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Evaluation of a revision of the BSPcast decision support system for control of brown spot of pear

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Summary. Control of brown spot of pear requires fungicide treatments of pear trees during the growing season. Scheduling fungicide sprays with the Brown spot of pear forecasting system (BSPcast) provides significant fungicide savings but does not increase the efficacy of disease control. Modifications in BSPcast were introduced in order to increase system performance. The changes consisted of: (1) the use of a daily infection risk ($R_m \geq 0.2$) instead of the 3-day cumulative risk ($CR \geq 0.4$) to guide the fungicide scheduling, and (2) the inclusion of the effect of relative humidity during interrupted wetness periods. Trials were performed during 2 years in an experimental pear orchard in Spain. The modifications introduced did not result in increased disease control efficacy, compared with the original BSPcast system. In one year, no reduction in the number of fungicide applications was obtained using the modified BSPcast system in comparison to the original system, but in the second year the number of treatments was reduced from 15 to 13. The original BSPcast model overestimated the daily infection risk in 6.5% of days with wetness periods with low relative humidity during the wetness interruption, and in these cases the modified version was more adequate.

Key words: forecast system; interrupted wetness; *Stemphylium vesicarium*.

Introduction

The disease brown spot of pear (*Pyrus communis* L.) (BSP) is caused by the fungus *Stemphylium vesicarium* (Wallr.) E. Simmons. The economical losses caused by BSP are very important in several pear production areas of Europe including Spain, Italy, France, Portugal, The Netherlands and Belgium (Llorente and Montesinos, 2006).

Control of BSP is based on fungicide applications during the growing season according to fixed schedules or timed using the BSPcast forecasting system. This model was obtained from experiments performed under controlled environment conditions and is based on a polynomial equation which relates disease severity with wetness duration and mean temperature during the wetness periods (Montesinos *et al.*, 1995). A cumulative risk index (CR) is obtained by totaling daily infection risk values (R) for the past 3 days, and CR values of 0.4 or 0.5 are used to trigger fungicide applications. The model was evaluated and validated in different field trials in Spain and Italy under a wide range of orchard and climatic conditions (Llorente *et al.*, 2000). BSPcast is currently implemented as a warning system in the agrometeorological network of the Plant Health Services of Catalonia (Spain) and of the Servizio Fitosanitario, Regionale Emilia-Romagna (Italy).

The efficacy of BSP control using the BSPcast is similar to that achieved with the fixed fungicide spray schedule and provides an average of 30%

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savings in fungicide use (Llorente *et al.*, 2000). These reductions in fungicide use are important both economically and because of reduced fungicide residues in fruit and in the potential negative environmental impact of treatments. The experience with the model utilization over years has led us to explore ways of refining accuracy based on the facts that: (1) CR tends to give a smooth response and may overcome high daily risk values (R) when days are followed or preceded by very low R value days, and (2) the model does not take into account the effect of interruptions of wetness within individual days. In previous research on pear orchards, wetness periods were found to be interrupted in 8% of the days of wetness (Llorente and Montesinos, 2002). It was considered that no modifications of the model were necessary if RH during the wetness interruption had been high (≥96%), but results suggested that wetness periods should be considered as interrupted when they included more than 3 h at low RH. However, the effect of these modifications in the model performance has not been tested as a tool for scheduling fungicide sprays.

The objective of the present work was to evaluate two modifications of the BSPcast model in order to improve its efficacy as a system for scheduling fungicides for disease control based on: (1) the use of a daily infection risk (R) to guide the fungicide sprays instead of the 3-day cumulative infection risk (CR) of the original model, and (2) to take into account interrupted wetness periods.

Materials and methods

Brown spot of pear forecasting system

A modified version of BSPcast was compared to the original model. The model determines when environmental conditions are favorable to infection of pear by *S. vesicarium.* In the original model, daily wetness duration (W) and mean air temperature during wetness periods (T) are used to compute a daily infection risk according to a previously published equation (Montesinos, *et al.*, 1995; Llorente et al, 2000). Two indices are obtained: a daily infection risk (R) which ranges from 0 to 1, and a 3-day cumulative infection risk (CR) which is computed by totaling R values for the past 3 days, and ranges from 0 to 3. R and CR are calculated every 24 h. A value of CR≥0.4 is used as the action threshold to trigger the decision to spray trees with fungicide.

