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Original Article

Management of Apple Scab and Powdery Mildew Using Bicarbonate Salts and Other Alternative Organic Products with Fungicide Effect in Apple Cultivars

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Abstract

The control of apple scab and powdery mildew is a challenge for organic fruit growing. Bicarbonate salts are already consecrate in reducing the attack of scab and powdery mildew in organic apple culture. In the current study the influence of some products accepted in organic apple production to control scab and powdery mildew (potasium bicarbonate, lime sulphur, wettable sulphur, potassium silicate, cooper ammonium-phosphate, potassium bicarbonate + potassium silicate, potassium bicarbonate + wettable sulphur) in comparison with untreated control, were used. The biological material was represented by three scab resistant cultivars ('Luna', 'Topaz' and 'Sirius') and three scab susceptible cultivars ('Elstar', 'Pinova' and 'Golden Delicious'). The experiments were carried out during 2014-2016 at Steluța LTD, Cluj-Napoca, N.W. Romania, as a bifactorial experiment arranged in randomized blocks. The trees were planted in 2011 at a density of 3,175 trees/ha. Depending of the year, a number of 18-22 treatments were made annually after each rain. It can be concluded that the combination of potassium bicarbonate + wettable sulphur significantly reduced the attack degree of scab and powdery mildew on leaves and fruits and increased the yield of the scab-susceptible and scab resistant cultivars. Good results were obtained in the case of treatment with potassium bicarbonate with potassium silicate, potassium bicarbonate and cooper ammonium phosphate. The treatments with the products used in the experiments did not register symptoms of phytotoxicity on leaves or fruits, except lime sulphur and wettable sulphur and cooper ammonium phosphates.

Keywords: apple, bicarbonate, organic, powdery mildew, scab

Introduction

In the last decades, organic apple crop is constantly expanding, and the demand for healthy apples, with no chemical residual products, is increasing. For organic apple growers, the biggest challenge is scab and powdery mildew diseases control.

Most commercial apple grown cultivars are very sensitive to scab, so that in an commercial apple orchard, very frequent fungicide applications (15-22 annually) are applied in order to control apple scab, depending on weather conditions, disease pressure and cultivar susceptibility (Holb *et al.*, 2005).

In organic apple growing, just a few approved chemical products are available for disease control, mainly based on sulphur and copper (Holb, 2008); various natural plant extracts containing triterpenoid saponins, polyphenols and specific flavonoids have been reported to have antifungal properties (Köhl *et al.*, 2007; Bahraminejad *et al.*, 2008; Bengstsson *et al.*, 2009; Jamar *et al.*, 2010).

Another way to control these diseases could be the cultivation of low scab-susceptible or scab-resistant cultivars having the *Vf* gene. However, new scab races, virulent to the *Vf* gene, have appeared in most European countries (Gessler *et al.*, 2006). Consequently, monogenic, polygenic and incorporated monogenic + polygenic resistance needs to be

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carefully integrated into anti-breakdown strategies (Jamar *et al*., 2010; Sestras *et al*., 2011; Dan *et al*., 2015).

The use of copper as fungicide in organic apple is often disputed even if the copper as fungicide is effective, persistent, highly active, cheap and covers a well-known number of fungal diseases.

Over the years, using of copper-based compounds especially in high quantities is leading to an accumulation of copper in the orchard soil over of official limit in Europe of 36 mg kg^{-1} soil). More than that, in some European countries (Nederland and the Scandinavian countries) using of cooper based products is forbidden.

Therefore, the chemical option for apple scab control in organic farming is the use of elemental sulphur and lime sulphur products (Holb *et al*., 2003).

Elementary sulphur and sulphur based compounds often have less curative proprieties against scab and powdery mildew than copper-based compounds, especially in cold weather (unless lime sulphur).

Several studies have shown that the repeated application of large amounts of sulphur compounds has eco toxicological and phytotoxic side-effects (Mills, 1947; Kreiter *et al*., 1998; Holb *et al*., 2003; Palmer *et al*., 2003).

