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Original scientific paper

The effectiveness of potassium phosphite and captan mixture in controlling *Venturia inaequalis* in apple orchards

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SUMMARY

Venturia inaequalis is a common apple disease in Serbia and its intensity depends on weather conditions. The most successful method of combating apple scab is to use a lower dose of an active ingredient and increase its effectiveness by adding substances that do not cause environmental damage.

The effectiveness of a fungicide mixture of captan and potassium phosphite against *V. inaequalis* was investigated in apple orchards in 2008 and 2009. A relevant EPPO standard method was used in all trials. Captan 50 WP was used as a standard fungicide. In order to determine the exact conditions marking the onset of apple infection, key meteorological conditions were monitored in the orchards using an automated *i*Metos weather station and a Lufft electronic instrument. The results showed high efficacy of the tested fungicides which remained similar in both years of investigation. The intensity of leaf infection after treatment with the mixture of captan and potassium phosphite was 0.7-2.4%, while fruit infection was 0.5-3.0%. The efficacy of this mixture ranged from 96.3-97.9% on leaves and 87.4-98.7% on fruits. The standard fungicide Captan 50 WP showed an efficacy ranging from 95.3-96.7% on leaves and from 87.8-99.3% on fruits. No statistically significant differences were found between the fungicide tested and the standard fungicide.

Keywords: Apple scab; Potassium-phosphite; Captan; Effectiveness

INTRODUCTION

Apple scab, caused by the fungus *Venturia inaequalis* (Cooke) Winter, is economically one of the most damaging diseases of apple in all apple-growing regions. The loss of yield can be up to 100% under weather conditions favorable for the pathogen's development (cool, wet spring and summer) (Ivanović & Ivanović, 2001). Economic damage includes yield loss, deteriorated fruit quality, reduced ability to bear fruit over the following season and increased susceptibility to frost. Successful growing of apples is not possible without intensive application of chemical fungicides.

In order to protect apple trees from the apple scab, a wide spectrum of chemical substances have been used that belong to different chemical groups with different modes of action (preventative, preventative-curative and curative), and they are often combined in order to enhance their effectiveness or avoid the development of resistance.

In order to keep trees scab-free during the growing season, more than 20 treatments may be needed (MacHardy, 1996; Ivanović & Ivanović, 2001). Such a large number of treatments with different or the same fungicides often results in toxic effects in soil and the environment in general, and the negative impact occurs especially as a residual effect on the fruit, and consequently on other processed food products consumed by people. It is therefore very important to apply evironmentally-friendly treatments with none or minimal health risks. For this reason, maximum allowed doses of active substances in different fungicide preparations have been constantly reviewed and restricted. The number of treatments can be restricted, as well as the timing and quantities of fungicides and pesticides in general, and not only against apple scab but against other pests and diseases too. The most successful method of combating apple scab is to use a lower dose of an active ingredient and increase its effectiveness by adding substances that do not cause environmental harm.

The aim of this paper was to investigate the effectiveness of the new product Ventura (containing potassium phosphite and a low dose of captan as an active ingredient) in combating apple scab (*V. inaequalis*).

MATERIALS AND METHODS

This investigation was conducted at the locality Morović in 2008, and at Morović and Obrenovac, Serbia, in 2009 (Table 1), using the OEPP method PP1/5 (3) (EPPO, 1997a). The experimental design was a random block system with four repetitions (EPPO, 1997b). The new product Ventura (Luxemburg Industries Ltd.), comprising two active ingredients: 360 g/l captan and 657 g/l potassium phosphate, was used. The application rates of Ventura were 2 and 3 l/ha. For the purpose of comparison, a standard preparation of captan WP-50 was used containing 500 g/l and it was applied at a rate of 3 l/ha. Twelve treatments were carried out in each locality in 2008 and 10 treatments

Table 1. Dates of preventative chemical treatments and growth stages of apple trees