The modified version (BSPcast-m), which was evaluated in the present study, utilizes an action threshold based on the daily infection risk (R) instead of the CR. To determine the relationship between R and CR, 511 values of R and CR observed in five different orchards during 3 years were analyzed in relation to the disease progress. A linear relationship between R and CR was observed ($R=0.653*CR-0.085$, $r^2=0.49$, $P<0.0001$) (*data not shown*). According to this relationship, a value of CR=0.4 corresponds to a value of R=0.2. Therefore, a value of R=0.2 was selected as the action threshold to guide the fungicide applications in the BSPcast-m model. In addition, information related to interrupted wetness periods was incorporated in the BSPcast-m using the following procedure. First, given a day when R was higher than 0.2 the wetness dynamics during the corresponding 24 h period was analyzed using hourly data. Then, two options were possible:

1) If the wetness period is continuous, R remains unchanged and the fungicide must be applied if the canopy is unprotected by a previous treatment.

2) If the wetness period is interrupted, then the RH during the wetness interruption is analyzed using hourly values, and different situations may be possible:

2.1) If RH≥90%, then the wetness period is considered as continuous, R remain unchanged and the fungicide treatment has to be applied.

2.2) If RH<90%, then two wetness periods were considered and R is recalculated for each wetness period. Therefore, two R indices are obtained during the corresponding daily period. If one of these R values is higher than 0.2 the fungicide treatment has to be applied, but if neither of the two R values are higher than 0.2 then no sprays are necessary.

In order to avoid confusion, R obtained using BSPcast-m is hereafter coded as R_m.

Weather parameters measurement

Environmental parameters were monitored with an automatic weather station that consisted of a CR10X datalogger (Campbell Scientific Ltd. Loughborough, UK) connected to combined temperature-relative humidity (model HMP45C), wetness (model 237), and rainfall (model ARG100) sensors. Temperature and relative humidity sensors were placed on trees at 1.8 m above the soil surface within the canopy and in the middle of the orchard plots. The rainfall sensor was placed at the end of a row of trees. Two wetness sensors were placed within the canopy, at 1.8 m, with an angle of 45° and oriented to East and West respectively. Wetness sensors provided data ranging from 0 (dry) to 100 (water film). Based on previous results, a wet-dry threshold of 50 was selected for the present study (Llorente *et al.*, 2000; Llorente and Montesinos, 2002). Temperature and relative humidity were measured every 10 min and wetness and rainfall every 20 s. Mean temperature and relative humidity, duration of wetness, and total rainfall were recorded by the data logger at 1 h intervals. Since the duration of wetness period could vary between the two sensors, the longest wetness duration was used. For each day, the 24 h period considered for calculations started at 8:00 h (GMT) of the previous day and finished at 8:00 (GMT) of the current day. Each day, data were transferred to a personal computer into the laboratory directly by a GSM modem at 8:00 h (GMT). Then, the daily infection risk (R and R_m) and cumulative infection risk (CR) according to BSPcast and BSPcast-m were obtained.

Orchard trials

Two field trials were conducted in pear orchards (cv. Passe Crassane) in the Catalonia region, Spain, during 2003 (trial I) and 2004 (trial II). The orchards were naturally infected by BSP. The fungicide used was thiram (200 g a.i.·hL^{-1}; Thiram 80, Aragonesas-AgroSA, Madrid, Spain). Fungicide treatments were applied with an engine-operated portable sprayer (Stihl, model SR400, Waiblingen, Germany). Spray volume was calibrated to 1 L per tree (1000 L ha^{-1}). Thiram was assumed to provide 7 days of protection, except when rainfall surpassed 20 mm, where the canopy was considered unprotected.

In both trials, a complete randomized block design, with three blocks, each including five trees, was used. Treatments tested were: (1) fungicide applications according to BSPcast (action threshold $CR \geq 0.4$), (2) fungicide applications according to BSPcast-m (action threshold $R_m \geq 0.2$), and (3) non-treated control. Fungicide applications started in April and ended before harvest in October. Calendar treatments were applied according to the corresponding forecasting system.

Disease assessments were done on fruit and leaves each 20 to 30 days, starting after fruit set (April) and ending at harvest (October). On fruit, disease incidence (percentage of fruits) and severity (number of lesions per fruit) were assessed on 20 fruits per tree. At harvest, all fruit were assessed for the disease parameters. On leaves, severity evaluations were performed on 10 leaves from four shoots per tree located in both sides of the row. Each leaf was assigned to a severity class based on the following scale: 0 (no lesions), 1 (one to five lesions), 2 (six to 25 lesions), and 3 (more than 25 lesions). Mean disease severity of each plot was calculated using the following formula:

$$S = \sum_{n=1}^{N} I_n \Big/ 3 \cdot N$$

where: *S* is the index of relative disease severity (from 0 to 1); I_n is the disease severity class of each n^{th} leaf; N is the total number of leaves assessed; and 3 is the maximum level of severity. Disease incidence was calculated as the percentage of leaves with at least one lesion. The mean disease incidence and severity on leaves for each tree were calculated from the values of each of the four shoots per tree and used in statistical analyses.

