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Neringa Rasiukevičiūtė*, Skaidrė Supronienė, Alma Valiuškaitė

Effective onion leaf fleck management and variability of storage pathogens

DOI 10.1515/biol-2016-0036

Received May 2, 2015; accepted September 5, 2016

Abstract: *Botrytis* spp. cause several diseases in *Allium* crops and depending on meteorological conditions economic losses can exceed 50%. Forecasting models improve plant protection and sometimes reduce consumption of fungicides, because applications are made precisely during the favourable periods for disease development. Our aim was to evaluate the iMETOS@sm *B. cinerea* forecasting model as an effective onion leaf fleck management system and estimate the variability of onion bulb pathogens during storage. Assessment of forecasting model data showed that favourable conditions for leaf fleck development arise in July, but greatly depend on that year's meteorological conditions. During an experimental year the first sprayings with fungicides were applied as forecasted from the model, which resulted in application 19, 6 and 23 days earlier than conventional treatment application times. In 2012-2014 iMETOS@sm treatment yield increased by 3.51 t ha⁻¹, 3.87 t ha⁻¹ and 3.40 t ha⁻¹ relative to the control. During storage most frequent injuries were fungal (44%) and bacterial (41%), followed by insects (7%) and physiological (9%). The highest prevalence of injuries was detected after 2 months of storage.

Keywords: *Botrytis cinerea* infection, onion leaf fleck, risk periods, iMETOS@sm, storage pathogens

1 Introduction

Onion (*Allium cepa* L.) is a very important vegetable grown all over the world and consumed in various forms. The damage caused by diseases is difficult to measure, however depending on meteorological conditions economic losses can exceed 50% [1-5]. Several *Allium* crop diseases are caused by *Botrytis* spp., which results in yield losses in different parts of the world. *Botrytis cinerea* infects more than 200 host plants worldwide. In onions it causes leaf fleck, blight and is the causal agent of neck rot [3,4,6]. The fungus overwinters in the form of sclerotia and may survive more than 2 years in the soil. During the onion growth season *B. cinerea* causes oval and small spots on the leaves [4,9].

Postharvest diseases cause major losses during onion storage [7,8]. Disease severity is influenced by the weather and storage conditions, crop rotations, harvesting periods and disease control methods. The physiological maturity of onions at harvest can also affect the incidence and severity of rot in stored onion bulbs. If the control of onion diseases in the field is not efficient, the storage losses will also increase [9]. Neck rot is primarily a storage disease, but the origin of infection is associated with the field. The fungus usually infects onions through the neck tissues or wounds in the bulbs [10]. The major pathogens responsible for postharvest diseases are *Botrytis*, *Penicillium*, *Mucor*, *Fusarium* and *Aspergillus*, while *B. cinerea* is among the prevailing fungi [7,8,10].

It is difficult to control *Botrytis* spp. because of the capability of the fungus to attack vegetables at almost any stage of growth, and infect all plant parts, including leaves, stems, flowers and fruits [4,9,11]. The appropriate agro-technical handling, pesticide application time, crop rotation and proper varieties have very important effects on the control of these diseases, and also influence crop storage time and the onion's quality characteristics [3-5,8,9,12,13].

The primary strategy for controlling *Botrytis* spp. and other pathogens are pesticides. Conventionally onion diseases are controlled by routine applications of

*Corresponding authors: Neringa Rasiukevičiūtė, Laboratory of plant protection, Lithuanian Research Centre for Agriculture and Forestry, Babtai, Kaunas distr., Lithuania, E-mail: n.rasiukeviciute@lsdi.lt

Skaidrė Supronienė, Department of plant pathology and protection, Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Akademija, Kedainiai distr., Lithuania

Alma Valiuškaitė, Laboratory of plant protection, Lithuanian Research Centre for Agriculture and Forestry, Babtai, Kaunas distr., Lithuania

fungicides once a week. The consumption of pesticides in the world is about two million tonnes per year. Chemical pesticides have negative effects on the environment and to human nutrition. The usage of pesticides is becoming more restricted, based on public consideration about the negative influences of pesticides on human health and the environment. The inadequate usage of pesticides also leads to pesticide resistance [3,4,7,14,15]. These kind of applications are becoming unacceptable, because they are being used - whether necessary or not [3,4,11].

Development of fungal infections is associated with meteorological conditions. Forecasting models help to minimize the usage of fungicides so that they are applied only when needed. The *B. cinerea* forecasting model calculates how favourable the period is for the risk of infection. Forecasting models predict occurrence and intensity of a disease according to weather, host or pathogen data. The primary factors for *Botrytis cinerea* occurrence are leaf wetness, high humidity or rain periods together with optimal temperature. Various types of forecasting models have been developed, but they all are based on the calculation of a disease index predicting the optimal conditions for disease development [3,4,7,8,12,14-17].

Bulger et al. [2] found correlations for leaf wetness periods and temperature. If leaf wetness periods last more than 32 hours at 20°C, the probability of grey mould infection is 60% [2-4]. The iMETOS@sm onion leaf fleck risk forecasting model indicates the possibility of developing *B. cinerea* based on the interaction between air temperature and duration of leaf wetness [5,13].

