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Evaluation of Two Models to Predict Grey Mould in Strawberry

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Summary

Two models developed to predict flower infections by *Botrytis cinerea*, the cause of grey mould, were evaluated in field grown June bearing strawberries in Norway. Fungicide applications based on model predictions were compared to a standard spray programme. The Ohio model predicted risk of infection based on temperature and number of hours with free water, and the BOTEM model used day time vapour pressure deficit and night time temperature. The Ohio model was tested in 16 site/year combinations and the BOTEM model in 8 of the same sites/years. The standard spray programme included 4 (14 sites/years), 3 (one site/year) or 2 (one site/year) routine sprays during flowering and early fruiting with different fungicides, approximately one week apart. All plots treated with fungicides had a lower level of grey mould and a higher yield compared to unsprayed. The mean percentages of grey mould in fruits at harvest were 7.2, 11.5, and 16.5 if following the standard programme, the Ohio, or the BOTEM models, respectively. In several sites/years, very good control of grey mould was achieved using a less intensive spray programme based on infection predictions, but the models need improvement to more clearly identify conditions that do not permit a reduction in fungicide applications. When all three strategies were included, the mean number of fungicide applications was significantly lower ($P < 0.001$) using the Ohio and BOTEM models (1.4 and 1.1, respectively) compared to the standard programme (3.8). For all sites/years including the standard programme and the Ohio model, 3.8 and 2.0 sprays were applied, respectively. Yield was always higher in treated plots than in untreated, but the difference was significant only in 7 and 5 out of 16 site/year combinations for the normal programme and the Ohio model, respectively, and 2 out of 8 site/year combinations for the BOTEM model.

Key words. *Botrytis cinerea* – cyprodinil – disease warning – fenhexamid – fludioxinil – tolylfluanid

Introduction

Grey mould, caused by the fungal pathogen *Botrytis cinerea* Pers. ex Fr., is the most important disease of strawberry (*Fragaria* × *ananassa* Duch) in Norway, causing severe yield reductions. Primary infection by *B. cinerea* occurs from conidia in open flowers, either causing wilting of flowers or latent infections that may develop when the fruit ripens (Powelson 1960; Jarvis 1962; Wilcox and Seem 1994). Flowers are susceptible at all stages of development, but the level of resistance increases with time. An open flower is more likely to become infected than fruits at the green bud stage (Jarvis and Borecka 1968; Hjeljord et al. 2001), and periods of high humidity or free moisture are necessary for an infection to occur (Bulger et al. 1987). Different alternative management strategies have been investigated, including use of biocontrol agents (Sutton and Peng 1993; Sutton 1994; Boff et al. 2002, Elad and Stewart 2004; Hjeljord et al. 2011) and by reduced fungicide rates (Sønsteby et al. 1996). However, effective control of grey mould still relies on several routine applications of fungicides. In June bearing cultivars in Norway, 4–6 sprays during flowering and early fruiting is normal. This usually controls the disease effectively, but may fail during conditions highly favourable for disease development (Strømeng et al. 2006). Bulger et al. (1987) in Ohio, USA, developed a model relating the probability of infection during bloom to temperature and wetness duration. At optimal temperatures (15 to 25 °C), a minimum of 11 h of leaf wetness or dew was needed to get 25 % flower infection. The model is based on data from laboratory and growth chambers, and gives a relationship between incidence of petal necrosis and infected fruit from infected flowers, as a function of temperature and hours of free water. Xu et al. (2000) in UK has developed several models to predict infection of *B. cinerea* in strawberry flowers based on field data. The models related incidence of flower infections to weather conditions and inoculum (alone or in combination). Models using weather variables only gave better

predictions than models based on inoculum, and including both parameters only slightly improved the predictions. Of the models tested, one including day time vapour pressure deficit and night time temperature gave the best prediction of flower infections (Xu et al. 2000). The latter model and the one from Ohio were selected for further evaluation in the present work.