Data analysis

Disease incidence and severity, on fruit and leaves at harvest were analyzed using the SAS system (v.9.1, SAS Institute Inc. North Carolina, USA). Disease progress on fruit and leaves was analyzed using the area under disease progress curve (AUDPC) (Campbell and Madden, 1990). For each trial, AUDPC was analyzed for disease incidence and severity separately. AUDPC values were tested using the GLM procedure. Data sets were tested for equality of variances (Bartlett test) and normality (Shapiro-Wilk test). The effect of treatments was determined using ANOVA for a complete randomized block design with the GLM procedure. Means comparisons were performed with Fisher's least significance difference test at $P=0.05$. In addition, data from repeated trials at harvest were combined for analysis and the effect of treatments on disease was determined by a repeated measures analysis of variance (ANOVA), using the SAS procedure GLM with the option repeated and contrast options among the treatments were examined. Classical *F* test was used because the number of repeated measures was only two and the sphericity conditions was thus satisfied (Rouanet and Lépine, 1970). Finally, the effect of treatments on disease incidence and severity on fruit and leaves at harvest was determined in pooled data of trials I and II using a multivariate analysis of variance (MANOVA) with the SAS procedure GLM.

Results

Weather

During the period from March 15 to October 15 of both years, leaf wetness periods longer than 12 h were observed mainly in April and May and also from the middle August to September. However, a few days during June and July showed long periods of wetness duration (Figure 1). A relationship between days with rain and long leaf wetness periods was also observed, but some long wetness periods were not related to rain and were due only to dew. The daily mean temperature during 2003 (trial I) was 19.8°C with a minimum temperature of 6.7°C and a maximum of 29°C. In 2004 (trial II) the total amount of rain was important during the spring, and the daily mean temperature (18.7°C) was slightly lower than for 2003, with a minimum temperature of 5.3°C and a maximum of 27.6°C. The daily mean relative humidity was greater than 90% on 15 days during 2003 and on 22 days during 2004. Days with high relative humidity were observed mainly during March and April and from late September to October.

Dynamics of disease risk

In general, periods of high risk according to BSPcast or BSPcast-m were observed especially after mid-August (Figure 2).

In the trial I, CR values reached the action

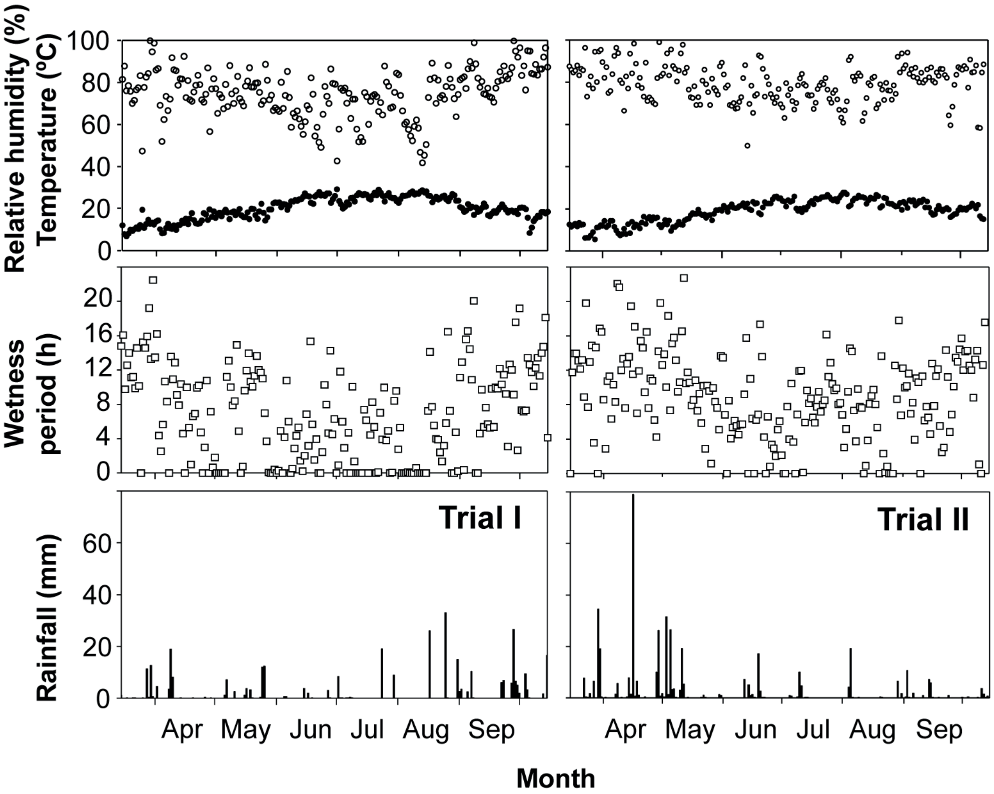

Figure 1. Dynamics of daily mean relative humidity (□), mean temperature (●), duration of wetness periods and rainfall in trials I and II.

