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Relationships between weather variables, airborne spore concentrations and severity of leaf blight of garlic caused by *Stemphylium vesicarium* in Spain

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Abstract

Ascospores and conidia released into the air were recorded around plots on which garlic debris infected by *Stemphylium vesicarium* were fixed onto the soil surface. Symptoms in garlic trap plots located in the vicinity of infected debris, started in March and developed during April–May to reach disease incidence close to 100%, final disease severity values being lower in 1993 and 1995 than in 1994 and 1996. Whereas daily concentrations of ascospores were rather erratic, with 30% of captures between 0 and 6 h, conidia showed a daily periodicity with highest concentrations between 12 and 18 h, with a pronounced peak between 14 and 16 h, and lowest values at night. Ascospore release occurred mainly in February and March. It coincided with rainfall periods, 14 h with vapour pressure deficit $\leq$5 mb and solar radiation $<$145 W m^{-2} on the current day of the capture. In contrast, greatest captures of conidia started in late April and were prevalent in May, and were associated with rainfall in days previous to the capture in which rather high temperature occurred and solar radiation was 109–345 W m^{-2}. Among the weather variables considered, rainfall appeared directly related to the aerial concentration of ascospores and conidia. The role of relative humidity seemed essential when rainfall did not occur. There was a relationship between conidia concentration in the air and number of hours with temperature in the range 12–21 °C. Ascospore production was not essential for infections to take place, since primary infection from conidia may occur and disease can develop from them readily.

Introduction

Stemphylium vesicarium (teleomorph *Pleospora allii*), causes severe epidemics in garlic, onion and leek crops in the main producing areas of the world (Rao and Pavgi, 1975; Miller et al., 1978; Shishkoff and Lorbeer, 1989; Aveling and Naude, 1992; Lima et al., 1993; Basallote Ureba et al., 1993; Suheri and Price, 2000a). In Southern Spain, symptoms of disease on garlic and onion crops include both white small oval lesions and large purple spots (Basallote et al., 1993; Basallote-Ureba et al., 1999). The infection and colonisation of leaves by this fungus determine extensive necrosis followed by a premature dessication of the plants, which leads to important yield reductions (Rao and Pavgi, 1975; Miller et al., 1978; Shishkoff and Lorbeer, 1989; Aveling and Naude, 1992; Aveling, 1993; Lima et al., 1993; Basallote et al., 1993; Basallote-Ureba et al., 1999; Suheri and Price, 2000a,b).

Pseudothecia of the teleomorph develop during winter on infected plant debris, the latter constituting the main inoculum source for the initiation of leaf blight epidemics (Rao and Pavgi, 1975; Prados-Ligero et al., 1998; Basallote-Ureba et al., 1999). The period required for pseudothecial maturation of *P. allii* is 1–4 months, depending on climatic conditions; this period is highly correlated with accumulated rainfall, and with the period (h) with temperatures between 4.5 and 10.5 °C and relative humidity (RH) over 98%. Ascospore release occurs after pseudothecia mature, and has been associated with dew or rainfall (Prados-Ligero et al., 1998).

Field observations indicate that the development and severity of leaf blight epidemics in *Allium* crops are much influenced by environmental conditions (Basallote-Ureba et al., 1999; Suheri and Price, 2000b; 2001). Studies on artificial inoculation of *Allium* plants with *S. vesicarium* indicated that temperatures of 18–26 °C and a minimum leaf wetness period of 6 or 8 h is required for infection (Shishkoff and Lorbeer, 1989; Aveling and Naude, 1992; Basallote et al., 1993; Lima et al., 1993; Basallote-Ureba et al., 1999; Suheri and Price, 2000a,b; 2001). However, increasing the wetness period to 24–48 h resulted in more consistent reactions, with larger number and size of lesions (Basallote-Ureba et al., 1999). There is a sequence of biological events, each with precise environmental requirements, in the process of leaf blight development. Recently, Suheri and Price (2000b), studying the processes of onion infection by *S. vesicarium*, observed that conidia germinate after 2 h incubation at 4 °C but appressoria were not formed at this temperature. The maximum germination rates and the highest numbers of appressoria were recorded after 24 h incubation at 25 °C. Similarly, the frequency of infections increased when temperature and period of incubation were increased, the maximum number of penetrations being observed after 24 h at 18–25 °C and a minimum leaf wetness period of 16 h . Montesinos and Vilardell (1992), working with *S. vesicarium* isolates from pear leaves, showed that temperatures of 5–35 °C and RH $\geq$ 98% were required for the germination of conidia, whereas optimal temperature for mycelial growth was 21 °C and showed a shorter range (15–25 °C).