Treatment	Locality, year								
	Morović, 2008			Obrenovac, 2009			Morović, 2009		
	Date	Growth stage (BBCH)	t (°C)	Date	Growth stage (BBCH)	t (°C)	Date	Growth stage (BBCH)	t (°C)
1	14.03.2008	10	24	07.04.2009	23-26	21	06.04.2009	23-26	18
2	21.03.2008	26-53-55	11	13.04.2009	26-53-55	25	14.04.2009	26-53-55	21
3	31.03.2008	57	18	21.04.2009	69	21	21.04.2009	69	23
4	07.04.2008	61	23	27.04.2009	71	19	27.04.2009	71	19
5	14.04.2008	66-69	21	05.05.2009	71-74	18	04.05.2009	71-74	18
6	21.04.2008	69	25	12.05.2009	74-75	23	11.05.2009	74-75	24
7	29.04.2008	71	24	19.05.2009	75	22	18.05.2009	75	22
8	06.05.2008	71-74	24	26.05.2009	76	25	25.05.2009	76	26
9	14.05.2008	74-75	26	03.06.2009	76-77	26	01.06.2009	76-77	20
10	21.05.2008	75	25	09.06.2009	77	27	08.06.2009	77	25
11	28.05.2008	76	27						
12	04.06.2008	77	26						

in 2009 from the BBCH 23-26 to BBCH 77 growth stages. The application was carried out by the ultra-dispersal method, using a Solo backpack atomiser and the rate of 1000 l/ha. The control treatment was fungicide-free.

The intensity of leaf infection was recorded after primary infection and the incubation period following the last set of favorable conditions for primary infection. Assessments of the intensity of leaf infection on newly-grown branches were made at three stages of plant growth: up to 1 m height of trees (I stage), between 1 and 2 m (II stage), and over 2 m (III stage). Five categories on a scale of 0-4, following the Townsend-Heuberger method, were used (Ciba-Geigy, 1981). Four stems from different sides of each tree were sampled in order to estimate the degrees of infection in stages I and II, and 2 stems were used for stage III. The intensity of infection was assessed according to the Townsend-Heuberger formula and the effectiveness of treatments according to Abbott (1925). The results were analyzed by the variance method and statistical significance calculated by Duncan's test.

Checks for the intensity of leaf and fruit infections were conducted on 17 June 2008 (Morović), and on 24 June (Morović) and on 3 July (Obrenovac) in 2009. The conditions favoring apple infection were monitored very closely, as they are extremely important in epidemiological studies and for assessing the effectiveness of apple scab treatment.

The dynamics of maturing and emptying of the pathogen's pseudothecia was monitored in both locations in order to determine the duration of the period of primary infections (Aleksić, 2006). For that purpose, samples of overwintered apple leaves (varieties Golden Delicious and Idared), were taken at 7 days intervals during the March-June season. Fifty pseudothecia were taken from each leaf sample and then macerated. The prepared pseudothecia were examined under light microscope and classified into 5 categories (0-4) according to a scale proposed by Aleksić (2006). The ripening, maturation and dispersal of pseudothecia were calculated using the following formulae:

$$P = \frac{K_1 + 2K_2 + 3K_3 + 4K_4}{U \cdot 4} \times 100 \qquad I = \frac{Ni}{U} \times 100$$

P – percentage of pseudothecia ripening,
K – category of pseudothecia ripening,
U – total number of examined pseudothecia,
I – percentage of dispersal,
N*i* – number of dispersed/empty pseudothecia.

In order to determine the exact conditions setting off apple infection, key meteorological conditions were monitored in the orchards using an automated meteorological station *i*Metos (Pessel Instruments, Austria) and a Lufft electronic instrument (Germany).

All data collected for the following parameters: air temperature, length of leaf wetness and relative air humidity, were analysed and processed using a software. The whole procedure was conducted during the period of primary apple infection (March until end of June) as suggested by Mills.

The growth stages of apple trees were monitored using the Fleckinger and BBCH scale (EPPO, 1989; Meier, 1997; Mitić, 2004). The most important practical aspect of apple scab infection is the detection of the exact BBCH 10/54-55 development stage on the basis of first dispersal of ascospores in apple orchards (according to Mills). Twenty randomly selected apple trees of each studied variety, were used to determine the exact stage of development. It enabled the exact timing of the first set of conditions favorable for primary apple scab infection in the orchards.

For monitoring the release and dispersal of ascospores in the orchards, we used a Burkard volumetric spore sampler (Manufacturing Co Ltd, Rickmansworth, Hertfordshire, England).

RESULTS

In 2008, the growth season started early, as well as the period of primary apple scab infection, which lasted as long as 87 days (14 March - 8 June 2008). During the period, favorable conditions for light scab infection were recorded 22 times in total (Table 2). The first set of conditions were recorded on 18 March when the Golden Delicious apple variety was in its early growth stages (BBCH 23-26) and the last set of conditions was detected on 8 June 2008.