threshold level of 0.4 on 52 days and the number of fungicide treatments was 10. During the remaining 42 days with high infection risk the canopy was covered by the fungicide applied on previous days. In 31 days the R_m value was equal to, or higher than, 0.2 and the number of fungicide applications according to BSPcast-m was 10, whereas in the other 21 days the canopy was protected by previous fungicide sprays.

In the trial II, there were 77 days with CR≥0.4 according to BSPcast, and the number of fungicide applications recommended was 15. The remaining days with high risk corresponded to days with the canopy covered by previous fungicide sprays. On 46 days R_m values were higher than or equal to 0.2 and the number of treatments performed was 13, so that in the remaining 33 days the canopy was protected by previous fungicide sprays.

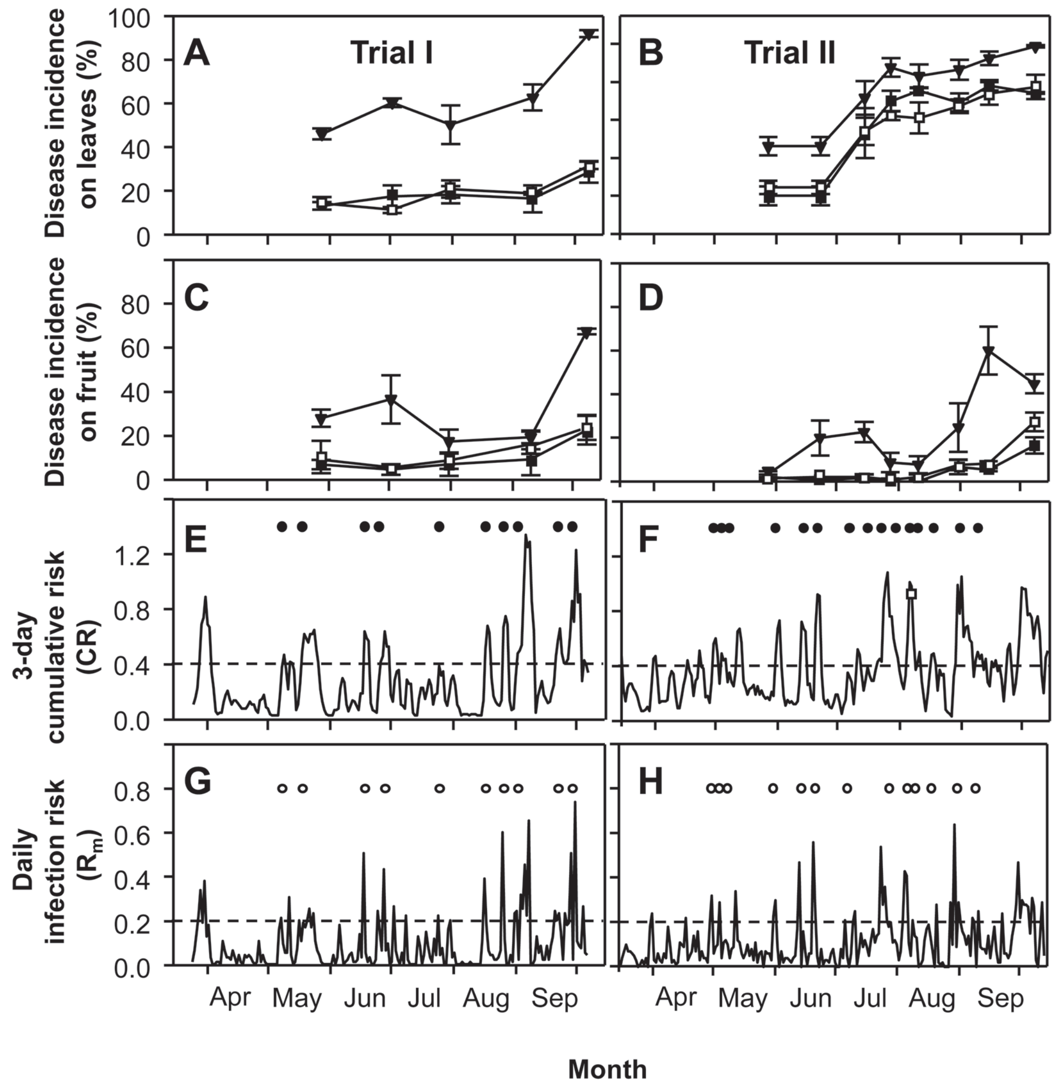

Figure 2. Brown spot disease progress curves on leaves and fruit in relation to the dynamics of the 3-day cumulative infection risk (CR) and daily infection risk (R_m) in trials I and II. Treatments corresponded to non-treated control (□) and fungicides applied at CR≥0.4 (□) or R_m≥0.2 (□) (A, B, C and D). Bars represent the standard error of the mean. Dates of treatments are indicated and corresponded to dates of CR≥0.4 (□) (E, F) or R_m≥0.2 (□) (G, H). Dashed line corresponds to action threshold values.

The action threshold was reached the same day in BSPcast (CR≥0.4) and BSPcast-m (R≥0.2) in 72.7% (trial I) and 78.6% (trial II) of cases or within 1 day of difference (27.3% in trial I and 21.4% in trial II). In this last case the daily risk above the threshold (R_m≥0.2) was always a day before the cumulated infection risk was reached (CR≥0.4).