Sporulation of *S. vesicarium* on asparagus and garlic tissues affected by leaf blight was induced by the incubation of lesions at 18–25 °C under saturation humidity and a photoperiod of 12–18 h (Falloon et al., 1987; Basallote-Ureba et al., 1999) or in the dark (Suheri and Price, 2000b). More recently, studying the epidemiology of purple leaf blotch of leeks in Australia, Suheri and Price (2001) observed that most conidia were trapped when precipitation or leaf wetness period $\geq$10 h occurred during the day preceding trapping. A diurnal pattern of airborne conidia of *S. vesicarium* in garlic and leek crops has previously been reported in Australia (Suheri and Price, 2000b; 2001). Knowledge of the requirements under which the production and release of conidia of *S. vesicarium* take place under our environmental conditions is, however, lacking.

The requirements for the production and maturation of pseudothecia of *P. allii* on infected garlic debris under natural conditions were reported (Prados-Ligero et al., 1998). Likewise, the pathogenicity of the ascospores produced in pseudothecia formed on infected debris has been tested (Basallote-Ureba et al., 1999). However, the environmental conditions under which the discharge of ascospores into the air take place has not been determined and the involvement of ascospores as primary inoculum on epidemics of leaf blight in *Allium* crops has not been elucidated.

The aims of this work were: (a) to determine the influence of the aerial concentration of ascospores of *P. allii* and of conidia of *S. vesicarium* on the incidence and severity of leaf blight epidemics of garlic crops, and (b) to study the relationship between meteorological conditions during several garlic crop cycles and the release of spores of *P. allii* and *S. vesicarium* into the air, in order to establish the bases that allow the forecast of the development of severe epidemics of leaf blight and, thus, to minimize yield losses and reduce the number of fungicide sprays required for disease control.

Materials and methods

Inoculum source and trap plots

Plastic net bags containing 10–15 segments of garlic leaves with lesions due to natural infections by *S. vesicarium*, collected at the end of the previous garlic crop, were fixed onto the soil surface of a 4 m^2 plot by late October of every year in the period 1992–1995. Each year, this plot was located in the experimental farm of CIFA in Córdoba, Spain, at 200 m from a trap plot, according to prevalent winds. Trap plots were planted with garlic cv. Morado de Cuenca, highly susceptible to *Stemphylium* leaf blight, in November–December of every year. The trap plot (3 m × 5 m) had eight furrows, 0.6 m apart, with garlic cloves planted at 0.1 m within the row. This experimental array allowed monitoring of ascospores and conidia concentration in the air using a volumetric spore trap device (Burkard Manufacturing Co. Ltd., Rickmansworth, UK) located in the vicinity of the trap plot. Observations of foliar spot symptoms were carried out every 2 wk on 36 random plants in four central rows of the trap plot from early March until the late stage of the crop cycle in May of every year.

Seasonal dynamics of aerial spores concentration

The concentrations of conidia of *S. vesicarium* and of ascospores of *P. allii* were continuously recorded with the volumetric spore trap having the suction slit at 0.7 m over soil level and the suction flux fixed at 10 liter min^{-1} according to a previous methodology (Trapero-Casas et al., 1996). The ribbon was changed weekly, cut into seven 48 mm fragments, each corresponding to one day, and marked at 2 h intervals before the fragments were laid on a slide and stained with acid fuchsin diluted in lactophenol. The number of spores collected for each 2 h period was determined by the conidia and ascospores deposited on a 0.33 mm traverse across the ribbon centered on each 4 mm exposure corresponding to 2 h intervals. Spore counts were adjusted as to the number of spores per m^3 air. Conidia and ascospores were identified according to the descriptions of Simmons (1969). In the four years of study, spore captures were recorded along the crop cycle. The daily periodicity of spore concentration of *P. allii* and *S. vesicarium* in the air was determined by the mean values of ascospore and conidia captures, respectively, all the days from February 1 to May 29 during 1993–1996.

Influence of weather conditions on the spores concentration in the air

For the four years study, hourly records of precipitation (P) using a tipping-bucket rain gauge (AR6 100 Institute of Hidrology, England), RH measured with a hair hygrometer (SAINCO, Madrid, Spain), maximum, minimum and mean temperature, using a Pt 100 thermistor, (SAINCO, Madrid, Spain), vapour pressure deficit (VPD), solar radiation (SR) measured with a pyranometer CM 6B (Kipp and Zonen), and wind velocity (WV) using an anemometer A100 R (Vector Instruments) were obtained from one meteorological station in the farm where the experiments were conducted.

