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The use of forecasting model iMETOS® for strawberry grey mould management

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Abstract

Traditionally, management of strawberry (*Fragaria* × *ananassa* Duch.) diseases is based on chemical control; however, because of the high cost of pesticides and their adverse environmental effects, it is essential to determine the correct application timing. Disease forecasting models calculate optimal conditions for disease development, therefore model-based applications of fungicides are more precise. This study aimed to evaluate how to apply fungicides more precisely by using grey mould (*Botrytis cinerea* Pers.: Fr.) risk forecasting model iMETOS® in order to reduce the number of applications, to obtain yield increase and ensure the safety and quality of strawberries. Field experiments were carried out at Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry during 2008–2014 on a strawberry cultivar 'Elkat'. The experimental treatments were: 1) untreated, 2) conventional disease management system and 3) using forecasting model iMETOS®.

The experimental data indicated that the most favourable conditions for the spread of strawberry grey mould occurred in the 3rd–4th week of May and in the 1st week of June. The application time as determined by the forecasting model iMETOS®, gave yield increases in 2008–2014 of 0.9, 9.5, 1.0, 2.8, 4.3 and 3.2 t ha^{-1}, respectively, compared to the control treatment. In 2008–2014, the yield increase in the conventional disease management treatment was 3.2, 7.0, 3.5, 2.8, 2.7 and 2.7 t ha^{-1} higher compared to the control treatment. In 2009, the yield increases in the iMETOS® treatment were 2.5 t ha^{-1}, in 2013 – 1.6 t ha^{-1} and in 2014 – 0.5 t ha^{-1} compared with the conventional disease management treatment. In 2011, there was no yield increase; the yield was similar in both treatments. In the iMETOS® treatments, the amount of rotten fruit was 0.7, 2.3, 0.7, 0.1, 0.2 and 0.6 t ha^{-1} lower than in the control treatment.

Fungicide application according to the recommendations of the forecasting model iMETOS® allows reduction of plant protection costs, especially when the conditions for the spread of diseases are not favourable.

Key words: *Botrytis cinerea*, disease risk, incidence, leaf wetness.

Introduction

According to FAOSTAT, in 2016 the harvested area of strawberry (*Fragaria* × *ananassa* Duch.) was more than 107741 ha in the European Union (FAOSTAT, 2016). In 2015, the top three producers of strawberry were Spain, Poland and Germany (FAOSTAT, 2016). Lithuanian strawberry production is on the increase. In 2017, the declared area of commercial strawberry farms in Lithuania totalled 587 ha (LTDS, 2018).

The climate change is becoming an important issue nowadays because of considerable variation in the meteorological factors such as rainfall, humidity and temperature. The change of the temperature slightly shifts the agro-climatic zones. Despite this, pathogens can spread into new geographical areas, survive the winter season in northern regions and increase susceptibility to the host infection (Nazir et al., 2018). Pathogens are infecting the plants at the specific development stages, for example, grey mould affects strawberry plants at the flowering stage (Carisse, 2016; González et al., 2016; Fillinger, Walker, 2016; Nazir et al., 2018).

Among strawberry diseases, grey mould (*Botrytis cinerea* Pers.: Fr.) is one of the most significant yield-reducing diseases, causing substantial economic losses worldwide. Annual yield losses due to grey mould are severely destructive, with ranges from 15% to 50%, particularly under humid conditions. Frequently, the pathogen is invisible until ripening and causes fruit rot during the harvest, storage, transportation, thus reducing market value (Blanco et al., 2006; Miličevič et al., 2006; Shtienberg, 2007; Carisse, 2016; Elad, 2016; Siegmund, Viefhues, 2016). The conventional disease control of strawberries relies on several applications of fungicides. Therefore, the fixed-interval application of fungicides in strawberry relies on their high inputs. However, due to the high cost of pesticides and their adverse environmental effects and resistance potential, the use is often based on the need (Xu et al., 2000; Blanco et al., 2006; Miličevič et al., 2006; Shtienberg, 2007; MacKenzie, Peres, 2012; Carisse, 2016; Elad, 2016; Fillinger, Walker, 2016). It has been reported that a regular use of fungicides leads

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to a decrease in their efficacy and to the development of resistance (Nicot et al., 2016; Elad, 2016; Fillinger, Walker, 2016). However, strawberries have a short decay period, because of natural softening. Furthermore, postharvest diseases cause additional yield losses. Post-harvest fungicide use is not allowed on strawberries. Therefore, a good disease control strategy is required in the field (Satin, 1996; Droby et al., 2009; Sharma et al., 2009; Elad, 2016; Fillinger, Walker, 2016).