Influence of the *B. cinerea* forecasting model on onion disease and the timing and efficacy of fungicide application were investigated at the LAMMC Institute of Horticulture in 2012-2014. The aim was to evaluate the iMETOS@sm *B. cinerea* forecasting model and determine an effective onion leaf fleck management system to estimate the variability of onion bulb pathogens during storage.

2 Methods

2.1 Field experiments

Three-year field experiments were carried out at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry in the Central part of Lithuania (55°04'58.1"N 23°48'30.0"E) in May-September of 2012–2014. We investigated the iMETOS@sm (Pessl Instruments, Austria) onion leaf fleck risk forecasting model as an effective onion *B. cinerea* management system.

The experimental trials were set up according to EPPO standards PP1/152(4) and PP1/120(2) [18, 19]. Onion cv. 'Stuttgarter Riesen' was grown from sets, on 10.0 m long and 1.0 m wide beds of four rows. The experiment was initiated every year at the beginning of May.

During experimental years the onions were harvested at the end of August (2013-08-22) or in the beginning of September (2012-09-11 and 2014-09-08). The trials were arranged in random complete blocks. The experiments were replicated four times. Onion experimental plots were not irrigated.

The fungicide applications against onion leaf fleck were made according to the conventional plant protection system and the iMETOS@sm forecasting model. The fungicide conventional system was applied when the first symptoms of leaf fleck appeared and a second time 10 days later. According to the iMETOS@sm forecasting model applications were made when the model indicated disease risk. Applications in both systems were made with Signum 1.8 kg ha⁻¹ (6.7% pyraclostrobin + 26.7% boscalid), twice every 10–14 days, and the last spray was conducted no later than 14 days before harvesting. The experimental design of application times are provided in Table 1.

Yield-loss potential for *B. cinerea* was calculated using formula: Yield-loss potential (%) = 100 x ((Sprayed-untreated)/sprayed), in this formula sprayed = means bulbs yielded from experimental plots were sprayed according to the iMETOS@sm or conventional treatment, untreated

Table 1. Onion field trials experimental design of different application time.

Treatment (Factor B)	Year (Factor A)		
	2012	2013	2014
Control	Untreated	Untreated	Untreated
Conventional	17-Jul	11-Jul	9-Jul
	27-Jul	22-Jul	18-Jul
iMETOS@sm	29-Jun	4-Jul	17-Jun
	16-Jul	17-Jul	4-Jul

stands for a bulbs yield from control plots that were not treated with fungicide [11].

2.1.1 Forecasting model

The iMETOS@sm forecasting model is an automatic meteorological database station, recording air temperature, leaf wetness, relative humidity, precipitation amount and other parameters which are needed for the disease calculations. The station data are received on the internet http://metos.at/pikernel_dev/index_new.php/, where the model records and calculates the risk of infection on an hourly basis. The model calculates accurate disease infection risk at the range of 10 km around the meteorological station [5,12,13].

The onion leaf fleck forecasting model calculates favourable periods for the risk of infection. The figure indicates a leaf wetness period leading to 30% *B. cinerea* risk. Dry days reduce the risk time (Fig. 1). The infection prevalence depends on the excess of humidity on onion leaves. The model calculates the risk of onion *B. cinerea* infection during the leaf wetness period from 4 to 16 hours at the optimal temperature 7 – 24°C and indicates the disease. According to manufacturer guidelines, if the iMETOS@sm leaf fleck risk model shows the infection risk periods more than 60% (which lasts longer than 3 days), it is recommended to apply fungicides. The infection risk periods are classified into groups; a group is established if infection lasts longer than 3 days or more than 60%.

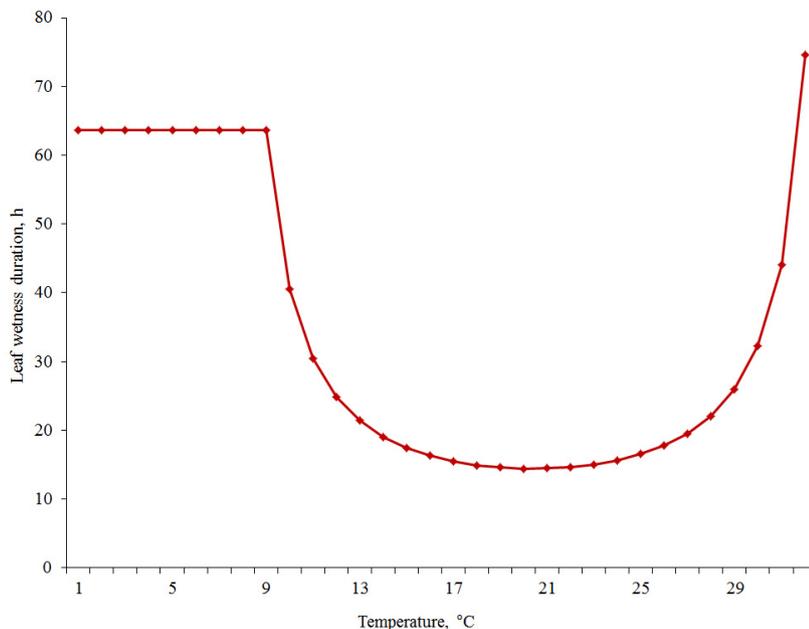


Figure 1. Meteorological parameters characterizing *Botrytis cinerea* infection.