Unfortunately, lime sulphur can be injurious to the trees, lowering photosynthesis rates, reducing fruit set, fruit yield and pollen germination, inducing phytotoxic burns on leaves and fruits, affecting fruits quality (MacDaniels and Furr, 1930; Burrell, 1945; MacHardy, 1996; Palmer *et al*., 2003; Environmental Protection Agency, 2006; McArtney *et al*., 2006; Cromwell *et al*., 2011).

Due to the negative fungal properties of the standard sulphur/lime sulphur fungicides in organic apple production, it is necessary to evaluate the effectiveness of other alternative, organically approved or proposed to approval fungicides (Creemers *et al*., 2006).

The efficacy of bicarbonate salts in the control of these diseases was known many years ago (Marloth, 1931). Efficacy of bicarbonate salts is the focus of scientific worldwide research. The mode of bicarbonate salts action is bound to the perturbation of pH, osmotic pressure, the bicarbonate/carbonate ion balance of sensitive fungi and these salts acts by contact to fungi in aqueous solution and inhibits the development of fungal mycelium (Marku *et al*., 2014).

The aims of this 3-year study were to evaluate the effectiveness of bicarbonate salts and other alternative organic products with fungicide effect, alone or mixed (wettable sulphur, lime sulphur, potassium bicarbonates, potassium silicate and copper) in apple scab and powdery mildew control. In addition, their phytotoxicity and effects of these products on yield and fruit quality on cultivars with varying degrees of resistance and sensitivity to these diseases were investigated.

Materials and Methods

Location and orchard density

The research has been carried out in a commercial apple orchard with a density of 3,175 trees/ha (trees were planted at a distances of 3.5 × 0.9 m) established in 2011 belonging to Steluța LTD, Cluj-Napoca, Transylvania (N.W. Romania), in 2014-2016.

Plant material

Plant material was represented by three scab resistant cultivars ('Luna', 'Topaz' and 'Sirius') and three scab susceptible cultivars ('Elstar', 'Pinova' and 'Golden Delicious'). The growing technology was specific to apple super-intensive orchards. The trees have not been maintained according to organic production standards, excepting the control of scab and powdery mildew.

In Table 1 are presented the information about the products, alone or mixed, used in the experiment (trademark, active ingredient, dose).

Cultural management of the plantation

First treatments were applied just before or at the beginning of the infection risk periods. Depending of the year, a number of 18-22 treatments were made annually, after each rain, immediately after rain stopped. Each treatment combination was applied in each block after each rain, during all period of the infection process. All treatments were applied at a low spray rate of 500 l ha^{-1}.

Potassium and silicon based products and copper ammonium phosphate were prepared in collaboration with the Faculty of Chemistry, Cluj-Napoca, Romania: potassium bicarbonate solution had a concentration of 20% and potassium silicate 30%.

Experimental design

The experiment was bifactorial, set up in randomized blocks, the first factor being the treatment with eight

Table 1. Treatments and active ingredients application rates

Trademark	Active ingredient	Dose ha^{-1}
Control	no treatment	-
Potassium bicarbonate + Potassium silicate	Potassium bicarbonate (20%) + Potassium silicate (30%)	2.5 ha^{-1} Potassium bicarbonate + 0.5 kg ha^{-1} Potassium silicate
Lime Sulphur	Calcium polysulphide 1%	5 kg ha^{-1}
Potassium Bicarbonate + Thiovit jet (Syngenta Agro, Fr.)	Potassium bicarbonate (20%) + Wettable sulphur (80%)	5 kg ha^{-1} Potassium bicarbonate + 2 kg ha^{-1} Wettable sulphur
Potassium silicate	Potassium silicate (30 %)	2.6 kg ha^{-1}
Thiovit jet (Syngenta Agro, Fr.)	Wettable sulphur (80%)	4 kg ha^{-1}
Potassium bicarbonate	Potassium bicarbonate (85 %)	5 kg ha^{-1}
Cooper ammonium phosphate	Copper hydroxide (40 %)	300g ha^{-1}

graduations: control (untreated), mixture between potassium bicarbonate and potassium silicate, lime sulphur, mixture between potassium bicarbonate and wettable sulphur, potassium silicate, wettable sulphur, potassium bicarbonate, cooper ammonium phosphate. The second factor was the cultivar with six graduations, thus resulting in 48 variants, in three replications (3 trees / replication).