Meteorological conditions play an important role in the development and spread of fungal diseases. Various forecasting models that calculate the risk of infection for a particular disease with the use of meteorological data have been developed. Disease forecasting models help in assessing the risk of disease epidemics on the farms. The usage of forecasting models enables growers to make timely applications of fungicides when conditions are favourable for the disease, thus reducing the number of applications and avoiding unnecessary sprays. The forecasting models may optimise the use of pesticides. The risk of strawberry flower infection caused by grey mould depends on the air temperature and humidity (Miličevič et al., 2006; Shtienberg, 2007; Valiuškaitė et al., 2008; Pavan et al., 2011; Rasiukevičiūtė et al., 2013; 2016; Shtienberg, 2013; Cordova et al., 2017 a). The weather conditions of the autumn and winter have a significant impact on strawberry yield (Pathak et al., 2016).

Favourable conditions for grey mould are high humidity, moderate temperature and leaf wetness period. It has been observed that lesser flower infection, caused by grey mould, occurs at the temperatures below 15°C or above 25°C (Carisse, 2016; Romanazzi, Droby, 2016; Fillinger, Walker, 2016). Bulger et al. (1987) found correlations between leaf wetness and temperature, where favourable temperature and leaf wetness periods are sufficient for the pathogen to infect flowers. The forecasting model iMETOS® calculates favourable periods for the development of grey mould infection (Raudonis et al., 2008; Valiuškaitė et al., 2008; Rasiukevičiūtė et al., 2013; 2016).

In this study, we evaluated the efficacy of grey mould risk forecasting model iMETOS® for strawberry grey mould management.

Materials and methods

Experimental design. Research on the adaptation of the disease risk forecasting model iMETOS® (Pessl Instruments, Austria) for grey mould (*Botrytis cinerea* Pers.: Fr.) management was carried out at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry. The open field strawberry (*Fragaria* × *ananassa* Duch.) experiments were planted on 16 May 2007, 12 May 2009 and 14 May 2012. The applications according to the model were carried out in 2008–2014. The experiments were done on a strawberry cultivar 'Elkat', planted at a spacing of 0.8 × 0.3 m in a profiled soil on two rows of white film-mulch. The treatments were replicated four times and arranged in a randomised complete block. The plot size was set up according to the OEPP/EPPO (2015) standard PP 1/16 (3), at least 26 (~3.2 m^2) plants each. The strawberry experiments were irrigated and fertilised through drip lines.

Forecasting model. A detailed description of the forecasting model iMETOS® is provided in Rasiukevičiūtė et al. (2013; 2016). The optimal temperature for grey mould development is 20°C (15–20°C) and leaf wetness periods of above 80%, which last more than 4 hours. The longer the infection risk periods last, the higher the probability of fruit infection is. In this study were evaluated meteorological data: temperature, leaf wetness and risk periods for disease development. Therefore, were calculated average air temperature and divided it into minimal and maximal °C temperature of the day. Leaf wetness period was measured in minutes. The rainy days were counted, and one rainy day is considered if more than >0.5 mm rain falls per day. Favourable days for disease development were counted and were expressed as days per month. The risk periods of infection were classified into groups; one group is considered if the infection risk higher than 60% lasts longer than 3 days. The environmental factors monitoring system iMETOS® was located 700 meters away from the strawberry plantation.

Treatments. 1. Untreated: the pathogen was not controlled on these plots in order to evaluate grey mould progress. 2. Conventional: conventional plant protection system, fungicides were sprayed starting from 10% flowering stage (BBCH 61–65) and repeated every week (three times). 3. iMETOS®: fungicides were applied according to the forecasting model iMETOS®, when the risk period higher than 60% lasts longer than 3 days. The last fungicide application in the conventional and iMETOS® treatments was conducted no later than seven days before harvesting. Applications in both systems were made rotating Signum 1.8 kg ha^{-1} (a.i. boscalid 267 g L^{-1} + pyraclostrobin 37 g L^{-1}) and Switch 62.5 WG 1.0 kg ha^{-1} (a.i. ciprodinil 375 g L^{-1} + fludioxonil 250 g L^{-1}). The same active ingredient was used not more than twice per season. The experimental design of application times is provided in Table 1.