The aim of this study was to evaluate the two selected models in comparison with a standard calendar based spray programme under weather and growing conditions in Norway, and to investigate if a control programme based on prediction of infections may reduce the need for fungicide applications against grey mould in strawberry.

Materials and Methods

Models

The model developed in Ohio (hereafter referred to as the Ohio model) (Bulger et al. 1987) was included in 16 sites/years of open field grown strawberry. In 2001, the infection risk was calculated manually based on on-site climatic data, using a table showing the minimum number of hours of wetness required for 25 % flower infection at different temperatures that may lead to subsequent flower wilting or fruit decay. From 2002, the model warnings were broadcasted online through the Norwegian warning system for pests and diseases in crop plants (www.VIPS-landbruk.no), and was based on precipitation, leaf wetness and air temperature from on-site weather stations (Instrumenttjenesten AS, Ås, Norway).

The model developed in UK (Xu et al. 2000) was included in 8 sites/years. The model was supplied by the developer as a readymade program named BOTEM (hereafter referred to as the BOTEM model), and used daily average vapour pressure deficit (VPD) and temperature to estimate the daily incidence of flower infections. Percentage of predicted flower infection was then converted to percentage of fruit infection based on the model derived by Bulger et al. (1987). The program produced a graph that showed predicted fruit infection, and fungicides were applied when BOTEM predicted a fruit infection risk higher than 10 %. BOTEM was run manually, using weather data from on-site weather stations. In 2006 and 2007, fungicide applications were only performed when the model predicted infection. The following two years, fungicides were also applied if no sprays had been performed by the time approximately 30 % of the flowers had opened, or if more than 14 days had elapsed since the previous application. This strategy was recommended by the developer of the model (X. Xu, East Malling Research, pers. comm.).

Trial design

Experiments were conducted at two different sites from 2001 to 2003, where one was located in south-eastern Norway (Kvelde, Vestfold County) and one in western Norway (Valldal, Møre og Romsdal County). One additional site in western Norway was included in 2002 and 2003 (Sandane, Sogn og Fjordane County). Treatments included a normal spray programme and spraying based on warnings from the Ohio model. From 2006 to 2009, experiments were conducted in Valldal in western Norway and also at one site in south eastern Norway (Lier, Buskerud County). In these experiments, spraying based on warnings from the BOTEM model was included in addition to the treatments described above. In all trials, an untreated control was included. There were four replicates (five in 2001) of each treatment for each site, and each replicate consisted of 6 meters of single row (or 3 meters double row), and one row was always left unsprayed on each side.

The normal spray programme consisted of two applications with 0.5 kg ha^{-1} Switch (fludioxonil + cyprodinil, 25.0 + 37.5 % a.i., Syngenta) in alternation with two applications with 1.5 kg ha^{-1} Teldor (fenhexamide, 50 % a.i., Bayer CropScience) at all sites and all years except in Kvelde in 2001 and Lier in 2007. In Kvelde in 2001, only one application with Switch and one with 3.0 kg ha^{-1} Euparen M (tolylfluanid, 50 % a.i., Bayer CropScience) were applied, and in Lier in 2007 there were two applications with Switch and one with Teldor. Switch was used when spraying after a warning was issued by the models, and applied as soon as possible after an infection was predicted, preferably within 5 days (in 2001–2003) or 1500 degree hours (base temperature 0 °C) (in 2006–2009). If a new warning was issued within 5 days or 1500 degree hours after the previous application, no fungicides were applied. Fungicides were applied with Hardi wheel barrow sprayers, with a hand held lance with one nozzle. Spraying was applied to run-off (800–1000 L ha^{-1}) using a pressure of 500–600 kPa. All cultivars in these experiments were June bearers, cultivated as a perennial crop. Information for each site/year, location, planting year and planting system is provided in Table 1.