2.2 Neck rots and pathogen assessment during the onion bulbs storage.

Healthy onion bulbs (Fig. 2 a) of the same size and free of physical damage were assessed and collected in a mesh bags (Fig. 2 c) from each replication of field trials. Onion bulbs were stored at the temperature of 2-4°C. One replication comprised of 50 onion bulbs. Incidence of neck rot was evaluated according to the EPPO standards PP1/054(3) and PP1/120(2) [18, 19, 21] after 2 and 4 months of storage. At the same time, the occurrence of *B. cinerea* (Fig. 2 b) was assessed for other pathogens on onion bulbs. We first identified the pathogens visually, and then they were cultured on PDA and identified according to the morphological traits typical of the colonies microscopically [3,6,20]. The relative density (RD% – percent ratio of species number to a total number of species) – was calculated according Gonzalez et al. [22].

2.3 Data analysis

All experiments were carried out in four replications. The data were analysed with Anova module of *STATISTICA* 7.0 software. We used two-way ANOVA to determine yield differences between treatments, factor A - different harvest year, factor B - different plant protection system. A standard error (SE) was estimated for every experimental point and marked in a figure as an error bar. The means were compared with the least significant difference (R05) and evaluated at the probability level of 95% ($P = 0.05$).



Figure 2. Onions harvested at total leaves drop (a) and an infected bulb with *B. cinerea* after 2 months of storage (b), prepared for storage in mesh bags (c).

3 Results

3.1 Influence of management method on the onion yield

Comparison of the three year's data showed that the yields for the iMETOS@sm based leaf fleck management were higher compared to the control and conventional treatments. Two-way analysis of variance (ANOVA) was carried out according to the following scheme: factor A different harvest year, factor B different plant protection system were used to reveal the significance of factors for onion yield (Table 2). Two-way ANOVA showed that experimental treatments were significant at $P < 0.05$ probability for onion yield. The experimental data revealed that investigation year had significant influence on onion yield. In 2012-2014, there were significant differences between treatments ($F = 0.51$, $df = 2$, $P < 0.6087$), with the highest yield was in the iMETOS@sm treatment. In the iMETOS@sm 2012 the treatment yield amounted up to 48.00 t ha^{-1} , an increase by 3.51 t ha^{-1} higher than the control. In 2013 the iMETOS@sm

yield was 32.02 t ha^{-1} and in 2014 - 32.38 t ha^{-1} . These year yield increases were 3.87 t ha^{-1} and 3.40 t ha^{-1} higher than the controls. These results demonstrate that all experimental year fungicide applications based on the iMETOS@sm model were more precise and obtained higher yields than conventional treatments.

The iMETOS@sm forecasting model was helpful in evaluating the favourable periods for the risk of *Botrytis cinerea* infection in onions and led to specify the fungicide application timing and increase the onion bulbs yield on average by 3.59 t ha^{-1} and 3.16 t ha^{-1} during the years of 2012-2014 compared to untreated and conventionally treated fields, respectively. In 2012-2014 the iMETOS@sm treatment yield increase was 3.51 t ha^{-1} , 3.87 t ha^{-1} and 3.40 t ha^{-1} higher than the control (Table 2).

The yield-loss potential of *B. cinerea* in the control treatment was highest in 2013 compared to other years. The yield-loss potential averaged 8.81% compared with the conventional, 10.85% with iMETOS@sm treatments.

The iMETOS@sm based leaf fleck managements system yield-loss potential was 2.05% lower than the

Table 2. The different application time effect on onion yield (t ha^{-1}), 2012-2014.

Treatment (Factor B)	Yield, t ha^{-1} (Factor A)			Average B ($P < 0.01^*$)
	2012	2013	2014	
Control	44.49	28.15	28.98	33.87
Conventional	47.76	31.98	31.37	37.03*
iMETOS@sm	48.00	32.02	32.38	37.47*
Average A	46.75	31.05	30.57	
$R_{05} (^*) A - 4.64, B - 4.63 AB - 9.29$				
Yield-loss potential, %				
Control – Conventional	6.84	11.96	7.62	
Control – iMETOS@sm	7.31	14.74	10.52	

conventional. This demonstrates that the model was more precise.

According to the 2012-2014 data, it was determined that the conditions varied from year to year and plant protection products were used at various times (Table 1, 3, Fig. 3). The applications according to the iMETOS®sm model occurred before symptoms of leaf fleck were detected.

Analysis of the forecasting model records showed that conditions for leaf fleck in 2012 were favourable both in June and July (Fig. 3). When infection risk periods are more than 60%, and last longer than 3 days, it is recommended to use fungicides. The infection risk in 2012 lasted for 21 days greater than 60% and 8 days in June, 13 days in July (Table 3). Onion leaf fleck risk development in 2012 formed four periods (one period in June and three in July).