Assessment. The grey mould assessment was done starting from the beginning to the end of the harvest. Fruits were harvested into plastic boxes twice a week and were sorted into two classes: 1) visually healthy (disease-free) and 2) grey mould infected. The weight of healthy and rotten fruits was determined in kg $plot^{-1}$ and calculated as t ha^{-1}. The evaluations of the strawberry were set up according to the OEPP/EPPO (2015) standard PP 1/16 (3). In 2013–2014, after sorting and weighing the fruits were transported to a laboratory for storage. A sample of 50 fruits per plot from the same harvesting time, maturity, size and free of physical injuries was stored in a climate chamber KBF 720 (Binder, German) at a temperature of 5–7°C. The strawberry decay level (shelf-life) was evaluated according to the OEPP/EPPO (2015) standard PP 1/16 (3) after 4 and 8 days of storage. Fruits were classified into healthy (disease-free) and infected by grey mould (OEPP/EPPO, 2015). The decay experiment was replicated at least four times.

Statistical analysis. The results are expressed as a mean ± standard deviation and vertical bars in figure as an error bar of mean. The data was analysed by statistically estimating the least significant difference (LSD) at the 95% probability level of analysis of variance (*ANOVA*) (Raudonius, 2017). Disease incidence was calculated: $P = n / N \times 100$, where P is disease incidence, %, n – the number of affected fruits, N – total number of inspected fruits.

Results and discussion

The use of the forecasting models can help growers to reduce the number of applications and costs of production, especially when the conditions for disease development are not favourable. The *Botrytis cinerea* life-cycle components are significantly correlated with meteorological factors. Various meteorological factors affect disease risk and development. Fungal pathogens cause infection only when conditions (temperature, leaf wetness, etc.) are suitable for disease development. Hence, disease prediction models provide risk levels, which help to evaluate disease epidemics and enable optimisation of fungicide application timing. The interactions between

Table 1. Experimental design of the management systems against strawberry *Botrytis cinerea*

Year	Treatment	Application time			
2008	Control	untreated			
	Conventional	BBCH 61 12 May	BBCH 62 20 May	BBCH 63 26 May	untreated
	iMETOS®	BBCH 61 13 May	BBCH 85 17 June	BBCH 86 21 June	untreated
2009	Control	untreated			
	Conventional	BBCH 61 12 May	BBCH 62 20 May	BBCH 63 26 May	untreated
	iMETOS®	BBCH 62 20 May	BBCH 63 25 May	BBCH 71 4 June	BBCH 73 12 June
2010	Control	untreated			
	Conventional	BBCH 61 20 May	BBCH 65 28 May	BBCH 67 9 Jun	BBCH 71 16 Jun
	iMETOS®	BBCH 61 20 May	BBCH 66 4 June	BBCH 71 14 June	untreated
2011	Control	untreated			
	Conventional	BBCH 61 19 May	BBCH 63 26 May	BBCH 67 3 June	BBCH 71 9 June
	iMETOS®	BBCH 61 19 May	untreated		
2013	Control	untreated			
	Conventional	untreated	BBCH 62 28 May	BBCH 67 6 Jun	BBCH 71 11 Jun
	iMETOS®	BBCH 61 24 May	BBCH 63 31 May	BBCH 67 7 June	untreated
2014	Control	untreated			
	Conventional	BBCH 61 11 May	BBCH 63 21 May	BBCH 65 27 May	BBCH 71 3 June
	iMETOS®	untreated			BBCH 71 1 June

meteorological conditions, pathogen and host determine if the infection develops to an epidemic level that could cause significant yield losses (Blanco et al., 2006; Miličevič et al., 2006; Pavan et al., 2011; MacKenzie, Peres, 2012; Damos, 2015).

The primary approach of forecasting models is the possibility to reduce fungicide treatments avoiding economic losses and environmental disadvantages (Miličevič et al., 2006; Damos, 2015; Elad, 2016). The grey mould forecasting model iMETOS® calculates the risk of infection based on the leaf wetness periods and the temperature during these periods. In this study, we analysed forecasting model iMETOS® for strawberry grey mould management. Our investigations were carried out in May and June of 2008–2014. Meteorological conditions for *B. cinerea* infection are provided in Table 2. Analysis of the data produced by the model showed that the most favourable conditions for the spread of strawberry grey mould occurred in June in all experimental years (Fig. 1). According to the experimental data, conditions for grey mould occurrence differed from year to year. A graphical representation of the data of the model evaluation is given in Figure 1.

The research data showed that the risk of infection lasted from 9 up to 30 days in 2008–2014 (Table 2). Our data indicate that the risk of strawberry grey mould infection in May 2008 was higher than 60% for 5 days and 12 days in June. However, grey mould risk development in 2008 formed only four periods (one period in May and three in June). The factors that determined the risk periods were the air temperature ranging within 2.1–14.44°C, leaf wetness period lasting from 0–1020 minutes. The first application of fungicides against the strawberry grey mould recommended by the forecasting model iMETOS® was made one day later than in conventional disease management treatment on 13 May. During strawberry vegetation period in 2008, in total there were 16 rainy days: 9 in May and 7 in June.