Observation and measurements

Each year, diseases assessments on the leaves and fruits were made. Visual observations in the field were made on the intensity and frequency attack of apple scab and apple powdery mildew on leaves, the intensity and frequency attack of scab on fruits and phytotoxicity on leaves and fruit. Fruit scab intensity and fervency attack of infection was calculated as the proportion of total harvested fruit with at least one scab lesion.

Statistical analysis

Data processing was done by means of the analysis of variance (ANOVA test) and the interpretation of results was performed through Duncan test.

Results and Discussion

The influence of environmental conditions

Environmental conditions, especially temperature and precipitations, have a strong influence on triggering primary and secondary infections with scab and powdery mildew in the apple orchards. The number of annual necessary treatments against these diseases is depending on weather conditions, disease pressure and cultivar susceptibility (Holb *et al*., 2005). The monthly and annual mean values of temperature during 2014-2016 presented in the Fig. 1 express differences between monthly mean values from one year to another. The highest temperature values were in August 2015 and the lowest in January 2015, all being over to the multiannual average values of temperature for the study area.

The rainiest year within the study interval was 2015, when the pressure of infection was also the highest one. However, the differences between values of average monthly precipitations sum were not too big from one year to another (Fig. 2). The climatic conditions of the three years of experience were favorable to development of apple scab and powdery mildew; actually, Transylvania region is a favorable one for development of these apple diseases, even in conventional orchards.

The influence of different products against apple scab attack, on leaves

Regardless the cultivar, between the seven variants of treatments and control there were differences statistically assured (Table 2).

Usage of treatments with bicarbonate salts determined a reduction of the attack degree of 2-6.5 times. Even more, all other products used in the experiment reduced the attack degree compared to the control variant. The most efficient spray treatment was recorded in the variant with potassium bicarbonate + wettable sulphur (3.4 % ad), followed by the variant potassium bicarbonate + potassium silicate (4.6 % ad), compared to the control (21.6 % ad). Good results were obtained also in the case of lime sulphur variant, followed by the variants with cooper ammonium phosphate, potassium silicate and wettable suphur.

Regardless the influence of treatment, between cultivars sensitive to scab and the cultivars resistant to scab and between cultivars sensitive to scab themselves, differences statistically assured were registered. Among the cultivars susceptible for apple scab, the lowest value of attack degree was obtained for 'Pinova' (14.7 %), followed by 'Elstar' (19.5 %). During the 3 years of the experiment, there were no symptoms of apple scab observed on the leaves of any of the scab-resistant cultivars under study.

The influence of different products against apple scab attack, on fruits

Regarding the scab attack on fruits, it can be observed that all treatments strongly reduced the attack degree (Table 3). The highest pressure of infection value was recorded at 'Golden Delicious' (16.2%) followed by 'Elstar' and 'Pinova'. The scab resistant cultivars behaved similarly from the statistically point of view, without scab infection symptoms.

Irrespective of cultivars, the best treatment in reducing scab attack degree on fruits was the mixture between potassium bicarbonate and wettable sulphur, respectively, the mixture potassium bicarbonate + potassium silicate. All products used in the experience gave better results than the untreated control variant.