Evaluation of fruit rot

At each picking date, the number and weight of healthy and number of infected fruits were recorded for each plot. The infected fruits were subdivided according to the disease (other fruit diseases than grey mould only occurred to a minor degree and were not further considered). For each replicate, the percentage of fruits (based on numbers) with grey mould and the weight of healthy fruits were recorded. The efficacy of the different treatments was calculated based on the following equation:

$$\text{Efficacy} = \frac{A - B}{A} \times 100$$

where A is percent grey mould in the untreated plot and B is percent grey mould in the treated plot. Within each site/year combination, data for yield, percent grey mould

Table 1. Site, year, cultivar, planting year and planting system where field experiments took place.

Site	Year	Cultivar, planting year	Planting system
Kvelde	2001	'Korona', 2000	Double row, plastic mulching
	2002	'Korona', 2000	Double row, plastic mulching
	2003	'Korona', 2001	Double row, plastic mulching
Sandane	2002	'Polka', 1999	Elevated ridge, single row, plastic mulching
	2003	'Polka', 2001	Elevated ridge, single row, plastic mulching
Valldal	2001	'Senga Sengana', 1999	Elevated ridge, single row
	2002	'Senga Sengana', 2001	Elevated ridge, single row
	2003	'Senga Sengana', 2001	Elevated ridge, single row
	2006	'Senga Sengana', 2004	Elevated ridge, single row
	2007	'Senga Sengana', 2004	Elevated ridge, single row
	2008	'Polka', 2007	Elevated ridge, single row
	2009	'Polka', 2008	Elevated ridge, single row
Lier	2006	'Frida', 2006	Double row, straw mulching
	2007	'Frida', 2006	Double row, straw mulching
	2008	'Frida', 2006	Double row, straw mulching
	2009	'Senga Sengana', 2008	Double row, straw mulching

and efficacy were subjected to analysis of variance. For data on efficacy, pooled data from all sites/years were also analyzed. Significant treatment differences were separated by Duncan`s multiple range test, and different letters indicate significant difference ($P \leq 0.05$). All data were tested for homogeneity of variance, and no need for transformation was detected.

Results

Table 2 shows the weekly mean temperature and accumulated precipitation from first open flower until the end of harvest. The variation in temperature was low, but the amount of precipitation varied greatly both within and between sites and years. There was no obvious relationship between amount of precipitation and percentage of grey mould, even if periods during flowering and fruiting were investigated separately. For example, Lier 2006 had the second lowest total amount of precipitation (66.6 mm) and 42.1% grey mould in the untreated plots, and Sandane 2003 only had a total of 15.6 mm and 39.0 % grey mould in the untreated plots. The two years with the highest precipitation (Lier 2007 and 2009) had the second and third highest percentage of grey mould in the untreated plots (48.4 and 57.2 %, respectively).

The mean percentage of fruits infected by grey mould in the untreated plots was 30.1, but varied greatly between sites and years (3.2 to 69.9 %) (Table 3). For comparative purposes, both the overall mean and the mean for years where the BOTEM model was used are included in Table 3. In plots treated with a standard spray programme, the percentage of grey mould varied from 0.4 to 24.8 (mean 7.2), and the efficacy of the treatments from 43.8 to 96.7 (mean 78.3). For both parameters, the standard spray programme was always significantly better ($P \leq 0.01$) than unsprayed. For the Ohio and BOTEM models, the percentage of grey mould varied from 0.3 to 43.6 (mean 11.5) and 2.5 to 33.4 (mean 16.5), respectively, and the corresponding percentages of efficacy were 40.0 to 93.7 (mean 73.2) and 19.2 to 66.7 (mean 50.4), respectively. Fungicide applications based on the two models reduced grey mould compared to unsprayed at all locations in all years. For only one site/year the percentage of grey mould was significantly higher using the Ohio model (Valldal, 2001; $P = 0.026$) and the BOTEM model (Valldal, 2008; $P = 0.049$) compared to the normal spray programme. The Ohio model gave a significantly lower efficacy than the normal spray programme in 3 out of 16 site/year combinations ($P \leq 0.05$), and the corresponding number for the BOTEM model was 5 out of 8 ($P \leq 0.05$). The overall efficacy was significantly higher using the normal spray programme compared to spraying according to the two models ($P \leq 0.01$), and the efficacy of the Ohio model was significantly higher than that of the BOTEM model ($P = 0.01$).