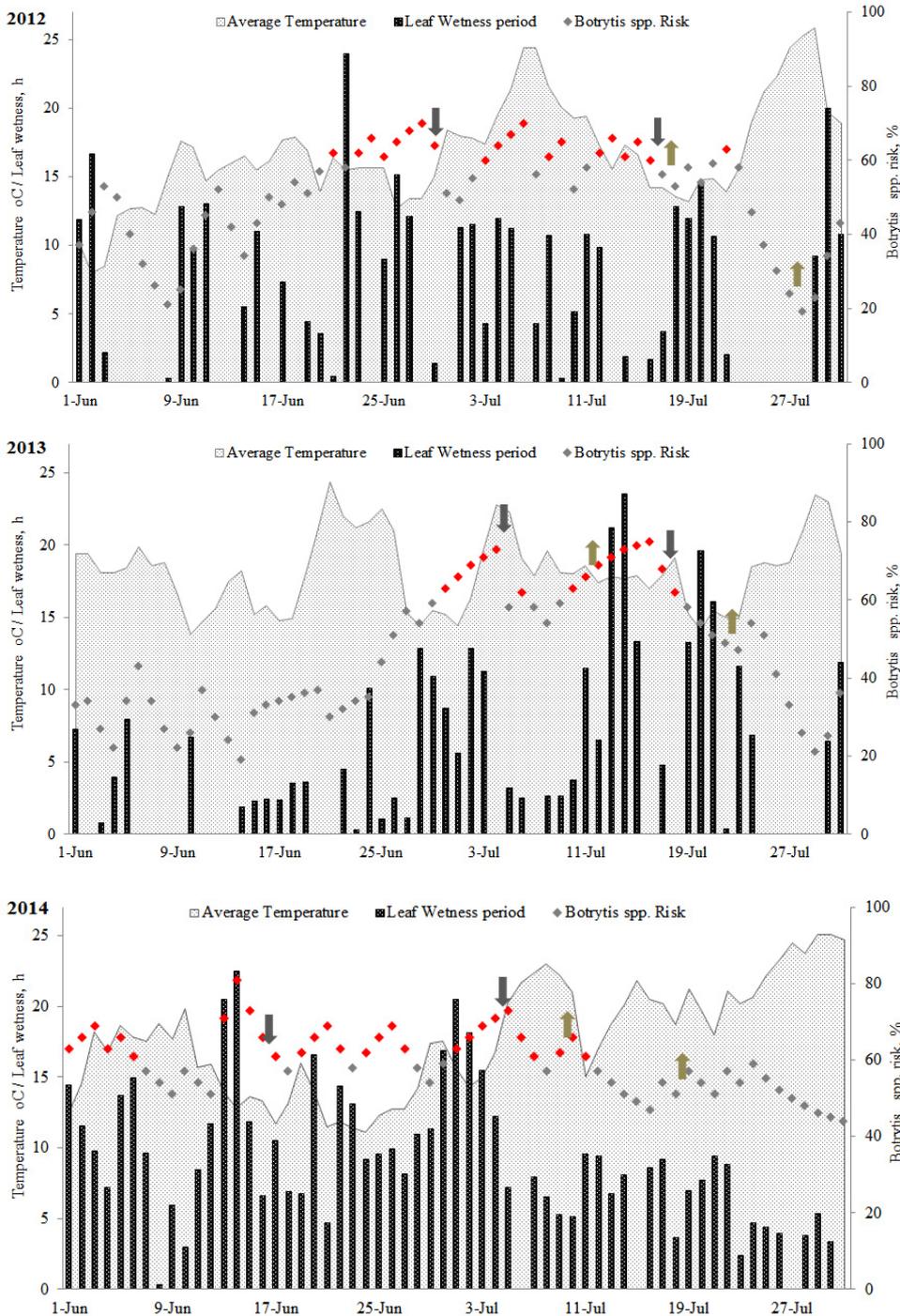


Figure 3. Favourable conditions for onion leaf fleck infection according iMETOS®sm forecasting model, 2012-2014. Note. Applications according: ↑ – conventional system, ↓ – iMETOS®sm forecasting model, ◆ – Favourable days, risk period more than 60%.

Table 3. Conditions for onion leaf fleck development according iMETOS@sm.

Infection conditions	2012		2013		2014	
	June	July	June	July	June	July
Air temperature, °C, min-max	8.0-18.5	13.2-25.9	13.8-24.4	14.1-23.5	11.5-19.8	14.3-25.1
Leaf wetness period, min.	0-1440	0-1200	0-770	0-1410	0-1350	0-1230
Total days of favourable conditions	8	13	1	14	19	10
Risk periods for disease development	1	3	0	2	4	2

Favourable conditions for leaf fleck occurred on the 23rd day (one risk period lasted more than 60% for 7 days) of June and in July – 3rd (for 4 d.), 8th (for 3 d.) and 12th (for 5 d.). Risk periods for infection were determined by the following factors: the air temperature was within 8.0 – 25.9°C, and the leaf wetness period lasted within 0-1440 minutes. In 2012 first spraying according to the model was made 19 days earlier than the conventional application (Table 1).