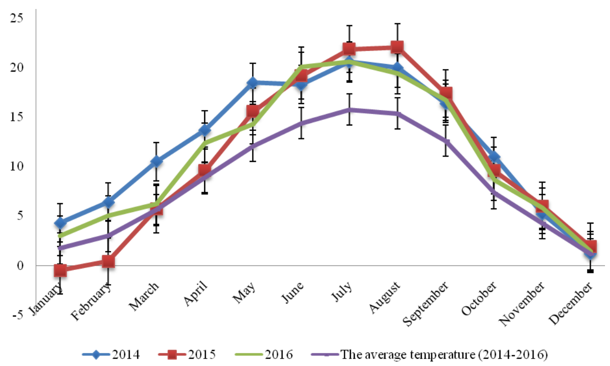

Fig. 1. Averages of monthly and annual temperatures in the experimental field during 2014-2016

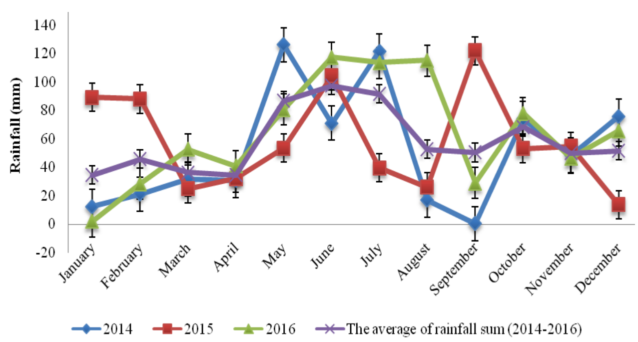

Fig. 2. The average monthly precipitations for each year of study and the average of rainfall sum in the experimental field during 2014-2016

Table 2. Influence of different products recommended in organic apple growing against scab attack (AD %) on leaves

Treatment / Cultivar	'Elstar'	'Pinova'	'Golden Delicious'	'Luna'	'Topaz'	'Sirius'	Mean treatment
Control	42.4 l	38.2 k	49.0 m	0.0 a	0.0 a	0.0 a	21.6 R
Potassium bicarbonate + Potassium silicate	8.2 c	7.9 c	11.5 d	0.0 a	0.0 a	0.0 a	4.6 M
Lime Sulphur	18.9 g	10.9 d	19.0 g	0.0 a	0.0 a	0.0 a	8.1 N
Potassium Bicarbonate + Thiovit jet	7.9 c	4.9 b	7.9 c	0.0 a	0.0 a	0.0 a	3.4 L
Potassium silicate	19.7 g	12.0 d	23.1 i	0.0 a	0.0 a	0.0 a	9.1 O
Thiovit jet	19.1 g	14.0 de	21.7 h	0.0 a	0.0 a	0.0 a	9.1 O
Potassium bicarbonate	23.1 i	12.3 d	25.1 j	0.0 a	0.0 a	0.0 a	10.1 P
Cooper ammonium phosphate	16.7 f	17.3 f	20.0 g	0.0 a	0.0 a	0.0 a	9 O
Mean cultivar	19.5 C	14.7 B	22.0 D	0.0 A	0.0 A	0.0 A	
LSD 5% cultivar				0.6-0.7			
LSD 5% treatment				0.7-0.8			
LSD 5% int. cv. × tr.				1.8-2.3			

Note: Different letters between variants denote significant differences (Duncan test, $p < 0.05$)

Table 3. Influence of different products used in organic apple growing on apple scab attack (AD%) on fruits