In 7 out of 16 site/year combinations the yield was significantly higher if treated according to a normal spray programme ($P \leq 0.05$) compared to unsprayed. When spraying was based on the Ohio model, a significantly higher yield ($P \leq 0.05$) compared to the unsprayed was

Table 2. Weekly mean temperature (°C) and accumulated precipitation (mm) from start of bloom until end of harvest.

Site/ Year		Weeks from first bloom until end of harvest									$\bar{x}$ temp./ Σ prec.
		1[a]	2	3	4	5	6	7	8	9	
Kvelde	Temp.	11.8[1,2b]	12.0[1]	13.0[1,2]	15.7	17.7	20.0	16.2	15.7	16.3	15.4
2001	Prec.	11.4	19.8	10.0	13.6	9.6	19.0	60.8	5.0	0.0	149.2
Kvelde	Temp.	12.9[1,2]	14.2[1,2]	13.6[1,2]	19.2[1]	15.0	16.6	14.0	14.9	17.9	15.4
2002	Prec.	4.6	38.6	25.4	10.0	29.2	26.6	5.6	53.0	26.4	219.4
Kvelde	Temp.	16.2[1,2]	15.9[1,1,2]	16.2[1]	17.3	18.4	19.6	–[c]	–	–	17.3
2003	Prec	10.8	3.8	36.4	41.6	3.6	1.8	–	–	–	98.0
Sandane	Temp.	12.0[1,2]	14.5[1,2]	13.8[1,2]	16.7[1]	17.8	14.7	12.8	13.1	13.7	14.9
2002	Prec.	7.6	0.4	3.2	0.6	1.8	20.0	29.2	26.6	23.4	112.8
Sandane	Temp.	11.2[1]	12.5[1,2]	14.2[1,2]	12.6[1,2]	13.5[2]	16.8	17.5	16.1	21.7	13.5
2003	Prec.	1.0	4.4	3.6	6.2	0.0	0.2	0.2	0.0	0.0	15.6
Valldal	Temp.	9.4[1]	11.8[1]	15.9[1,2]	14.9[1,2]	17.4	13.1	14.9	14.8	–	13.7
2001	Prec.	39.8	4.6	6.9	18.0	3.0	49.3	7.0	14.4	–	143.0
Valldal	Temp.	14.2[1,2]	19.3[1]	14.5[1,2,2]	12.8[1]	12.9	13.5	16.6	16.3	15.2	14.5
2002	Prec.	2.6	0.0	21.8	17.4	34.0	36.2	2.6	0.6	22.8	138.0
Valldal	Temp.	13.9[1]	12.4[1,2]	14.5[1,2,2]	18.6[1]	15.8	18.8	19.3	17.2	–	15.7
2003	Prec.	26.2	15.4	2.0	0.0	8.8	11.8	11.4	16.2	–	91.8
Valldal	Temp.	12.9[1]	15.0[1,2]	13.0[1,2,2]	15.5[1]	17.2	14.2	17.1	18.8	17.1	14.6
2006	Prec.	0.2	13.0	24.0	1.8	19.4	24.6	3.0	9.2	20.4	115.6
Valldal	Temp.	16.6[1]	17.3[1]	11.3[1,2]	14.8[1,2,3]	15.1	19.3	14.3	14.4	15.0	15.7
2007	Prec.	10.0	33.8	13.6	15.4	7.4	0.0	21.8	42.2	23.6	167.8
Valldal	Temp.	18.2[1]	10.8[1,2]	13.2[1,2,3]	11.8[1,2]	18.1	15.8	13.3	17.8	22.3	14.6
2008	Prec.	3.2	60.0	6.6	13.2	8.4	13.8	11.0	0.0	0.6	116.8
Valldal	Temp.	11.4[1,2]	10.1[1,3]	10.9[1]	14.5[1,2,3]	20.6	17.6	15.7	15.9	14.8	14.2
2009	Prec.	24.4	17.6	7.0	11.0	21.2	0.0	36.2	54.6	18.0	190.0
Lier	Temp.	10.9[1]	13.7[1]	16.9[1]	16.7[1]	14.0	18.7	18.1	18.3	21.1	15.1
2006	Prec.	14.8	0.6	0.0	16.0	18.0	0.0	15.4	1.8	0.0	66.6
Lier	Temp.	10.8[1]	11.5[1]	14.5[1,2,3]	19.7	14.1	15.4	14.9	16.2	16.0	14.3
2007	Prec.	6.0	51.2	35.6	2.0	3.4	88.6	126.0	61.2	24.4	398.4
Lier	Temp.	10.0[1]	16.5[1]	19.1[1,3]	12.5[1]	13.4	14.4	17.3	16.3	15.5	14.3
2008	Prec.	3.0	0.0	0.0	17.4	16.6	8.4	45.2	8.4	30.0	129.0
Lier	Temp.	13.3[1]	12.6[1,3]	13.0[1,2]	18.1[1,3]	22.8	15.3	16.3	15.8	15.7	15.8
2009	Prec.	1.4	8.0	17.4	0.0	14.6	96.2	28.8	30.4	30.8	227.6