Analysis of the 2013 forecasting model records showed that the conditions for leaf fleck were unfavourable in June, but favourable in July (Fig. 3). The 2013 model data showed that the risk of infection lasted for 15 days, 1 day in June and 14 in July (Table 3). In July only two risk periods formed. Favourable conditions for leaf fleck formed on the 2nd day (risk period lasted more than 60% for 4 days) and 12th day (for 9 d) of July (Fig. 3). Infection risk periods were determined by air temperatures within 13.3 – 26.4°C and the leaf wetness periods lasted within 0-1410 minutes. In 2013 the first spraying according to the iMETOS@sm forecasting model was applied 6 days earlier than the conventional applications (Table 1).

According to the forecasting model, conditions for the leaf fleck in 2014 were similar to the year 2012 (Fig. 3). The risk of infection in 2014 was greater than 60% and lasted for 29 days, 19 days in June and 10 in July (Table 3). In 2014, six risk periods formed: 4 in June and 2 in July. Favourable conditions for onion leaf fleck formed on the 1st day (risk period lasted more than 60% for 6 days), 13th (5), 19th (4) 24th day (4) of June and on 1st (7) and 9th day (3) of July. Risk periods for infection factors like air temperature was within 11.5-25.1°C and leaf wetness period lasted within 0-1350 minutes. In 2014 the first spraying according to the forecasting model was applied 23 days earlier than conventional applications (Table 1).

According to the conventional plant protection system, the first sprays were made in the first and second weeks of July. The application dates, according to the iMETOS@sm forecasting model, vary in different years (Table 1). In 2012-2013 applications according to the model

were made in proximate dates in the third week of June and in the first week of July. In 2014 the application dates were different, taking place during the third week of June.

The iMETOS@sm showed that in different years the conditions for leaf fleck varied. The most favourable conditions for onion leaf fleck development in Lithuania formed in July, but this mostly depended on yearly weather conditions. One of the most efficient tools to reduce consumption of plant protection products is disease forecasting, which allows optimizing the usage of fungicides.

In all of our 2012-2014 experimental years the iMETOS@sm forecasting model showed favourable conditions for *B. cinerea* infection. The results of the iMETOS@sm 2014 data showed that favourable conditions for leaf fleck started earlier, on the 1st of June, compared with other years. In 2012 and 2013 the risk of disease was recorded on the 21st and 30th of June (Table 3).

3.2 Influence of management method on pathogen occurrence

During the 2012-2014 storage experiments we detected several types of pathogens that infected and damaged onions (Fig. 4). Through all experimental years fungal (44%) and bacterial (41%) injuries were dominant, but followed by insects (7%) and physiological (9%) injuries. The most common pathogen in all three experimental years was *B. cinerea*. During storage, onion bulbs were infected with four fungi genera: *B. cinerea*, *Aspergillus* spp., *Penicillium* spp. and *Fusarium* spp. In 2012 – 2014 in all plant protection systems bacterial injuries manifested at 41%, 36% and 49% respectively (Fig. 4 a, b, c). In the control treatment *B. cinerea* (27%) injuries were significantly higher compared with conventional and iMETOS@sm treatments, followed by *Aspergillus* spp. (10%), *Penicillium* spp. (5%) and *Fusarium* spp. (1%) fungal injuries (Fig. 4 a). In the conventional and iMETOS@sm treatments, *B. cinerea* injuries during storage

were 14% and 15% respectively (Fig. 4 b, c). The onions in the iMETOS®sm treatment were infected by *B. cinerea* at a rate of 15%, 14% for *Penicillium* spp., 11% for *Aspergillus* spp. and 7% for *Fusarium* spp.

Comparison of the relative density of infections after 2 and 4 months of storage showed dissimilar results in all experimental years (Fig. 5 a, b). The relative density (RD, %) of bacterial damage ranged from 20.69% to