The dynamics of wetness, temperature and relative humidity was analyzed when R≥0.2 in order to determine if the wetness period was interrupted, and in case of interruption, to determine the duration of the interruption and the relative humidity during the interrupted period. Different patterns were observed (Figure 3 and Table 1). In most events with R≥0.2, wetness was continuous (26 days corresponding to 81.2% in trial I and 43 events corresponding to 86% in trial II) (Figure 3A). Wetness was interrupted during less than 3 h and with RH>90% in four events (12.5%) in trial I and one event (2%) in trial II (Figure 3B). The relative humidity was lower than 90% during the interrupted period in two events in trial I (6.3%) and in six events (12%) in trial II (Figure 3C).

The effect of relative humidity during the interrupted period was incorporated into the model calculations in the modified model when wetness periods with low relative humidity during the wetness interruption were considered as separate periods. On 1 out of 32 days with R≥0.2 (trial I) and 5 out of 50 days with R≥0.2 (trial II), the values were lower than 0.2 and did not reach the action threshold (Table 1 and Figure 4). Thus, on an average basis, in the two trials the BSPcast original model overestimated R on 6.5% of days.

Disease progress and efficacy of treatments

In non-treated controls, the epidemics on leaves started in May in both years, whereas on fruit epi-

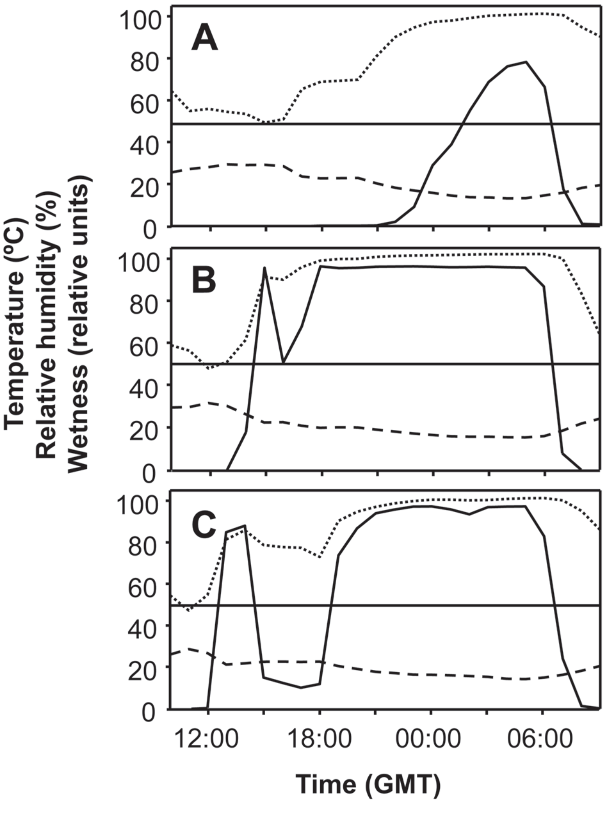

Figure 3. Patterns of the dynamics of wetness (solid line), temperature (dashed line), and relative humidity (dotted line) in the pear orchards studied. A, wetness caused by dew; B, interrupted wetness period with high relative humidity (≥90%); C, interrupted wetness period with low relative humidity (<90%).

Table 1. Frequency of the wetness events and comparison between daily infection risk predicted by BSPcast (R) or BSPcast-m (R_m) for two field trials.