In the locality Obrenovac in 2009, 27 days were recorded as days with conditions favoring light infection and calling for chemical control of *V. inaequalis*. It is interesting that the first set of favorable conditions was registered quite late in that locality, on 17 April, and the last date was 30 May 2009 (Table 2). In the locality Morović, 22 days with conditions favouring light infection were recorded. The first set of conditions was recorded on 31 March and the last on 6 June 2009 (Table 2).

Table 2. Dates of recorded *V. inaequalis* ascospore infections

Locality, year								
Morović, 2008			Obrenovac, 2009			Morović, 2009		
Light infection	Medium infection	Strong infection	Light infection	Medium infection	Strong infection	Light infection	Medium infection	Strong infection
18.03.			17.04.	18.04.		31.03.	31.03.	31.03.
19.03.			19.04.	19.04.		01.04.	01.04.	01.04.
23.03.			20.04.	21.04.		17.04.		
03.04.			22.04.	22.04.		18.04.		
05.04.			23.04.			19.04.	19.04.	19.04.
09.04.			25.04.			20.04.		
13.04.			29.04.			21.04.	21.04.	21.04.
15.04.			30.04.	30.04.		30.04.	30.04.	
16.04.			01.05.			01.05.	01.05.	01.05.
17.04.			02.05.			20.05.	20.05.	20.05.
18.04.	19.04.		04.05.	05.05.		23.05.	23.05.	
26.04.			07.05.			25.05.		
02.05.	02.05.		09.05.			27.05.		
06.05.			10.05.			28.05.	28.05.	28.05.
07.05.			12.05.	12.05.		29.05.	29.05.	29.05.
20.05.	21.05.	21.05.	14.05.			31.05.		
21.05.	22.05.	22.05.	16.05.			01.06.	01.06.	01.06.
03.06.	04.06.	04.06.	18.05.	19.05.		02.06.	02.06.	02.06.
05.06.			20.05.			03.06.	03.06.	03.06.
06.06.	06.06.	06.06.	21.05.			04.06.	04.06.	04.06.
07.06.	07.06.		22.05.			05.06.	05.06.	05.06.
08.06.	08.06.	08.06.	23.05.			06.06.	06.06.	06.06.
			24.05.					
			25.05.					
			26.05.					
			28.05.					
			30.05.					

Table 3. The percentage intensity of apple leaf and fruit infections with *V. inaequalis* and fungicide effectiveness, Morović, 2008

Treatment	Concen-tration (%)	Leaf infection							Fruit infection						
		Repetition				Ms Duncan test	Sd	E (%) control	Repetition				Ms Duncan test	Sd	E (%) control
		I	II	III	IV				I	II	III	IV			
Control	–	58.1	21.6	16.1	43.7	**34.9 a**	19.54		24.0	30.5	43.5	20.0	**29.5 a**	10.29	
Ventura	0.2	2.5	0.4	0.3	0.6	**1.0 b**	1.08	**97.1**	0.5	1.5	0	1.5	**0.9 b**	0.75	**96.9**
Ventura	0.3	1.3	0.6	0.5	0.9	**0.8 b**	0.36	**97.7**	0	1.5	0.5	4.5	**1.6 b**	2.02	**94.6**
Delan 700 WG	0.05	2.6	3.9	2.1	1.8	**2.6 b**	0.93	**92.5**	0	1.0	1.0	0.5	**0.6 b**	0.48	**98.0**
Mankogal 80	0.25	2.2	0.6	0.4	0.7	**1.0 b**	0.83	**97.1**	0	2.0	0.5	0	**0.6 b**	0.95	**98.0**
Score 250 EC	0.015	0.5	5.1	1.1	3.0	**2.5 b**	2.08	**92.8**	4.0	4.5	5.0	2.5	**4.0 b**	1.08	**86.4**
Captan 50 WP	0.3	1.5	2.0	1.2	1.6	**1.6 b**	0.33	**95.4**	0.5	1.0	1.5	0	**0.75 b**	0.64	**97.5**
						$LSD_{0.05}$ = 9.76							$LSD_{0.05}$ = 5.18		

Ms – mean value, Sd – standard deviation, E – efficacy.