[a] Week numbers with white background indicate flowering but no harvest, lightly shaded background indicate start of harvest, dark shade indicate main harvest period until end of harvest.

[b] Elevated numbers indicate that fungicide applications were performed during that week: 1 = Sprayed according to the normal spray programme, 2 = sprayed according to the Ohio model and 3 = sprayed according to the BOTEM model. Two identical numbers means that two sprays were performed based on the same model during that week.

[c] Harvest not performed.

observed in 5 out of 16 site/year combinations. The BOTEM model gave significantly higher yield ($P \leq 0.05$) than unsprayed in 2 of the 8 site/year combinations, and for the same 8 site/year combinations the corresponding numbers for the normal spray programme and the Ohio model were 3 and 1, respectively.

The mean number of applications in the normal spray programme was 3.8, and it was significantly higher ($P < 0.001$) than the corresponding number for the Ohio (2.0 or 1.4) and the BOTEM (1.1) models. In 2009, no warnings were issued by the BOTEM model in any of the sites. Thus, one application was performed at 30 % bloom at both sites, and a second spray was applied two weeks later. In Lier in 2006 and 2008, no warnings were issued at all, and only one spray at 30 % bloom (according to the BOTEM model) was performed in 2008.

Table 3. Effects of three different spray (spr.) strategies on incidence of grey mould and yield of strawberry grown in open field at four different locations in Norway (from 2001 to 2009).

