental conditions, however. Our study showed that solar radiation directly reduced survival of spores for species like *Alternaria* that are generally resistant to extremes of other factors such as temperature (14).

The role of solar radiation in survival of spores in the field is underscored when results of our tests are compared to data obtained from other survival experiments in the laboratory in darkness. For example, the maximum longevity of detached sporangia of *P. tabacina* stored in the laboratory at 28 C and 30–45% RH, and at 40 C and 35% RH was 5 days and 1 day, respectively (1). Attached sporangia of *P. tabacina*, which are more resistant, survived up to 42 days at 25 C when dry (8). By contrast, about 3% of detached sporangia and 47% of the attached sporangia survived a 3-hr exposure to SR of 8.6 $MJ \cdot m^{-2}$ at about 32 C (Table 1, Fig. 1). Although about 20 days were needed to kill all urediospores of *U. phaseoli* stored in darkness at 33.2 C and 44–55% RH (16), only 3 days with a total of 28.5 hr of exposure to SR (a total of 71.1 $MJ \cdot m^{-2}$) at about 32 C killed all urediospores in our tests (Table 2, Fig. 2B). It took 5 mo to kill all spores of *A. solani* kept at 40 C and 53% RH in darkness (14), but 99% of the spores of this fungus were killed at 32 C by 4 days (32 hr) of exposure to SR totalling 60.6 $MJ \cdot m^{-2}$. In all these cases, spores more resistant to environmental extremes in the dark were also more resistant to SR. Thus, SR speeded up mortality, but it did not change the relative sensitivity of the species tested.

We did not measure RH close to the surface of the membrane filters and leaves but estimated decreases in RH due to higher temperatures under the UV filters using well-known data for the saturation vapor pressure over water. For single-day exposures with *A. solani* and *U. phaseoli* the temperature was 34.5 and 34.8 C, respectively, in the S treatment samples and was 36.1 and 36.5 C, respectively, in the F treatment samples (Table 1), resulting in about an 8% decrease in RH in the F treatment samples. Considering the effects of RH on survival of both species (14,16), such a decrease in RH during the 8-hr periods of exposure should not affect their survival very much. For *P. tabacina*, an increase in temperature from 32.1 C in S treatment samples to 37.3 C in the F treatment samples (Table 1) resulted in a decrease in RH of about 20%. *P. tabacina* is relatively sensitive to RH and, even during exposures as short as 3 hr, the sporangia might be affected by decreased humidity. However, the fact that sporangia of this fungus survived better in the drier F treatment samples than in the more humid S treatment samples indicates that the fungicidal effect of SR exceeds the effect of dryness.

Spores of all three pathogens that received the CH or L treatments survived much better than spores in full sun. In most cases, germination of these spores did not differ significantly from controls. Thus, if spores are deposited in the lower part of the crop canopy soon after take off they should survive relatively well. On the other hand, the germinability of spores transported several hundred kilometers in 1 or 2 days may be completely (*P. tabacina*), considerably (*U. phaseoli*), or slightly (*A. solani*) affected. The prospect for various species to remain infectious after such a long dispersal depends on the intrinsic level of their survivability, the time of take off, and the particular characteristics of the weather. Survivability of spores may also vary with conditions under which they were produced, (e.g., laboratory versus field) as was found with *Phytophthora infestans* (3). Our data could be used to estimate the prospects of survival after a long-range dispersal of the tested fungi for specific environmental conditions.

Results with the F treatment showed that UV is the main fungicidal element of SR. In all tests, fungal pathogens in the filter-protected F treatments survived significantly better than those in the S treatments and, in many tests, the survival of F treatment samples was equal to survival of those in the controls despite the relatively high temperatures under these filters (Tables 1 and 2). Survival of detached sporangia of *P. tabacina*, however, was significantly better in controls than in the F treatments (Fig. 1, 2B). For these, the high temperature under the filters was a factor in mortality. The relationships between mortality of spores and doses of UV found with *A. solani* and *U. phaseoli* for the several-day tests are nonlinear. More data are needed to establish these nonlinear relationships.

Short wavelength UV is a well-known fungicidal agent (4,13,17,18), however wavelengths below about 288 nm are essentially absent in the field, and the fungicidal effect of the available long wavelength UV is not clear (17). Previously, a fungicidal effect of long wavelength UV was demonstrated for *Exobasidium vexans* in the laboratory (6) and also to a certain degree for ascospores of *Sclerotinia sclerotiorum* in the field (5). Much higher doses of long- than of short wavelength UV were required to kill spores in our study (Fig. 3A and B) which is in agreement with the known bactericidal properties of different wavelengths of light (4). The much lower efficiency of long wavelength UV outdoors may, in part, be due to the processes of photoreactivation (10).

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