Table 4. The percentage intensity of apple leaf and fruit infection with *V. inaequalis* and fungicide effectiveness, Morović, 2009

Treatment	Concentration (%)	Leaf infection							Fruit infection						
		Repetition				Ms Duncan test	Sd	E (%) control	Repetition				Ms Duncan test	Sd	E (%) control
		I	II	III	IV				I	II	III	IV			
Control	–	41.9	21.9	18.5	53.5	**33.9 a**	16.63	–	25.0	18.8	21.6	30.0	**23.8 a**	4.82	–
Ventura	0.2	1.8	1.1	0.7	0.9	**1.1 b**	0.48	**96.8**	3.0	1.0	6.2	1.6	**3.0 b**	2.32	**87.4**
Ventura	0.3	1.0	1.0	0.5	0.4	**0.7 b**	0.32	**97.9**	1.8	2.3	3.0	2.2	**2.3 b**	0.50	**90.3**
Captan 50 WP	0.3	1.1	1.7	2.4	1.3	**1.6 b**	0.57	**95.3**	2.0	4.8	5.0	0.0	**2.9 b**	2.40	**87.8**
						$LSD_{0.05}$ = 13.41							$LSD_{0.05}$ = 5.14		

Ms – mean value, Sd – standard deviation, E – efficacy.

Table 5. The percentage intensity of apple leaf and fruit infection with *V. inaequalis* and fungicide effectiveness, Obrenovac, 2009

Treatment	Concentration (%)	Leaf infection							Fruit infection						
		Repetition				Ms Duncan test	Sd	E (%) control	Repetition				Ms Duncan test	Sd	E (%) control
		I	II	III	IV				I	II	III	IV			
Control	–	56.8	66.1	65.1	68.6	**64.2 a**	5.12	–	16.5	47.5	14.5	71.0	**37.4 a**	27.03	–
Ventura	0.2	5.4	1.2	1.8	1.0	**2.4 b**	2.06	**96.3**	0.0	1.0	1.0	0.0	**0.5 b**	0.58	**98.7**
Ventura	0.3	0.4	0.6	0.6	3.3	**1.2 b**	1.39	**98.1**	0.0	0.5	0.0	0.0	**0.13 b**	0.25	**99.6**
Captan 50 WP	0.3	2.0	2.9	2.4	1.0	**2.1 b**	0.81	**96.7**	1.0	0.0	0.0	0.0	**0.25 b**	0.50	**99.3**
						$LSD_{0.05}$ = 4.99							$LSD_{0.05}$ = 21.7		

Ms – mean value, Sd – standard deviation, E – efficacy.

The results of the percentage intensity of scab infection of apple leaves and fruit in the locality Morović in 2008 are shown in Table 3. The controls showed 34.9% and 29.5% infection, respectively. The results show that the Ventura treatment at its lowest dose of 0.2% (2 l/ha) provided the most effective control of apple scab both on leaves (97.1%) and fruit (96.9%), even under conditions propitious for severe infection. There were no statistically significant differences between the effectiveness of 0.2% and 0.3% concentrations of Ventura. Ventura was more effective than Delan 700 EG (a.i. dithianon) and Score 250 EC (a.i. difenoconazole), which were applied as a preventative measure. The effectiveness of Mankogal 80 (a.i. mancozeb) was similar to Ventura, although none of the treatments showed a statistically significant difference in the mean percentage of infection intensity.

Ventura also demonstrated a high effectiveness in controlling *V. inaequalis* in apple orchards during 2009 (Tables 4 and 5). The intensity of apple scab infection in nondiseased leaves (control) was 33.9% in the locality Morović and 64.2% in Obrenovac. The intensity of infection of the diseased apple fruit was 23.8 and 37.4%, respectively. When using Ventura, the intensity of leaf infection was 0.7-2.4% and the effectiveness 96.3-98.1%, whereas 87.4-99.6% of the apple fruit were infected. For comparison, when Captan 50 WP was used, the leaf infection was 1.6-2.1% and effectiveness 95.3-96.7%, while fruit infection was 0.25-2.9% with the effectiveness of 87.8-99.3%. However, no statistically significant difference was detected among the fungicides used.

DISCUSSION

Reduction in the use of pesticides is essential for the production of safe food and protection of the environment in general. It can be achieved through their judicious use, as a result of monitoring or reliable prediction of onsets of plant diseases and pests. Another strategy is to use environment-safe chemical treatments as an alternative or to reduce the quantities of active substances that are usually damaging to the environment and health.