Meanwhile, in 2009 favourable conditions for infection were 10 days in May and 20 days in June, and there were six risk development periods: two in May and four in June (Table 2). Risk periods for infection were determined by the air temperature when it was within 6.9–20.1°C, leaf wetness period when it lasted between 0–1165 minutes. Total rainy days were 9 in May and 14 days in June.

In 2009, the first application of fungicides according to the forecasting model was made 8 days later compared with the conventional application.

In 2010, favourable conditions for infection were 6 days in May and 12 days in June. However, there were two risk periods in May and three in June. Total rainy days were 17 in May and 15 in June. These factors were determined by the air temperature ranging within 4.1–21.4°C; leaf wetness period lasting from 0–1440 minutes. The first application in conventional and iMETOS® treatments was on 20 May.

Table 2. The data of the forecasting model iMETOS® for strawberry *Botrytis cinerea* development

Infection conditions	2008		2009		2010		2011		2013		2014	
	May	June	May	June	May	June	May	June	May	June	May	June
Average air temperature °C, min-max	2.1–11.1	6.7–14.4	7.7–17.2	6.9–20.1	4.1–16.6	9.1–21.4	6.0–21.9	14.8–23.9	9.4–22.4	14.9–25.5	5.4–22.9	10.9–20.1
Leaf wetness period, min	0–960	0–1020	0–1030	150–1165	25–975	0–1440	0–1070	0–1180	0–1325	0–920	0–1240	20–1350
Number of rainy days, > 0.5 mm	9	7	9	14	17	15	14	13	12	11	13	17
Total favourable days for disease development	5	12	10	20	6	12	2	7	10	5	6	16
Risk periods for disease development	1	3	2	4	2	3	1	1	3	1	1	3

Note. Single squares represent the risk of infection above 60%; the lines represent average temperature and columns represent leaf wetness periods; blue arrows indicate applications according to conventional and red arrows – according to iMETOS® system; dotted line divides the risk periods above 60%.

Figure 1. The development of *Botrytis cinerea* on strawberry according to the forecasting model iMETOS®

However, in 2011 favourable conditions for infection were 2 days in May and 7 days in June, one risk period developed in May and one in June. The air temperature was within 6.0–23.9°C, and the leaf wetness period lasted from 0–1180 minutes. Total rainy days were 14 in May and 13 in June. The application according to the model was on 19 May.

Our results show that in 2013 there were 10 days in May and 6 days in June with the risk of infection, while four risk development periods formed: three in May and one in June (Table 2). The conditions that determined the infection risk periods were when the air temperature was between 9.4–25.5°C, and with a leaf wetness period that lasted from 0–1325 minutes. During this period, there were in total 23 rainy days, 12 in May and 11 in June. According to the conventional plant protection system, the first fungicide sprays were made 4 days later than those made according to the forecasting model.

In 2014, the risk of infection was higher than 60% for 6 days in May and 19 days in June, and there were four risk development periods: one in May and three in June (Table 2). The conditions that determined the infection risk periods were air temperature between 5.4–20.1°C and leaf wetness period between 0–1350 minutes. In 2014, strawberry started to flower (BBCH 61–65) around 11 May, but the first spray according to the model was made 21 days later compared to the conventional application. In 2014, the application in iMETOS® treatment were made only at the end of May, when the risk of infection was higher than 60% and lasted for 3 days. The first spray according to the forecasting model in 2014 was done 7 days before harvest, at BBCH 71–75 stage. Total rainy days differed between years, but the highest number of rainy days during the strawberry vegetation period was in 2014, when the rainy days totalled 30: 13 in May and 17 in June (Table 2).

Our study shows that preventive spray applications according to the forecasting model are done, while the symptoms of grey mould are still not detectable. The comparison of the spraying systems showed that the application times varied in different years. Analysis of the data provided by the forecasting model indicates that the most favourable conditions for strawberry grey mould development in Babtai region, Lithuania were in the 3rd–4th week of May and the 1st week of June.

The local meteorological conditions influence disease pressure (Montone et al., 2016), which agrees with the findings obtained in our previous study (Rasiukevičiūtė et al., 2013). The optimal temperature that affects *Botrytis* spp. development is around 20 ± 1°C, followed by 15°C and 10°C (Sehajpal, Singh, 2014). A correlation was established between strawberry grey mould incidence and the accumulated number of conidia (Blanco et al., 2006). The web-based decision support system enables growers to decide when to use their fungicide applications effectively (Pavan et al., 2011). Using prediction system, the number of sprays could be reduced and range from 3 to 11 (Cordova et al., 2017 a).