Treatment / Cultivar	'Elstar'	'Pinova'	'Golden Delicious'	'Luna'	'Topaz'	'Sirius'	Mean treatment
Control	33.3 f	29.7 e	36.3 f	0.0 a	1.7 a	0.0 a	16.8 P
Potassium bicarbonate + Potassium silicate	6.3 bc	5.9 b	8.3 c	0.0 a	0.0 a	0.0 a	3.4 L
Lime Sulphur	11.0 c	7.3 bc	10.0 c	0.0 a	0.0 a	0.0 a	4.7 LM
Potassium Bicarbonate + Thiovit jet	4.3 b	2.6 b	6.5 bc	0.0 a	0.0 a	0.0 a	2.2 L
Potassium silicate	11.0 c	10.3 c	18.3 d	0.0 a	0.0 a	0.0 a	6.6 O
Thiovit jet	10.7 c	10.3 c	18.3 d	0.0 a	0.0 a	0.0 a	6.6 O
Potassium bicarbonate	11.3 c	10.7 c	19.0 d	0.0 a	0.3 a	0.0 a	6.9 O
Cooper ammonium phosphate	10.3 c	9.7 c	12.7 c	0.0 a	0.0 a	0.0 a	5.4 MN
Mean cultivar	12.3 C	10.8 B	16.2 D	0.0 A	0.3 A	0.0 A	
LSD 5% cultivar				1.0-1.1			
LSD 5% treatment				1.1-1.3			
LSD 5% int. cv. × tr.				2.7-3.5			

Note: Different letters between variants denote significant differences (Duncan test, $p < 0.05$)

The current results seem to be in accordance with the results obtained by Jamar *et al.* (2010) who indicated that potassium bicarbonate significantly reduced apple scab severity on the leaves and fruits, while potassium silicate treatments did not reduce scab severity on leaves, but did reduce it very slightly on fruits.

Potassium bicarbonate treatment on multiple cultivars in field experiments in Romania significantly reduced foliar and fruit apple scab (Mitre *et al.*, 2009, 2010).

The influence of different products against powdery mildew attack, on leaves

Power mildew control was more effective on the scab resistant cultivars than on the scab-susceptible ones (Table 4). Treatments with potassium bicarbonate + wettable sulphur induced the lowest degree of attack (2.5%). Potassium bicarbonate and wettable sulphur used separately also reduced the attack on the leaves, but in the smaller scale.

As noted in previous studies (Holb *et al.*, 2003; Jamar *et al.*, 2008; Jamar *et al.*, 2010)the treatments applied against apple scab and powdery mildew, after each rain, had several important advantages: no washing effect of products due to the rain; high effectiveness of treatments on spores in germinating phase; prevent new infections.

The efficiency of bicarbonate salts in controlling apple scab reported in previous studies (Schulze *et al.*, 2003; Ilhan *et al.*, 2006; Tamm *et al.*, 2006; Jamar and Lateur, 2007; Jamar *et al.*, 2007a, 2007b, 2008, 2010) suggests that this compound could be introduced in apple disease management, with the remark that is not to be used alone, but with other active compounds. Even bicarbonates seem to be effective against scab and powdery mildew, but a long lasting effect cannot be expected, because they are unstable compounds that are highly water-soluble and easily washed off the leaves by a small amount of precipitation (Jamar *et al.*, 2010).

Table 4. Influence of different products used in organic apple growing on apple powdery mildew attack (AD%) on leaves

Treatment / Cultivar	'Elstar'	'Pinova'	'Golden Delicious'	'Luna'	'Topaz'	'Sirius'	Mean treatment
Control	48.3^{g}	29.7^{e}	36.3^{f}	11.7^{c}	7.0^{cb}	9.0^{c}	23.7^{P}
Potassium bicarbonate + Potassium silicate	6.3^{cb}	5.9^{b}	10.3^{c}	1.4^{a}	1.4^{a}	1.8^{a}	4.5^{M}
Lime Sulphur	11.0^{c}	7.3^{c}	10.0^{c}	1.5^{a}	1.0^{a}	0.7^{a}	5.2^{M}
Potassium Bicarbonate + Thiovit jet	4.3^{b}	2.6^{a}	7.9^{c}	0.0^{a}	0.0^{a}	0.0^{a}	2.5^{L}
Potassium silicate	11.0^{c}	10.3^{c}	18.0^{d}	4.0^{b}	4.4^{b}	3.7^{b}	8.6^{O}
Thiovit jet	10.7^{c}	10.3^{c}	18.4^{d}	4.7^{b}	4.7^{b}	4.0^{b}	8.8^{O}
Potassium bicarbonate	11.3^{c}	10.7^{c}	19.0^{d}	4.8^{b}	4.8^{b}	4.2^{b}	9.1^{O}
Cooper ammonium phosphate	10.0^{3}	9.7^{c}	12.7^{c}	4.8^{b}	4.3^{b}	2.7^{a}	7.4^{N}
Mean cultivar	14.2^{C}	10.8^{B}	16.6^{D}	4.1^{A}	3.4^{A}	3.3^{A}	
LSD 5% cultivar				1.0-1.1			
LSD 5% treatment				1.1-1.3			
LSD 5% int. cv. × tr.				2.8-3.5			