Potassium phosphite belongs to the group of phosphonates [phosphonic acid salt anion metabolite of aluminium tris(ethyl phosphonate)]. This is a systemic fungicide, which moves through the plant fast, both by basipetal and acropetal transport. It stops mycelium growth and indirectly stimulates the resistance of plants because phosphite encourages the production of elicitin, which increases immunity (Guest & Bompeix, 1990; Guest & Grant, 1991; Johnson et al., 2004, Lobato et al. 2008). It was registered as a fungicide for the first time in Australia in 1989, and then in the USA in 2003. Potassium phosphite was classified in the FRAC lists of fungicides (FRAC, 2011) under the code 33 and in the group of fungicides with low risk of pathogens developing resistance, and it is an environmentally acceptable active material because it is harmless to bees and aquatic organisms (Tomlin, 2006).

Literature includes no records of a resistance of phytopathogenic fungi to captan (Brent, 1995; Brent & Hollomon, 1998). FRAC classifies captan in a group of fungicides not causing resistance (Fishel & Dewdney, 2012). However, its use in plant protection is restricted by the level of residuals allowed in the fruit and the environment (Tomlin, 2006).

Ventura, the fungicide investigated in this study, contains a reduced dose of captan (360g/l), compared to other commercial captan-based products, because potassium phosphite is added as a systemic fungicide (657g/l). Nevertheless Ventura demonstrated a strong preventative effect in controlling *V. inaequalis*.

Investigation of the effectiveness of different preparations based on potassium phosphite as one of the components has been conducted by many researchers. In a study of Fenix (chlorothalonil + potassium phosphite), Stepanović et al. (2009) found its high effectiveness in suppressing *Phytophtora infestans* over a 2-year period: 95.7-98.9% in 2007 and 95.4-98.3% in 2008. The difference in effectiveness, as compared to the standard Dakoflo (89.9-93.9% and 91.4-92.5%, respectively), was not statistically significant. Keinath (2010) also reported that potassium phosphite in a mixture with other fungicides prevented a significant yield reduction of *Brassicacea* due to a blight infection. The results of Rebollar-Alvitar and Ellis (2004) showed that the product ProPhyt, based on potassium phosphite, achieved high effectiveness (89.0%) in controlling/suppressing *Phytophthora cactorum,* a causal agent of strawberry rotting, compared to the standard Ridomil Gold (84%) and a control. Similar results were reported by Rebollar-Alvitar et al. (2005) in a two-year trial investigating the effectiveness of potassium phosphite and strobilurin in controlling *P. cactorum* on strawberry plants.

We can therefore conclude that potassium phosphite, as an environmentally-friendly active substance, has significantly improved the environmental credibility and acceptability of the new fungicide Ventura, throught its reduced amount of captan, while its effectiveness is preserved or even enhanced in apple scab control, as shown in this study. There are indications that potassium phosphite has a curative effect on fungi, which requires further study.

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Efikasnost mešavine kalijum fosfita i kaptana u suzbijanju *Venturia inaequalis* u jabučnjacima

REZIME

Venturia inaequalis je široko rasprostranjena bolest jabuke u Srbiji, a njen intenzitet zavisi od vremenskih uslova. Najuspešniji metod borbe protiv čađave krastavosti jabuke je korišćenje manjih doza aktivnih materija uz istovremeno povećavanje efikasnosti dodavanjem supstanci koje ne prouzrokuju štetu u životnoj sredini.

Tokom 2008 i 2009 godine, proučavana je efikasnost fungicidne mešavine kaptana i kalijum fosfita protiv *V. inaequalis* u jabučnjacima. U svim ogledima je korišćen standardni EPPO metod. Captan 50 WP je korišćen kao standardni fungicid. Kako bi se tačno odredili uslovi za početak zaraze na jabuci, praćeni su osnovni meteorološki parametri u voćnjacima pomoću ***i***Metos stanice i elektronskog uređaja Lufft. Rezultati su pokazali visoku efikasnost testiranih fungicida koja je bila slična u obe godine istraživanja. Intenzitet zaraze lista nakon tretmana mešavinom kaptana i kalijum fosfita bio je 0.7-2.4%, dok je zaraženost plodova bila 0.5-3.0%. Efikasnost mešavine bila je 96.3-97.9% na listovima, a 87.4-98.7% na plodovima. Standardni fungicid Captan 50 WP pokazao je efikasnost u opsegu 95.3-96.7% na listovima i 87.8-99.3% na plodovima. Nisu konstatovane statistički značajne razlike između ispitivanog i standardnog fungicida.

Ključne reči: Čađava krastavost jabuke; kalijum fosfit; kaptan; efekasnost.