Site	Year	Untreated[a]		Normal				Ohio				BOTEM			
		% GM[b]	Yield (kg)[c]	Spr.[d]	% GM	Efficacy[e]	Yield (kg)	Spr.	% GM	Efficacy	Yield (kg)	Spr.	% GM	Efficacy	Yield (kg)
Kvelde	2001	39.2 a[f]	12.7 a	2	6.3 b	83.6 a	21.2 b	2	12.1 b	63.6 a	21.1 b				
	2002	11.7 a	5.1 a	4	4.3 b	66.4 a	6.1 a	3	3.9 b	66.0 a	5.6 a				
	2003	21.9 a	5.6 a	4	0.7 b	96.7 a	6.6 a	1	5.2 b	76.3 a	6.8 a				
Sandane	2002	28.5 a	6.4 a	4	1.7 b	94.0 a	11.5 b	3	2.1 b	92.6 a	11.0 b				
	2003	39.0 a	6.9 a	4	6.5 b	83.2 a	13.9 b	4	5.4 b	86.3 a	14.8 b				
Valldal	2001	69.9 a	3.3 a	4	18.3 c	73.6 a	10.8 c	2	27.3 b	60.6 b	8.8 b				
	2002	30.3 a	9.0 a	4	2.9 b	90.4 a	11.6 a	3	7.1 b	75.6 b	11.5 a				
	2003	6.6 a	3.7 a	4	0.4 b	93.0 a	4.4 a	3	0.3 b	93.7 a	4.0 a				
	2006	18.1 a	6.5 a	4	2.7 b	84.2 a	6.9 a	2	5.2 b	72.7 a	7.6 a	1	5.9 b	66.7 a	9.0 a
	2007	6.7 a	7.0 a	4	0.5 b	91.6 a	8.1 a	2	1.9 b	67.4 b	7.8 a	1	2.5 b	55.9 b	7.1 a
	2008	29.5 a	6.6 a	4	2.4 c	91.9 a	9.0 b	3	2.8 c	91.1 a	7.4 a	1	10.7 b	63.9 b	8.4 b
	2009	29.8 a	5.3 a	4	4.5 b	84.0 a	6.1 a	2	6.7 b	77.3 a	6.5 a	2	10.0 b	66.5 b	7.4 a
Lier	2006	42.1 a	8.4 a	4	17.7 b	57.9 a	14.7 b	0	43.6 a	–[g]	8.5 a	0	33.1 a	–	9.0 a
	2007	48.4 a	7.1 a	3	24.8 b	46.0 a	10.2 a	1	29.4 b	40.0 a	8.2 a	1	33.4 b	29.1 a	8.8 a
	2008	3.2 a	4.7 a	4	1.3 b	43.8 a	5.6 a	0	3.7 a	–	5.3 a	1	2.6 a	19.2 b	5.8 a
	2009	57.2 a	2.6 a	4	15.6 b	72.6 a	5.4 b	1	22.3 b	61.4 a	4.6 b	2	27.5 b	51.6 b	4.9 b
Average (2006–2009)		29.4 a	5.9 b	3.8 a	8.7 b	71.5 a	8.3 a	1.4 b	15.6 b	68.3 b	7.0 ab	1.1 b	16.5 b	50.4 c	7.6 ab
Total average		30.1 a	6.3 b	3.8 a	7.2 b	78.3 a	9.5 a	2.0 b	11.5 b	73.2 b	8.7 a	1.1 b	16.5 b	50.4 c	7.6 a

[a] Untreated = no fungicides applied, Normal = four calendar based fungicide applications alternating between cyprodinil + fludioxinil and fenhexamid (in Kvelde 2001 there was one treatment each with cyprodinil + fludioxinil and tolylfluanid, and in Lier 2007 there was two treatments with cyprodinil + fludioxinil and one with fenhexamid), Ohio and BOTEM are applications with cyprodinil + fludioxinil according to predictions developed by Bulger et al. (1987) or Xu et al. (2000), respectively.

[b] % GM = percentage of strawberry fruits with grey mould

[c] Yield = kg healthy strawberry fruit per plot

[d] Spr. = number of fungicide applications per treatment

[e] Efficacy is the effect of the treated plots compared to the level of disease in the untreated plot [((untreated – treated)/ untreated) × 100]

[f] For each site/year, percent grey mould and yield from the four spray strategies were compared using Duncan's Multiple Range Test, and values followed by different letters are significantly different ($P \leq 0.05$). For the average values, percent grey mould, yield and number of sprays were compared.

[g] Efficacy was not calculated if no sprays were performed.

Discussion

The present investigation showed that models predicting risk of infection by *B. cinerea* can be used to reduce the number of fungicide applications during strawberry flowering and fruiting, and still retain a relatively good level of disease control, as indicated before (Van Laer et al. 2005; MacKenzie and Peres 2012). The number of sprays issued by the Ohio model varied from 0 to 4, and in general it issued more warnings than the BOTEM model. A maximum of two sprays were applied in one season when the BOTEM model was used to set the time of fungicide application. There was some variation in marketable yield between the different treatments, but the differences were not always significant. This is comparable to previous studies, where number of fungicide applications could be reduced by 50 % or more without significant reduction in marketable yield (Van Laer et al. 2005; MacKenzie and Peres 2012).