Data surveyed	No. of days	
	Trial I	Trial II
Wetness event		
Continuous wetness	26	43
Interrupted wetness		
Interruption with RH≥90%	4	1
Interruption with RH<90%	2	6
Daily infection risk		
R≥0.2[a]	32	50
R_m≥0.2[b]	31	45

[a] Daily infection risk predicted by BSPcast.

[b] Daily infection risk predicted by BSPcast–m.

demics started in May in trial I and in June in trial II (Figure 2). Disease progress was discontinuous and the disease levels increased after periods with high values of CR or R_m. The disease levels were greater and progressed more rapidly on leaves than on fruit. In both years the disease incidence on fruit decreased between mid-July and August due to fruit drop. Treatments decreased the disease progression rate on leaves and fruit in comparison to non-treated controls. The dynamics of severity on fruit (lesions/fruit) or leaves (relative index) were similar to disease incidence (data not shown).

The number of fungicide sprays prescribed by both models was the same in trial I (ten applications), but in trial II differed (BSPcast, 15 applications; BSPcast-m, 13 applications). The disease control level was not different and the average savings were 13%.

The effect of treatments was measured in relation to the entire epidemics using the areas under the disease progress curves taking into account either the incidence or the severity on leaves or fruit. AUDPC-incidence and AUDPC-severity in plots treated with fungicide according to BSPcast

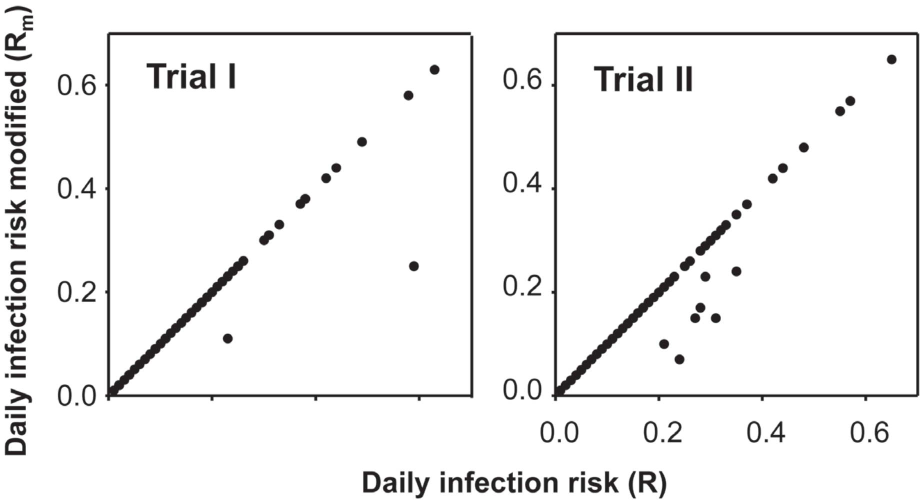

Figure 4. Comparison between daily infection risks obtained using BSPcast (R) or BSPcast-m (R_m) in trials I and II.

Table 2. Effect of different treatments scheduled by BSPcast or BSPcast–m on the areas under disease progress curves (AUDPC) for incidence and severity on fruit and leaves for two field trials.

Trial	Treatment	No. of sprays	Fruit		Leaves	
			AUDPC–Incidence	AUDPC–Severity	AUDPC–Incidence	AUDPC–Severity
I	Non–treated	0	3920.2 a[a]	113.0 a	7945.0 a	30.5 a
	BSPcast	10	1173.4 b	21.7 b	2402.7 b	8.5 b
	BSPcast modified	10	1633.9 b	20.7 b	2435.8 b	8.3 b
II	Non–treated	0	3231.3 a	114.1 a	9967.5 a	53.9 a
	BSPcast	15	413.9 b	5.9 b	7447.4 b	38.5 b
	BSPcast modified	13	612.6 b	13.6 b	7201.4 b	34.8 b

[a] Mean values followed by the same letter are not different according to the Fisher's least significance difference test at $P=0.05$.

and BSPcast-m were significantly less in relation to non-treated controls in the two trials and on leaves and fruit (Table 2). The level of disease control was similar when the fungicide treatments were applied according to BSPcast or BSPcast-m, and there were no significant differences in AUDPC-incidence and AUDPC-severity between the two spray schedules.

Disease incidence on fruit at harvest in non-treated controls was greater in trial I (67.3%) than in trial II (44.7%). Similarly, mean disease severity was 1.9 lesions/fruit in trial I and 1.3 lesions/fruit in trial II (Table 3). On leaves in non-treated controls disease incidence was similar in the two trials (from 91.8 to 98.9%) and the severity ranged from relative index of 0.47 (trial I) to 0.61 (trial II). When the fungicides were applied according to BSPcast or BSPcast-m, the incidence and severity of disease on fruit and leaves decreased in relation to non-treated controls but were not significantly different between scheduling strategies (Table 3). In trial I the reduction of disease incidence was around 67% and in trial II it was about 24%. For disease severity, the reduction compared to non-treated controls was between 78% in trial I and about 35% trial II. The efficacy of disease control did not differ in either of the trials when fungicides were applied according to BSPcast-m or BSPcast systems.