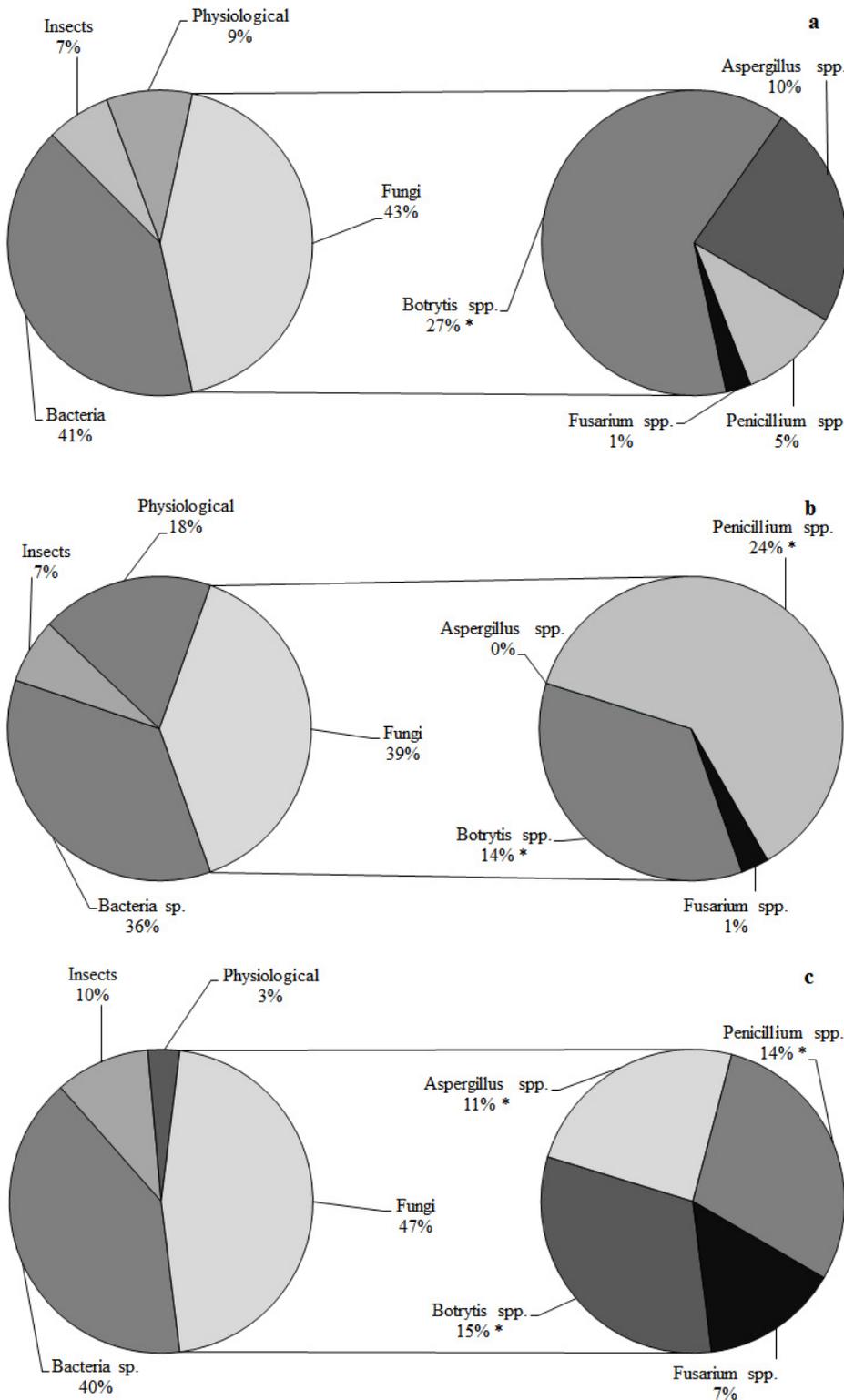


Figure 4. Composition of pathogen types in storage during 2012-2014: a – control, b – conventional, c – iMETOS®sm treatment. Differences significant at * - $P < 0.05$.

Table 4. Types of onion bulbs infections prevalence after 2 and 4 months of storage.

Types of bulbs infections	Mean of infections prevalence, %					
	2012		2013		2014	
	2	4	2	4	2	4
Bacteria sp.	6.15	6.15	13.59	0.97	3.56	2.91
Insects	4.76	9.52	14.29	4.76	0	0
Physiological	24.69*	7.41	0	1.23	0	0
<i>B. cinerea</i>	0.68	0.68	8.84	1.36	10.20*	11.56*
<i>Aspergillus</i> spp.	24.56*	7.02	1.75	0	0	0
<i>Penicillium</i> spp.	2.70	22.52*	6.31	0	1.80	0
<i>Fusarium</i> spp.	0	20.83*	12.50	0	0	0
R05	1.41	1.56	1.77	0.21	0.66	0.61

Note. Differences significant at * - $P < 0.05$.