The amount of grey mould in the unsprayed plots in these experiments varied from 3 to almost 70 %. In

Valldal 2001, the marketable yield in unsprayed plots was 70 % lower than in plots sprayed with a standard spray programme, while in Valldal 2007, the corresponding reduction was 14 %. Valldal 2001 and Valldal 2007 had 70 and 7 % grey mould in the untreated plots, respectively, and the corresponding levels of disease after a standard spray programme were 18.0 and 0.5 %. Still, the effect of reducing the number of fungicide applications from 4 to 2 when sprays were based on warnings was similar, with efficacies of 61 (Valldal 2001) and 67 (Valldal 2007). Also in Lier in 2007 and 2009, where the disease level in untreated plots was high (approximately 50 %), reduced number of sprays (one or two sprays based on warnings) gave an efficacy comparable to the three or four sprays applied in the standard spray programme.

There was no coherence between the amount of precipitation during flowering and harvest and the level of disease in the unsprayed plots in these experiments, even though a positive correlation between amount of precipitation during harvest and incidence of grey mould has been reported earlier (Hjeljord et al. 2011). Lier 2006 and 2007 had approximately the same level of disease (42 and 48 %, respectively) in the untreated plots, despite a difference in total precipitation of 332 mm. In Kvelde 2001 and Sandane 2003, 149 mm (Kvelde) and 16 mm (Sandane) both resulted in 39 % infected berries in the untreated plots. One explanation for this apparent lack of connection between precipitation and disease development is the ability of conidia to maintain their infectivity if exposed to protracted dry periods. In detached strawberry flowers in laboratory experiments, dry-inoculated conidia were still able to infect flowers after 5 days with RH below 50 % (L. G. Hjeljord, Norwegian University of Life Sciences, pers. comm.). The results further showed that germinated conidia in detached flowers (24 to 72 h with RH above 90 %) could be exposed to dry periods (24 to 72 h with RH below 50%) and still retain their infectivity. Necrosis on sepals appeared after 72 to 96 h with RH above 90 % independent of length and timing of the dry period. Although these experiments took place in protected environment with e.g. no UV-exposure, they indicate that the criteria for resetting models during insufficient surface wetness may need to be examined more carefully. In some of the sites/years there were no warnings issued by the models, even if the disease level was high in the unsprayed plots. For the Ohio model, this was apparent in Lier in 2006 and 2008. For the BOTEM model in 2008 and 2009, applications were carried out at 30% bloom and two weeks afterwards as no warnings were issued. This indicates that the recommended threshold of 10 % fruit infection (X. Xu, East Malling Research, pers. comm.) was set too high. Using a threshold of 6 % fruit infection would have resulted in an average of 2.5 warnings for the 4 years in Lier, and 2.8 warnings for the 4 years in Valldal.

The main difference between the two models is that the Ohio model uses leaf wetness (LW) and BOTEM uses vapour pressure deficit (VPD; based on RH and temperature) to predict the duration of surface moisture. Definition of surface moisture is difficult (Magarey et al. 2005), and its measurement needs an automatic data logger, but there are no standards in the design of leaf wetness sensors. Using VPD eliminates the problems with estimating surface wetness duration, and there is no need for a threshold of dry periods to reset the model after an infection period, because no surface wetness parameter is included in the model.

In management of grey mould in strawberry, reducing the number of fungicide sprays often receives attention, as public awareness of environment and food safety is increasing. The strawberry industry will continue to depend on using efficient fungicides in the foreseeable future, and a good way of reducing the number of applications without losing efficacy is by better timing of applications in accordance with infection risks. These experiments have shown that good control of grey mould can be achieved using a less intensive spray programme based on infection predictions, but the models need improvement to more clearly identify conditions that do not permit a reduction in fungicide applications.

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