According to the 2008–2014 iMETOS® and conventional treatments, yield increases were significantly higher compared to the control (Table 3). In 2008, in the iMETOS® treatment the yield increase was 0.9 t ha^{-1}, which was significantly higher compared to the control. The iMETOS® forecasting model-based spray programs increased strawberry yields by 9.5 t ha^{-1} in 2009, 1.0 t ha^{-1} in 2010, 2.8 t ha^{-1} in 2011, 4.3 t ha^{-1} in 2013 and 3.2 t ha^{-1} in 2014 compared to the control treatment. In the conventional treatment, yield increases were stable compared to the control, but they differed every year depending on the meteorological conditions. In 2008, in the conventional disease management system the yield increase was 3.2 t ha^{-1}, in 2009 it was 7.0 t ha^{-1}, in 2010 – 3.5 t ha^{-1}, in 2011 – 2.8 t ha^{-1}, in 2013 and 2014 – 2.7 t ha^{-1} higher compared to the control teatment. However, the yield in iMETOS® and conventional disease management systems varied. In the iMETOS® treatment, the yield increase in 2009 was 2.5 t ha^{-1}, in 2013 – 1.6 t ha^{-1} and in 2014 – 0.5 t ha^{-1}. In 2011, there was no yield increase; the yield was similar in both treatments. However, in 2008 and 2010 there was a yield decrease in iMETOS® treatment compared with a conventional disease management system. Nevertheless, the usage of iMETOS® helps to reduce the costs of strawberry production, especially when the disease development conditions are not favourable.

The data of the different disease application programs help to optimize the disease management and reduce the spread of grey mould in strawberries (Table 3). There were fewer rotten strawberries (0.7, 2.3, 0.7, 0.1, 0.2 and 0.6 t ha^{-1}) in the iMETOS® plots in 2008, 2009, 2010, 2011, 2013 and 2014, respectively, compared with the control treatment. According to the conventional plant protection system, there were 0.5 t ha^{-1} of rotten strawberries in 2008 compared with the control tretment, 2.0 t ha^{-1} in 2009, 0.6 t ha^{-1} in 2010, 0.2 t ha^{-1} in 2011, 0.2 t ha^{-1} in 2014 and 0.7 t ha^{-1} in 2014. There were fewer rotten fruits in iMETOS® treatment (0.2, 0.3 and 0.1 t ha^{-1}) compared with the conventional disease management system in 2008, 2009 and 2010, respectively. In 2011–2014, in the iMETOS® treatment the amount of rotten fruits was similar to that in the conventional treatment.

Comparison of the yield data of 2009 and 2013–2014 harvest seasons showed that in iMETOS® treatments the yield was higher compared with other treatments. Similarly to our results, Cordova et al. (2017 b) found that fungicide application according to the forecasting model gives yield increase. However, the choice of fungicide is also important.

The forecasting model based spraying program helps to improve the timing of fungicides and adapts the application time, indicating that forecasting models are potentially useful for reducing potential environmental impacts of strawberry production disease management by chemical applications. The analysis of grey mould risk forecasting model iMETOS® shows that disease forecasting allows more precise protection

Table 3. The influence of the management systems on strawberry *Botrytis cinerea*

Treatment	2008	2009	2010	2011	2013	2014	2008	2009	2010	2011	2013	2014
	t ha^{-1}						%					
	Yield											
Control	16.6 ± 0.59	15.7 ± 0.84	18.0 ± 0.25	11.5 ± 0.29	11.1 ± 0.69	18.3 ± 1.66	100	100	100	100	100	100
Conventional	19.8 ± 2.04	22.7 ± 1.64	21.5 ± 1.01	14.3 ± 0.48	13.8 ± 0.99	21.0 ± 1.60	119.6	145.2	119.4	124.3	124.6	114.6
iMETOS®	17.5 ± 0.75	25.2 ± 1.54	19.0 ± 0.35	14.3 ± 0.49	15.4 ± 0.84	21.5 ± 0.77	105.7	160.7	105.6	124.3	138.6	117.5
LSD	*7.5*	*4.5*	*8.1*	*4.5*	*4.2*	*4.7*						
	Rotten fruits											
Control	1.1 ± 0.12	8.6 ± 0.58	1.2 ± 0.05	0.4 ± 0.06	0.4 ± 0.13	1.1 ± 0.23	100	100	100	100	100	100
Conventional	0.6 ± 0.05	6.6 ± 1.01	0.6 ± 0.03	0.2 ± 0.01	0.2 ± 0.04	0.5 ± 0.09	53.7	77.0	50.0	50.0	53.5	42.0
iMETOS®	0.4 ± 0.08	6.3 ± 0.28	0.5 ± 0.02	0.3 ± 0.02	0.2 ± 0.05	0.5 ± 0.17	38.0	73.4	41.7	75.0	41.9	46.4
LSD	*0.6*	*1.6*	*0.6*	*0.5*	*0.5*	*0.5*						