The onset of leaf lesions and the maximum severity of leaf spots symptoms were tested for association with the aerial concentration of spores and with weather conditions in the ten days previous to those events.

Correlations between the daily concentrations of spores in the air and the weather variables shown in Table 1 were studied during the periods of maximum capture of spores. These variables were calculated not only for the same day of the capture (day 0), but also for the cumulative periods of up to ten days previous to the considered capture. Different variables such as number of rainy days (RD), rainfall amount (P), duration of RH $\geq$ 98%, VPD and duration of VPD $\leq$ 5 mb were used to determine humidity conditions. Likewise, hourly and daily temperatures were recorded to determine the duration of temperature within a range.

The transformation $\log_{10}$(spores concentration + 1) was previously applied to data in order to avoid zero values and to compensate for the high variance of data (Everts and Lacy, 1990). The correlations of daily concentration of ascospores in the air with weather variables were determined for the period February 1–March 15 of every year. The period of mid April–end

Table 1. Weather variables examined* by correlation analysis with spores captured

P = daily precipitation (mm)
AP = accumulated precipitation (mm)
RD = number of rainy days
T_{max} = average maximum daily temperature (°C)
nT_{max} = number of hours with maximum daily temperature between 12 and 21 °C
T_{min} = average minimum daily temperature (°C)
nT_{min} = number of hours with minimum daily temperature between 5 and 15 °C
T_{mn} = average mean daily temperature (°C)
RH_{max} = average maximum daily relative humidity (%)
nRH = number of hours with relative humidity ≥98%
VPD = average vapour pressure deficit (mb)
nVPD = number of hours with vapour pressure deficit ≤5 mb
SR = average solar radiation (W m^{-2})
WV = average wind velocity (m s^{-1})

*Calculated not only for the same day of the capture (day 0) but also for cumulative periods of up to 10 days previous to the capture.

of May was used for the correlations between the daily concentration of conidia in the air and the weather variables mentioned above. Multiple stepwise regressions of spore concentration and the weather variables were also conducted.

Results

Development of leaf spots in the trap plots

The first symptoms of leaf blight, i.e. single white lesions on isolated plants, were observed in March of each year at the growth stage of 6–8 leaves. A rapid progress of disease incidence was observed two months later, reaching final disease incidence levels of 91% in 1993 and 100% in the other years. However, final disease severity differed between the years, being lower (<15 lesions per plant) in 1993 and 1995 than in 1994 and 1996 (11–100 and >350 lesions per plant, respectively) (Table 2).

Volumetric spore sampler records and data obtained from the meteorological station where the experiments were carried out, indicated that leaf spots were associated with the accumulated ascospores and conidia concentration in the air and with weather conditions in ten day period previous to disease evaluation. The most severe epidemics of leaf spots occurred in spring 1996 coinciding with a very high aerial concentration of conidia, heavy and frequent rainfall, VPD $\leq$ 7 mb, and maximum temperatures between 19 and 25 °C on ten days previous to the date of maximum severity of garlic leaf blight (Table 2).

Daily dynamics of aerial spores concentration

The daily patterns of spore concentration in the air were similar for the different years. However, the highest concentrations of ascospores and conidia, respectively, corresponded to 1993 and 1996, whereas the lowest concentrations were in 1996 and 1995, respectively (Figure 1). The erratic daily distribution of ascospores in the air, although ca. 30% of captures occurred between 0 and 6 h (Figure 1A), contrasted with a marked daily periodicity of conidia, which showed their highest concentrations between 12 and 18 h, with a pronounced peak between 14 and 16 h, and their lowest values at night (2–8 h) (Figure 1B).

Relationship between weather conditions and seasonal periodicity of spores

The year with maximum *P. allii* ascospores trapped was 1993, the most important ascospore peak (14280 ascospores m^{-3} day^{-1}) occurred in the first half of February, and showed two other important peaks of captures (6480 and 4520 ascospores m^{-3} day^{-1}) in March. All these peaks coincided with precipitation episodes (4–12 mm), maximum temperature of 15–18 °C, VPD of 2–5 mb and SR of 40–175 W m^{-2}. The last important ascospore concentration in the air took place between late April and early May, and were associated with environmental conditions similar to those previously described. In contrast, the conidia trapped were low (<300 m^{-3} day^{-1}) until late April. Afterwards, high conidia concentration (1000–11280 m^{-3} day^{-1}) were