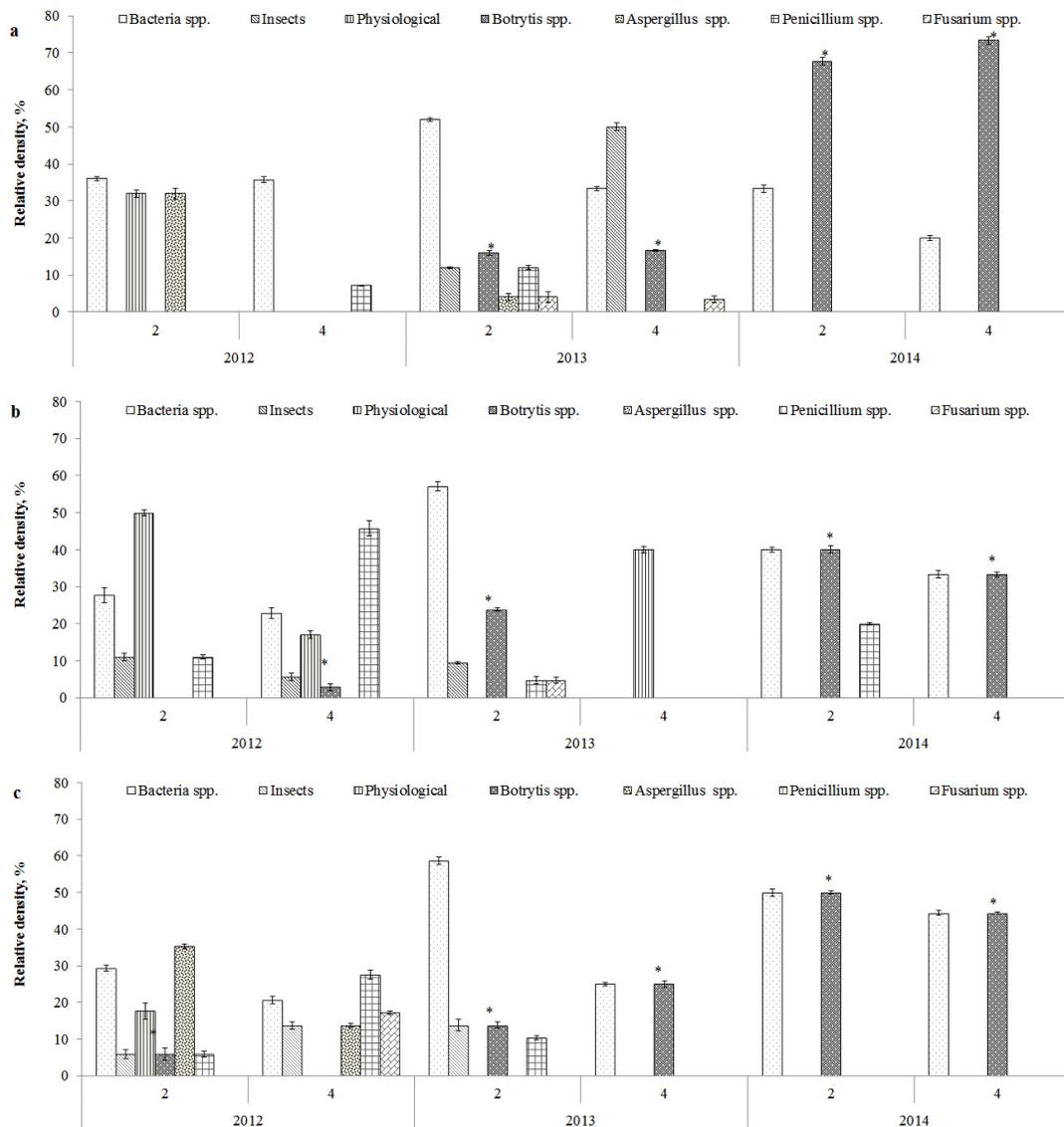


Figure 5. The relative density (RD,%) of fungal pathogens genera on the onion bulbs: a – control, b – conventional, c - iMETOS®sm treatment. Note. Standard error (SE) of pathogen relative density is listed and differences significant at * - $P < 0.05$.

58.62% in all treatments. The relative density of *B. cinerea*, *Aspergillus* spp. and *Penicillium* spp. in 2012 averaged to up to 1.96%, 22.43% and 5.66% respectively after 2 months storage.

Our findings indicate that in 2012 the relative density of *B. cinerea*, *Aspergillus* spp., *Fusarium* spp. and *Penicillium* spp. averaged 0.95%, 4.6%, 26.81% and 5.75% respectively after 4 months. In 2013 the relative density of *B. cinerea*, *Aspergillus* spp., *Fusarium* spp. and *Penicillium* spp. averaged 17.87%, 1.33%, 9.03% and 2.92% respectively after 2 months of storage. Using different data obtained after 4 months of storage, relative density of *B. cinerea* and *Fusarium* spp. averaged up to 13.89 and 1.55%. *B. cinerea* relative density in 2014 after 2 and 4 months of storage increased up to 52.56 and 50.37%.

Favourable weather conditions in 2014 (according to the forecasting model there were six *B. cinerea* risk periods, Table 3) led to an increase up to 73% of *B. cinerea* bulb injuries (Fig. 4). High *B. cinerea* infection rates revealed the importance of disease control methods on the open field to disease prevalence in stored bulbs. The relative density from untreated plots was about 22% higher than in conventionally or iMETOS[®]sm treatments (Fig. 5). According to the overall data it seems that the highest relative density of injuries was recorded after 2 months of storage.