Note. The results are expressed as a mean ± standard deviation.

of strawberries, reduction of production costs and application of fungicides at an optimal time. Similarly, in our study applications according to the forecasting model enabled reduction of the number of applications compared with the weekly program. The fungicide applications per season were reduced by 50% in sprays compared with the calendar approach (Cordova et al., 2017 a; b). The sprays according to the warning system reduced fungicide usage by 75% compared with routine treatment (Xu, Berrie, 2014). In addition, forecasting models reduce the number of chemical applications without a loss of the yield (MacKenzie, Peres, 2012). Our previous research showed that iMETOS® treatment gave a 10% yield increase in onion compared to the control (Rasiukevičiūtė et al., 2016). The fruit rot during harvesting correlates with the amount of precipitation (Boff et al., 2001). The forecasting model BOTMAN is effective in reducing grey mould incidence in strawberries by 10.3% (Miličevič et al., 2006). In addition, fungicide application according to a prediction model could reduce fungicide input by 60% in strawberry (Xu et al., 2000).

As expected, grey mould incidence at harvesting time differed between years depending on the meteorological conditions. The comparison of our research data showed that in treatments where the forecasting model iMETOS® had been applied, the incidence of grey mould at harvesting time was lower compared to the control treatment (Table 4). Fruit rot at harvest ranged from 11.5% up to 51.0% in all spray programs, while the incidence of grey mould in the control treatments averaged 41.0% compared to the conventional treatment – 21.7% and the iMETOS® treatment – 16.9%.

Table 4. The effect of the management system on the development of *Botrytis cinerea* infected strawberry fruit rot at harvesting time

Year	Treatment	Fruit rot incidence %		
		1st harvest	2nd harvest	3rd harvest
2008	Control	13.1 ± 0.04	51.8 ± 0.03	52.2 ± 0.03
	Conventional	7.0 ± 0.03	26.6 ± 0.02	27.9 ± 0.02
	iMETOS®	5.0 ± 0.02	21.2 ± 0.01	19.9 ± 0.01
2009	Control	10.7 ± 0.19	43.0 ± 0.14	39.9 ± 0.16
	Conventional	8.3 ± 0.34	33.2 ± 0.25	30.8 ± 0.29
	iMETOS®	8.1 ± 0.11	23.8 ± 0.06	29.3 ± 0.08
2010	Control	22.7 ± 0.06	62.7 ± 0.06	67.7 ± 0.05
	Conventional	12.1 ± 0.20	33.5 ± 0.22	36.1 ± 0.19
	iMETOS®	8.7 ± 0.08	23.9 ± 0.08	25.8 ± 0.19
2011	Control	8.1 ± 0.13	47.6 ± 0.05	56.8 ± 0.04
	Conventional	9.0 ± 0.13	38.1 ± 0.10	23.9 ± 0.07
	iMETOS®	10.2 ± 0.15	14.3 ± 0.05	19.3 ± 0.05
2013	Control	17.7 ± 0.02	45.8 ± 0.02	54.1 ± 0.13
	Conventional	6.9 ± 0.02	33.3 ± 0.03	28.6 ± 0.04
	iMETOS®	10.5 ± 0.02	20.8 ± 0.05	17.4 ± 0.07
2014	Control	12.0 ± 0.09	65.7 ± 0.12	66.8 ± 0.23
	Conventional	4.3 ± 0.03	13.3 ± 0.05	16.8 ± 0.08
	iMETOS®	8.7 ± 0.05	21.0 ± 0.13	16.4 ± 0.16

Note. B. cinerea fruit rot incidence is reported from the total amount of fruits; the results are expressed as a mean ± standard deviation.