Table 2. Influence of weather conditions on the development of leaf spot symptoms caused by *S. vesicarium* on a crop of garlic cv. Morado de Cuenca

Planting date	Sampling date[a]	Time after planting (days)	Lesion/ plant (number)	Disease incidence (%)	Ascospores[b] (per m^3)	Conidia[b] (per m^3)	Weather variables[c]			
							RD (days)	AP (mm)	T_{max} (°C)	VPD (mb)
11 November 1992	30 March 1993 (onset)	139	Traces		3400	360	1	3.0	18–21	5–11
	19 May 1993 (MDS)	188	≤10	93	5600	31360	6	28.6	21–27	4–15
2 December 1993	24 March 1994 (onset)	112	Traces		7880	5040	1	0.2	22–29	5–13
	29 May 1994 (MDS)	171	11–100	100	200	54120	3	14.0	24–31	5–15
24 November 1994	2 March 1995 (onset)	98	Traces		0	1200	2	0.6	16–23	3–8
	3 May 1995 (MDS)	160	<15	100	1000	7680	3	24.0	16–32	3–14
5 December 1995	19 March 1996 (onset)	95	Traces		400	4520	4	19.6	16–22	2–7
	9 May 1996 (MDS)	146	>350	100	360	58720	7	128.0	19–25	1–7

[a]Date of detection of first leaf spot symptoms (onset) and date of maximum disease severity (MDS) for every sampling year.
[b]Accumulated number of spores captured during ten days previous to the corresponding dates.
[c]Weather variables determined for ten days previous to the sampling date: RD = number of rainy days, AP = accumulated precipitation, T_{max} = range of maximum daily temperature and VPD = range of vapour pressure deficit.

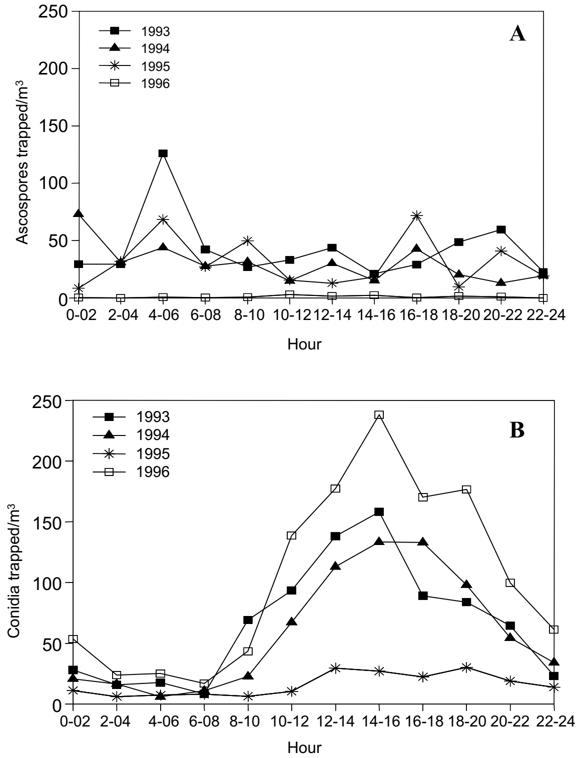

Figure 1. Daily dynamics of aerial concentration of ascospores of *P. allii* 3 (A) and *S. vesicarium* conidia (B) in experimental garlic plots. Data correspond to the mean values of aerial spore concentrations, at two hours intervals, for all days from February 1 to May 29 during 1993 to 1996.

recorded coinciding with frequent rainfall (18 days with 0.2–26 mm), simultaneous with maximum temperatures of 15–27 °C, fluctuations of VPD between 2 and 15 mb (Figure 2A) and SR of 140–325 W m^{-2}.

The most important captures of ascospores in 1994 occurred in February (2520–9120 m^{-3} day^{-1}), coinciding with rainfall (6–19 mm) or RH $\geq$ 98%, maximum temperature of 11–17 °C, VPD of 1.5–2.5 mb and SR of 43–187 W m^{-2}. The last important ascospore peak (3600 m^{-3} day^{-1}) was found by mid April with a precipitation of 23 mm, a maximum temperature of 12.5 °C, VPD of 1 mb and SR of 43 W m^{-2}. In 1994, the highest conidia concentration in the air (1120–13080 m^{-3} day^{-1}) took place during the second half of May. In this period, it rained for 8 days (0.2–11 mm), maximum temperature of 21–31 °C, VPD between 3.5 and 15.5 mb (Figure 2B) and SR of 109–335 W m^{-2}.