When pooled data of trials I and II were analyzed by repeated measures ANOVA, the effect of the year was not significant for incidence on fruit ($P=0.0517$), was at the limit of significance for the severity on fruit ($P=0.0399$), and was significant for incidence ($P<0.0001$) and severity on leaves ($P<0.0001$). The interaction between trial and treatment was not significant for disease incidence and severity on fruit ($P=0.7077$ and $P=0.1789$)), but was significant for disease incidence and severity on leaves ($P=0.0001$ and $P=0.0278$). The effect of treatment strategy was significant for incidence and severity on fruit and leaves ($P<0.0001$ in all cases). A contrast analysis showed that disease control levels (incidence and severity) on fruit and leaves by fungicide treatment according to BSPcast-m and BSPcast were similar, but in both cases disease levels decreased significantly in relation to non-treated controls. MANOVA revealed a significant effect of trial (Wilks'Lambda: 0.0439 and $P<0.0001$), treatment (Wilks'Lambda: 0.0277 and $P<0.0001$) and of their interaction (Wilks'Lambda: 0.0948 and $P=0.0021$). A contrast analysis showed no differences in disease control between BSPcast-m and BSPcast (Wilks'Lambda: 0.7695 and $P= 0.6266$), but significant between BSPcast-m and non-treated control (Wilks'Lambda: 0.0473 and $P<0.0001$) and also between BSPcast and non-treated control (Wilks'Lambda: 0.0472 and $P<0.0001$).

Discussion

The purpose of this study was to determine if

Table 3. Effect of different treatments scheduled by BSPcast or BSPcast-m on incidence and severity on fruit and leaves at harvest for two field trials.

Trial	Treatment	Fruit		Leaves	
		Incidence (%)	Severity (lesions/fruit)	Incidence (%)	Severity (relative index)
I	Non–treated	67.3 a[a]	1.91 a	91.8 a	0.47 a
	BSPcast	22.5 b	0.39 b	28.7 b	0.10 b
	BSPcast–m	23.9 b	0.37 b	31.7 b	0.11 b
II	Non–treated	44.7 a	1.27 a	98.8 a	0.61 a
	BSPcast	16.5 b	0.19 b	74.2 b	0.41 b
	BSPcast–m	27.3 b	0.30 b	77.3 b	0.39 b

[a] Mean values followed by the same letter are not different according to the Fisher's least significance difference test at P=0.05.

the BSPcast warning system can be modified to provide a more reliable assessment of BSP risk, and consequently to increase the efficacy of disease control. To increase the accuracy and save unnecessary treatments, a better understanding of the influence of climatic conditions on the disease cycle is required, as a key component of the development of weather-based disease forecast models. In previous research on BSP, we demonstrated that an interrupted wetness period interrupted germination-infection by conidia if the length of the interruption was ≥3 h at low relative humidity (Llorente and Montesinos, 2002). This is in agreement with the reports for *Venturia nashicola* (Li *et al.*, 2005) and *V. pirina* on pear (Villalta *et al.*, 2000), indicating that long, dry interruption periods resulted in fewer lesions, and that there was an effect of relative humidity during this period. In the case of apple scab, it has been suggested that in forecasting systems like the Mills, a dry period greater than 4 h at high temperatures (≥23°C) or greater than 8 h at low temperatures (<23°C) can be considered long enough to terminate an ongoing infection process (Li *et al.*, 2005). According to the above mentioned findings for apple scab, the effect of interrupted wetness periods and relative humidity on infection progression was incorporated into the BSPcast-m model.

The frequency of days with interrupted wetness periods observed in the present work was similar to those reported in a previous detailed study in pear orchards (Llorente and Montesinos, 2002). Most days with interrupted wetness corresponded to rainy days, and two patterns were observed: 1) wetness started after a rain during the day followed by a dry period and then dew appears at night, or 2) rain was intermittent during the whole day (24 h period) alternating wet and dry periods. Under these situations, leaves and fruit surfaces can be dry after rain, before an infection is completed and then can be re-wetted again due to further rain or dew. However, as mentioned above, under low relative humidity the infection process may be stopped irreversibly during germ-tube elongation or initial stages of host penetration. Another important observation is that on a few days the wetness period was considered interrupted because the model takes into account data from 8:00 h (GMT) to 8:00 h (GMT), even though at this time on cool mornings wetness was still present. So, these artificial interruptions of the wetness period due to the calculation procedure used by the BSPcast model may result in shorter wetness periods being recorded than actually occur. A similar situation has been reported in studies of downy mildew of lettuce (Wu *et al.*, 2001; Wu *et al.*, 2002). Although this problem imposed by the BSPcast timing is not frequent, it should be considered in future revisions of the model.