In the 2012-2014 experimental years different types of infections appeared (Table 4). It was concluded that most of the onion bulbs were infected by mixed types of infections. The predominant infections were *B. cinerea* and bacterial rot, although individual onion bulbs were often infected by more than three pathogens. In 2012 the bulbs were mostly injured by physiological (24.69%) and *Aspergillus* spp. (24.56%) infections after 2 months of storage and *Penicillium* spp. (22.52%) and *Fusarium* spp. (20.83%) infections after 4 months of storage. Bacterial infections were found throughout all three experimental years; it should be noted that bacteria accompanied all rots and the higher prevalence was 13.59% in 2013 after 2 months of storage. Analysis of 2013 data showed that bulb injuries were from insects (14.29%), bacteria (13.59%), *Fusarium* spp. (12.50%) and *B. cinerea* (8.84%) after 2 months of storage. In 2014 there were only three types of infections: bacteria, *Aspergillus* spp. and *Penicillium* spp. The leading infections were made by *B. cinerea* after 2 and 4 months of storage (10.20% and 11.56%). Highest prevalence was detected after 2 months of storage. Fungal (44%) and bacterial (41%) injuries dominated among postharvest diseases of onion bulbs, which much lower detection rates of physiological (9%) and insect (7%) associated injuries.

4 Discussion

4.1 *Botrytis* spp. management with forecasting models

The necrotrophic fungus *B. cinerea* causes numerous types of diseases on many plants. *B. cinerea* is difficult to control because of its different modes of infecting and various hosts of inoculum sources [3,4,6]. During the vegetable growing season significant amounts of pesticides are used to control fungal diseases. Conventionally growers use several different chemical classed pesticides in mixtures or rotation during the growing season for resistance management. Disease forecasting models could help to reduce pesticide usage by providing better predictions of the environmental conditions that facilitate development of diseases. Such models allow reduced consumption of fungicides and applications are made only when the conditions for the disease are favourable [3-5,7,8,11,13]. The use of forecasting models without adaptation to local conditions is inadequate and inconsistent, because meteorological conditions vary [3,4].

Shtienberg [7] found that by using *B. squamosa* Blight-alert model it is possible to apply fungicides only when needed and calculated that using the model resulted in an average savings of 29%. Use of the forecasting model system enabled fungicide reduction up to 60% [3]. Miličević et al. [14] used the Botman forecasting model and developed an integrated and effective open-field strawberry control strategy from *B. cinerea*. Botman forecasting model based *B. cinerea* control in the greenhouse was statistically equally effective as conventional control methods [14]. Raudonis et al. [5] found that using the iMETOS[®]sm *Venturia inaequalis* forecasting model optimizes application time from 30% up to 41% compared with the conventional. Using a forecasting model *Botrytis* incidence was 50% lower than the non-treated controls. Reduction in the number of fungicide applications using both Broome and Bulger models were similar. All treatments using the forecasting model had significantly higher yields [17]. After reviewing the literature it was found that only the iMETOS[®]sm forecasting model is suitable to control onion *B. cinerea*, based on the results of our study. Survilienė-Radzevičė et al. [13] found that forecasting allows fungicide application precisely when it is needed, which leads us to environmentally friendly plant protection. It is the first time that the study was done in order to investigate the onion iMETOS[®]sm *B. cinerea* forecasting model. Our investigations confirm the results of other researchers demonstrating that that forecasting

models are important predictors of disease and allow more precise use of fungicides. We discovered that the most favourable conditions for leaf fleck development occur in the July (Fig. 3, Tab. 3).

4.2 Pathogen occurrence during storage

Onion storage is affected by the environment, pathogens and crop genetic factors. It is important to consider the losses that occur during the storage of onion bulbs because it affects the continuous supply to the industry. Diseases caused by *Botrytis* are considered to be one of the most important onion fungal diseases which reduce yield, and also can devastate bulb yield during storage. Besides yield reduction, disease poses effects during post-harvest [4,10,23]. The bulb rot symptoms usually begin in the field and become severe during the storage time. *Aspergillus* spp., *Botrytis* spp. and *Fusarium* spp. are known as the onion seed-borne fungi and they are the agents that cause the rot diseases. The number of rotten bulbs varies depending on year [8]. Lorbeer et al. [23] found that primary infection of *Botrytis* rot depends on plant protection systems. Jonathan et al. [24] found that *Aspergillus* spp., *Fusarium* spp. and *Penicillium* spp. are the predominant pathogens that are associated with onion spoilage. The pathogens infect bulbs through wounds, obsolescent or dead plant tissue or improperly dried necks. The major problem of onion storage is neck rot, caused by *B. cinerea* and prevailing in cool and moist climate areas [3,4,6]. Our findings confirmed other researchers and in turn allowed us to demonstrate that the predominant infections were caused by *B. cinerea*, *Aspergillus* spp. and *Penicillium* spp. We also discovered that if meteorological conditions are favourable for leaf fleck, this causes more injuries from *B. cinerea* during storage in that year (Tab. 3, Fig. 4). Our storage experiments confirm that appropriate and optimal timing of controlling diseases reduces *B. cinerea* (Fig. 4, Tab. 2). Our findings suggest that it is very important to use disease forecasting models for effective disease control, only applying fungicides when the conditions for the disease are favourable and to reduce overall usage.

Acknowledgments: The paper presents research findings obtained through the long-term research program “Harmful Organisms in Agro and Forest Ecosystems (KOMAS)” implemented by the Lithuanian Research Centre for Agriculture and Forestry.

Conflict of interest: Authors declare nothing to disclose.

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