Five noticeable peaks of ascospores (1120–12000 m^{-3} day^{-1}) were recorded during the winter of 1995. These coincided with daily rainfall of variable intensity (1.6–33 mm), a maximum temperature of 14–21 °C, VPD of 2–4.5 mb, and SR of 16–115 W m^{-2}, on the same day of the capture. The last important ascospore peak occurred by mid-April, concurrent with a precipitation of 1.4 mm, maximum temperature of 28 °C, and VPD of 9.6 mb. The low concentrations of conidia recorded during the spring concurred with rainfall (2–19 mm) in days preceding the capture, along with maximum temperatures of 17–32 °C, VPD between 5 and 14 mb (Figure 2C), and SR of 176–257 W m^{-2}.

Levels of ascospores trapped along the crop cycle of 1996 were very low (<200 m^{-3} day^{-1}). In contrast, conidia were trapped continuously since early March, although the first relevant peaks (1080–3880 m^{-3} day^{-1}) were not recorded until the end of that month. For all the years studied, the highest concentrations of conidia trapped from the air were recorded in May 1996 (1160–25800 conidia m^{-3} day^{-1}). These catches were associated with rainfall of a very variable intensity (up to 65 mm) on the day of capture or in the previous ones, with maximum temperatures of 19–26 °C, with VPD of 1–9.5 mb (Figure 2D), and with SR of 131–342 W m^{-2}.

The correlations between aerial concentrations of spores and weather variables that were consistent in the four years of study are shown in Tables 3 and 4. The $\log_{10}$(daily ascospore concentration + 1) was significantly positively correlated with *P* (daily precipitation), as well as with *n*VPD, and it was negatively correlated with SR, for the periods February 1–March 15 of 1993–1995. In contrast, for the same period of 1996, $\log_{10}$(daily ascospore concentration + 1) correlated only with daily precipitation. The significance level was increased in all years except in 1996, when a multiple correlation, with *n*VPD and SR was considered (Table 3).

The most important peaks of ascospores coincided with rainfall of a very variable intensity (1.4–33 mm), nVPD $>$ 14 h and SR $<$ 145 W m^{-2} on the current day of the capture.

Significant correlations were found between the $\log_{10}$(daily conidia concentration + 1) and the prevalent weather conditions in ten days previous to the capture, for all the studied years. There were positive correlations between $\log_{10}$(daily conidia concentration + 1) and RD, and nT_{max}, and negative significant correlation