In 2008, grey mould incidence in the iMETOS® treatment was lower during the 1st harvest 2.0%, 2nd – 5.31% and 3rd – 8.0% compared with a conventional disease management system (Table 4). In 2009, grey mould incidence was 0.2, 9.4 and 1.4 % lower compared to conventional disease management system. In 2010, grey mould incidence was 3.4, 11.3 and 10.3 % lower compared to conventional disease management system. However, in 2011 grey mould incidence in the iMETOS® treatment at the 1st harvesting time was 1.2% higher compared with conventional disease management system, but lower during 2nd and 3rd harvest by 23.8% and 4.6%, respectively. A similar situation was in 2013, when the incidence of grey mould in iMETOS® treatment at the 1st harvesting time was 3.6% higher compared with the conventional treatment, but lower during the 2nd and 3rd harvest by 12.5% and 11.2%, respectively. In 2014, grey mould incidence during the 1st and 2nd harvests was by 4.3% and 7.6%, respectively, higher compared with a conventional disease management system, but 0.5% lower during the 3rd harvest, despite the fact that only one application against grey mould was made in 2014. In addition, as we removed rotten fruits from the field, the total number of rotten fruits was lower compared with that which could be in commercial strawberry production farms where rotten fruits are usually left in the field. The removal of rotten fruits is also one of the strategies to reduce disease incidence in the field.

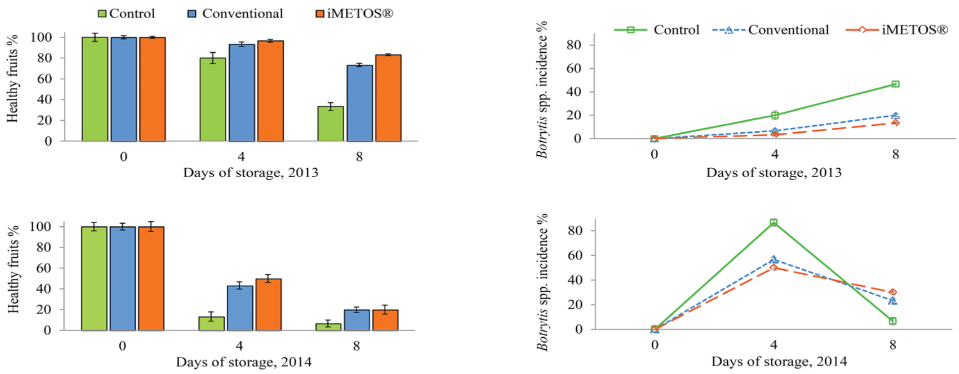
Postharvest diseases cause additional yield loss during the process of transportation and storage (Sharma et al., 2009). The primary strategy to reduce postharvest losses is appropriate agro-technical handling and fungicides (Droby et al., 2009). Strawberry susceptibility to mechanical injuries, and infection with fungal and bacterial pathogens reduce their disease-free period and shelf-life. Therefore, fruit decay losses can reach up to 40% (Satin, 1996).

Our results suggest that a forecasting model can help to prolong a disease-free period of strawberries and extend fruit shelf-life (Fig. 2). In our postharvest investigations, the grey mould was determined as the only causal agent of fruit rots. The 2013–2014 experiments on strawberries revealed that iMETOS® treatment reduced grey mould by 17% and 36.7% (after 4-day storage), respectively, compared with the control. The risk of infection during flowering in 2013 was moderate. The incidence of grey mould at harvesting time ranged from 6.9% to 17.7%. The experimental data revealed that in 2013 after 4 days of storage in the control treatment, *Botrytis* spp. infected strawberries accounted for 20%, whereas in the iMETOS® and conventional treatments the infected fruits accounted for 3% and 7%, respectively. After 4 days of storage, in the iMETOS® treatment there were 17% more healthy strawberries, and in conventional treatment there were 13% more healthy fruits compared with the control. After 8 days of storage, in the iMETOS® treatment there were 33% and 7% less rotten fruits compared with the control and conventional treatments.

Postharvest data suggest that grey mould development is associated with meteorological conditions. In 2014, there was only one spray against grey mould, but it was applied at the optimal time for the control of the disease. Treatments according to the iMETOS® model show that grey mould forecasting allows application of fungicides precisely when needed and reduces strawberry postharvest losses. Xu and Berrie (2014) observed that model-based treatments reduced postharvest incidence of *Botrytis* spp.

The results of this study showed that in 2014 after a 4- and 8-day storage, in iMETOS® treatment there were 36.7% and 23.3% less *Botrytis* spp. infected strawberries compared to the control. The incidence of grey mould at harvesting time ranged from 4.3% to 12.0% in all treatments. In the conventional treatment, the incidence of grey mould after 4- and 8-day storage was 30% and 17% lower compared to the control. After 4 days of storage, in the iMETOS® treatment there were 7% less *Botrytis* spp. infected strawberries compared with the conventional treatment (Fig. 2).