From the days with CR≥0.2 according to BSPcast when taking into account the effect of interrupted wetness periods (BSPcast-m), on only 5.5% of days was the threshold action value not reached. In addition, in several of these days the canopy was covered with the fungicide applied previously according to the model recommendation.

Since environmental conditions necessary for infections were more favourable during trial II than trial I, a higher number of fungicide sprays were applied in trial II than in trial I. A total of 10 and 15 fungicide applications were performed using the BSPcast ($CR \geq 0.4$) in the two trials, whereas using the BSPcast-m ($R_m \geq 0.2$) a total of 10 and 13 applications were performed, respectively. Therefore, in 2003 no reduction in the number of fungicide applications was obtained using the BSPcast-m, but in 2004 13% of treatments were saved in comparison to BSPcast. Similar disease control levels were obtained using BSPcast or BSPcast-m. On fruits at harvest disease incidence was reduced 60% and severity 80% in comparison to non-treated controls, which are similar values to those reported previously (Llorente *et al.*, 2000). The reduction of disease levels on leaves was less than on fruit but significant for both forecasting strategies. However, modifications to the BSPcast model were not sufficient to increase the efficacy of control. These fact can be explained because the CR (cumulative risk) is obtained by totalling the R (daily risk) of the past 3 days. Thus, when the R value is high the CR value is also high, and for this reason the dynamics of R_m and CR are highly correlated for the two strategies (BSPcast and BSPcast-m). The days in which the risk was higher than the action threshold were the same in the two strategies or at the maximum with a delay of one day. In most cases the fungicide treatments were applied on the same day in both strategies or with one day of difference. Thus, the results presented herein reinforce the robustness of the original BSPcast model as a disease predictor and show that the use of a daily risk as the action threshold does not increase its performance for disease control. Unfortunately no curative fungicides are available to control BSP, so timing of sprays before infection is critical for optimal efficacy. The objective of using a modified daily risk R_m was primarily to increase the efficacy of control but we can conclude that this modification does not affect efficacy. Although the original and modified models are equivalent in terms of efficacy, potentially the modified model may reduce the number of sprays. However, more trials have to be done under different conditions to validate BSPcast-m as an improved warning system.

The integration of weather forecasts into the model, specifically of leaf wetness, could have a strong impact on the practical implementation of the disease warning system. Using 24 h forecasts, growers could apply control measures while it is still possible to prevent the infection. Several models for forecasting leaf wetness have been tested. These models estimate leaf wetness from relative humidity, air temperature, rain and wind speed (Wu *et al.*, 2001; Kim *et al.*, 2005; Kim *et al.*, 2006; Magarey *et al.*, 2006; Raid *et al.*, 2008; Sentelhas *et al.*, 2008). It has been demonstrated that some of these models are accurate at site-specific levels and can enhance performance of disease warning systems (Kim *et al.*, 2006). However, the results presented herein showed that dew events were the dominant wetness source in pear orchards. Unfortunately, dew formation is influenced by several factors like leaf area, plant architecture, arrangement of plants in the field and crop height, and dew formation is mediated by temperature, vapour pressure, incoming short and long-radiation, and wind (Huber and Gillespie, 1992; Magarey *et al.*, 2005; Batzer *et al.*, 2008). Therefore, it remains difficult to obtain a leaf wetness predictor from other environmental parameters. Nevertheless, we still suggest that a specific leaf wetness duration predictor could be developed and evaluated under our climatic conditions.

Finally, in order to increase the efficacy of BSP control and to decrease the number of fungicide applications, a multicomponent warning system has to be developed, including information in relation to dormancy of the pathogen, reproduction and dispersal. This approach has been incorporated in forecasting of other pathosystems (Madden *et al.*, 2000; Wu *et al.*, 2001; Kim *et al.*, 2006; De Wolf and Isard, 2008; Raid *et al.*, 2008). Integrated control of BSP requires long-term strategies that take into account the biology of the pathogen, environmental factors affecting disease or the pathogen cycle (BSPcast and PAMcast models), host susceptibility, inoculum density and fungicide characteristics (Llorente and Montesinos, 2006). Future research should also aim to develop new fungicides, and biological control agents for better disease control.

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