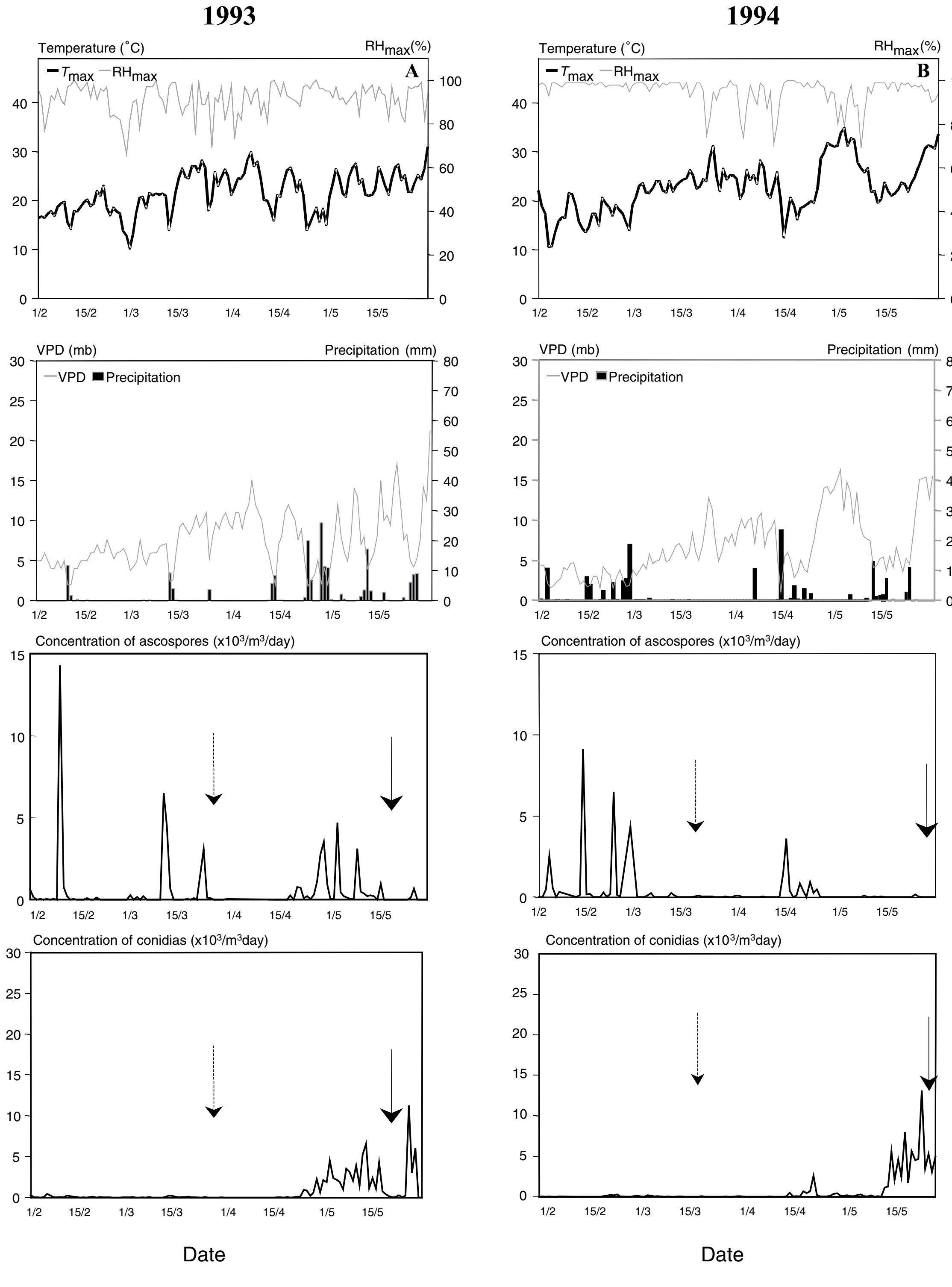

Figure 2. Daily maximum temperature (T_{max}), maximum relative humidity (RH_{max}), VPD, and precipitation (P), in relation to aerial concentration of spores of *P. allii* and *S. vesicarium* during the growing season of garlic for 1993 (A), 1994 (B), 1995 (C) and 1996 (D) (Dates when disease was first observed --→ and when it had reached maximum severity ↓ of garlic leaf blight).