The results of this research showed the practical use of the forecasting model iMETOS® in strawberry. Research on iMETOS® application in other crops in more locations would help to make more valid and complete disease forecasting decisions.



Note. Vertical bars in the figure indicate standard error.

Figure 2. Healthy and rotten *Botrytis* spp. infected strawberry fruits during the postharvest storage (2013–2014)

Conclusions

1. The forecasting model iMETOS® enabled accurate timing of fungicide applications. Grey mould control based on the forecasting model allowed reduction of fungicide inputs and costs.

2. In 2008–2014, the meteorological conditions for *Botrytis cinerea* infection risk varied. The most favourable conditions for strawberry grey mould development occurred in the 3rd–4th week of May and in the 1st week of June.

3. The use of the forecasting model resulted in a strawberry yield increase in 2009 – 9.5 t ha^{-1}, 2010 – 1.0 t ha^{-1}, 2011 – 2.8 t ha^{-1}, 2013 – 4.3 t ha^{-1}, 2014 – 3.2 t ha^{-1}, and a reduction in the amount of rotten fruit in 2008 – 0.7 t ha^{-1}, 2009 – 2.3 t ha^{-1}, 2010 – 0.7 t ha^{-1}, 2011 – 0.1 t ha^{-1}, 2013 – 0.2 t ha^{-1} and 2014 – 0.6 t ha^{-1} compared with the control treatment.

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Prognozavimo modelio iMETOS® taikymas braškių kekerinio puvinio kontrolei

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Santrauka

Braškių ligų kontrolė dažniausiai grindžiama augalų chemine apsauga, tačiau dėl didelės pesticidų kainos ir jų neigiamo poveikio būtina tiksliau parinkti fungicidų naudojimo laiką. Ligų prognozavimo modeliai apskaičiuoja tikslias ligos vystymosi sąlygas, todėl purškimai fungicidais būna tikslesni. Tyrimo tikslas – nustatyti, kaip taikant kekerinio puvinio (*Botrytis cinerea* Pers.: Fr.) prognozavimo modelį iMETOS®, parinkti tikslesnį fungicidų purškimo laiką ir tokiu būdu sumažinti fungicidų kiekį, gauti derliaus priedą ir užtikrinti uogų saugumą bei kokybę. Tyrimai atlikti 2008–2014 m. Lietuvos agrarinių ir miškų mokslų centro Sodininkystės ir daržininkystės institute. Tirtos veislės 'Elkat' braškės. Eksperimento schema: 1) kontrolinis variantas, 2) tradicinė augalų apsaugos sistema ir 3) prognozavimo modelio iMETOS® taikymas.

Tyrimo rezultatai atskleidė, kad didžiausia braškių kekerinio puvinio plitimo rizika būna gegužės III–IV – birželio I dešimtadieniais. Braškių apsaugai nuo kekerinio puvinio taikant prognozavimo modelį iMETOS®, buvo atlikti tikslesni purškimai. Lyginant braškių derlių su kontroliniu variantu, 2008 m. gautas 0,9, 2009 m. – 9,5, 2010 m. – 1,0, 2011 m. – 2,8, 2013 m. – 4,3 ir 2014 m. – 3,2 t ha^{-1} derliaus priedas. Tyrimo metais taikant tradicinę augalų apsaugos sistemą 2008 m. gautas 3,2, 2009 m. – 7,0, 2010 m. – 3,5, 2011 m. – 2,8, 2013 m. – 2,7 ir 2014 m. – 2,7 t ha^{-1} derliaus priedas, lyginant su kontroliniu variantu. iMETOS® variante 2009 m. nustatytas 2.5 t ha^{-1}, 2013 m. – 1,6 t ha^{-1}, 2014 m. – 0,5 t ha^{-1} derliaus priedas, lyginant su tradiciniu variantu. 2011 m. derliaus priedas nebuvo nustatytas, tačiau derlius buvo vienodas iMETOS® ir tradiciniame variantuose. Taikant modelį iMETOS®, supuvusių uogų kiekis 2008 m. buvo mažesnis 0,7, 2009 m. – 2,3, 2010 m. – 0,7, 2011 m. – 0,1, 2013 m. – 0,2 ir 2014 m. – 0,6 t ha^{-1}, lyginant su kontroliniu variantu.

Fungicidų panaudojimas taikant prognozavimo modelio iMETOS® rekomendacijas padeda sumažinti išlaidas augalų apsaugai, ypač kai sąlygos ligoms plisti yra nepalankios.

Reikšminiai žodžiai: *Botrytis cinerea*, lapų drėgmė, ligos rizika, plitimas.