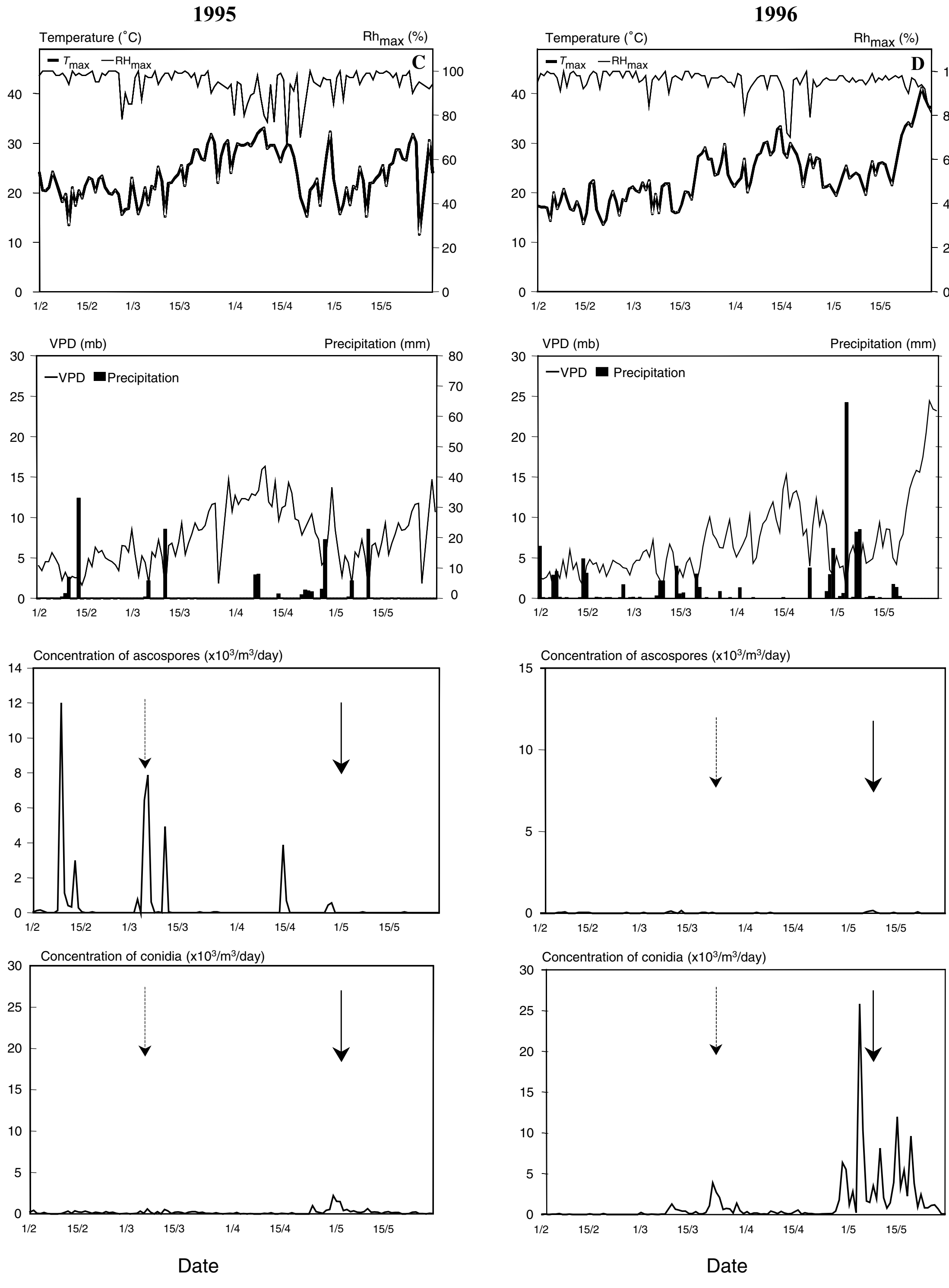

Figure 2. Continued.

Table 3. Linear and multiple correlation coefficients between daily aerial ascospores concentration[a] of *P. allii* and weather variables during the periods February 1–March 15 (1993–1996)

Weather variable[b]	Year[c]			
	1993	1994	1995	1996
P	0.610***	0.548***	0.454**	0.323*
nVPD	0.577***	0.520**	0.695**	0.291
SR	−0.492**	−0.593***	−0.669**	−0.201
P + SR	0.627***	0.634***	0.698**	0.324*
nVPD + SR	0.611***	0.611***	0.730**	0.314
Degrees of freedom	41	36	42	42

[a]Transformation: $\log_{10}$(ascospores concentration + 1).
[b]Weather variables determined on the current day of the capture: P = precipitation (mm), nVPD = number of hours with vapour pressure deficit ≤5 mb, SR = average solar radiation. [c]Significance levels for the correlation coefficients: $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***).

Table 4. Linear correlation coefficients between daily aerial conidia concentration[a] of *S. vesicarium* and weather variables during the period April 15–May 29 (1993–1996)

Weather variable[b]	Year[c]			
	1993	1994	1995	1996
RD	0.504***	0.551***	0.325*	0.726***
nT_{max}	0.471**	0.661***	0.303*	0.686***
nRH	−0.674***	0.500***	−0.524**	0.245
SR	−0.461*	−0.479***	−0.309*	−0.582***
WV	−0.290	0.621***	−0.179	0.668***
Degrees of freedom	44	44	44	42

[a]Transformation: $\log_{10}$(conidia concentration + 1).
[b]Weather variables determined during ten days previous to the capture: RD = number of rainy days, nT_{max} = number of hours with maximum temperatures in the interval 12–21 °C, nRH = number of hours with maximum relative humidity ≥98%, SR = average solar radiation, WV = average wind velocity.
[c]Significance levels for the correlation coefficients: $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***).

of $\log_{10}$(daily ascospore concentration + 1) with SR. Also, there were highly significant positive correlations of $\log_{10}$(daily conidia concentration + 1) with WV in 1994 and 1996, and with nRH in 1994, and a negative correlation of $\log_{10}$(daily conidia concentration + 1) with nRH in 1993 and 1995. Significant levels were not increased when multiple correlations were considered (Table 4).

In all cases, the most important concentrations of conidia in the air were observed when, in the previous ten days to capture, a minimum of three RD, at least 98 h of nT_{max}, SR values over 164 W m^{-2}, and WV < 3 m s^{-1} occurred.

The equations derived from multiple stepwise regressions conducted between aerial spores concentration and the weather variables shown in Tables 3 and 4 varied with different years (data not shown). Therefore, it was not possible to derive a consistent equation to relate the daily number of ascospores and conidia to weather variables for these four years.

Discussion

The results suggest that ascospores of *P. allii* and conidia of *S. vesicarium* developed on garlic debris from plants infected from previous crops constitute the primary inoculum for leaf blight epidemics. In contrast, secondary inoculum consists of conidia produced on necrotic lesions of the current crop, and are related with maximum symptom expression.

First leaf lesions in garlic plants were observed in March regardless of planting date, and maximum disease severity occurred in May, at crop maturity. This is related to increased susceptibility of *Allium* crops with age of tissues and crop phenology, according to previous studies (Basallote-Ureba et al., 1999; Suheri and Price, 2001).

Disease severity varied between the years. The results suggest a relationship between epidemic development and weather factors, especially rainfall, temperature and VPD, partially in agreement with previous studies on the purple blotch of onion (Everts and Lacy, 1990).

The diurnal periodicity of conidia of *S. vesicarium* observed in garlic crops in Southern Spain is similar to the results of Suheri and Price (2000b; 2001) for *S. vesicarium* in garlic and leek crops in Victoria, Australia. Furthermore, they have associated the diurnal pattern of conidia with temperature changes, leaf wetness duration and/or RH the previous night (Suheri and Price, 2000b).

According to observations in four consecutive garlic crops, seasonal periodicity for both types of spores is related to environmental conditions that favour their formation and release into the air. Thus, highest ascospore numbers were trapped in winter, coinciding with precipitation, moderate maximum temperature (10–21 °C) and low VPD (1–5 mb). In contrast, the highest conidia concentrations in the air were recorded in spring, and were associated with rainy events, and fluctuations of temperature (15–32 °C) and VPD (1–15 mb) in days preceding capture. Weather conditions similar to those observed in the *S. vesicarium*/garlic pathosystem were previously associated with release of *S. vesicarium* conidia in leek crops (Suheri and Price, 2001) and of *B. squamosa* affecting onion (Lacy and Pontius, 1983).

Among the environmental factors considered, rainfall appears as one of the most directly related with the spore concentration in the air. All the important events of ascospores capture coincided with rainfall occurrence on the same day or in the four days preceding capture. The association between precipitation and ascospores release has been previously referred in other Ascomycetes (Hirst, 1953; McCartney and Lacey, 1990; Spotts and Cervantes, 1994; Trapero-Casas et al., 1996; Arseniuk et al., 1998), as well as the fact that captures may be produced with precipitations as low as 0.25 mm, and they may continue for several days after rainfall, probably due to long dew periods (McCartney and Lacey, 1990; Spotts and Cervantes, 1994; Arseniuk et al., 1998). Furthermore, rainfall after release of spores provides the required environment for the germination (Montesinos and Vilardell, 1992) and for the sporulation after the fungus becomes established in new lesions of leaves (Falloon et al., 1987; Basallote-Ureba et al., 1999).

Relative humidity and/or duration of leaf wetness have been referred as determinant factors in the development of *S. vesicarium* in several hosts (Falloon et al., 1987; Shishkoff and Lorbeer, 1989; Aveling and Naude, 1992; Montesinos and Vilardell, 1992; Lima et al., 1993; Basallote et al., 1993; Basallote-Ureba et al., 1999; Suheri and Price, 2000a; Llorente and Montesinos, 2002). The accumulation of short humidity periods along several nights in order to reach the total humidity period is required for the sporulation of *Alternaria porri* f.sp. *solani*, *S. botryosum* f.sp. *lycopersici* and *A. dauci* (Cohen and Rotem, 1987; Strandberg, 1977). According to these results a similar process seems to occur in *S. vesicarium*.

The results suggest that temperature is involved in the release of conidia, but did not show a relationship with ascospores release. Temperature also plays an important role in infection and in the colonisation processes, with an optimal range of 18–26 °C (Shishkoff and Lorbeer, 1989; Aveling and Naude, 1992; Lima et al., 1993; Basallote et al., 1993; Basallote-Ureba et al., 1999). These conditions were achieved in 1996, when the most severe leaf blight epidemic occurred.

The low concentration of ascospores in the air in 1996 seemed to be related to the destruction of infected garlic debris, due to the intensive and frequent rainfall that occurred during that winter. However, the most severe epidemic of leaf blight occurred in this year, coinciding with the higher concentration of conidia recorded as compared with the other three years. Furthermore, weather conditions in the spring of 1996 were very suitable for conidia production as well as for the processes of infection and colonisation (Montesinos and Vilardell, 1992; Suheri and Price, 2000a; Llorente and Montesinos, 2002). Thus, very low concentrations of spores during winter are usually enough for the initiation of epidemics. High concentration of spores in early spring are not required for severe epidemics. These need precipitation or high RH for a minimum period of ten days with a suitable temperature for pathogen and disease development.

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