Note: Different letters between variants denote significant differences (Duncan test, $p < 0.05$)

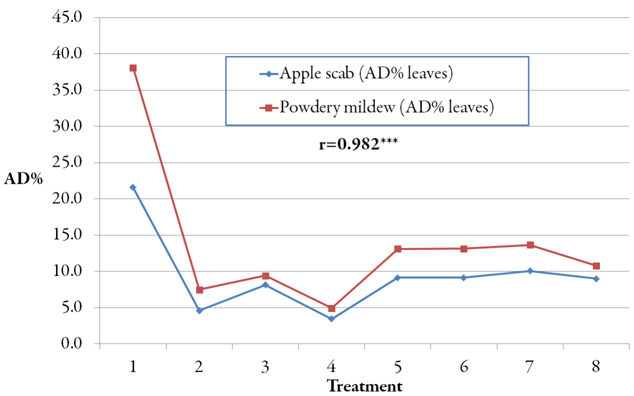

Fig. 3. Coefficient of correlation between apple scab and powdery mildew attack degree (AD%) on leaves, as mean values of cultivars without genetic resistance to scab ('Elstar', 'Pinova', 'Golden Delicious'), depending on treatments: 1-Control; 2-Potassium bicarbonate + Potassium silicate; 3-Lime Sulphur; 4-Potassium Bicarbonate + Thiovit jet; 5-Potassium silicate; 6-Thiovit jet; 7-Potassium bicarbonate; 8-Cooper ammonium phosphate

Opposite to the current results, Cromwell *et al.* (2006) found that potassium bicarbonate was not as effective as the sulphur/lime sulphur treatment, in an experiment under Vermont conditions.

In the eight treatments of the experience against fungus diseases, the correlation between apple scab and powdery mildew attack degree (AD%) on the leaves, as mean values of the cultivars without genetic resistance to scab ('Elstar', 'Pinova', 'Golden Delicious'), was very significant ($r = 0.982^{***}$; p 0.001 = 0.924).

The influence of different products against powdery mildew attack, on yield

Data about the influence of bicarbonate salts and other alternative organic products with fungicide effect used in the experiment upon fruit yield in 2014-2016 are presented in the Table 5.

The results of Table 5 show that the yield was strongly affected by the studied diseases particularly in the case of scab susceptible cultivars: 'Elstar', 'Pinova' and 'Golden Delicious'. The yield of cultivars having resistance to scab and tolerance to powdery mildew was not affected, as the differences between them were not statistically assured. Besides, irrespective of the influence of cultivar, the effect of treatments was not significant upon yield except the variants of treatment with potassium bicarbonate + wettable sulphur, potassium bicarbonate and potassium silicate. Similar results were reported in some previous studies (Trapman, 2006; Jamar *et al.*, 2010).

Several studies have shown that the repeated application of large amounts of sulphur compounds has eco toxicological and phytotoxic side-effects (Mills, 1947; Kreiter *et al.*, 1998; Holb *et al.*, 2003; Palmer *et al.*, 2003).

Lime sulphur, wettable sulphur and cooper ammonium phosphates induced phytotoxicity on leaves and russeting on fruits, especially on 'Golden Delicious' cultivar.

Other authors also reported similar cases about phytotoxicity or foliar damage due to sulphur and copper treatments (Mills, 1947; Holb *et al.*, 2003; Palmer *et al.*, 2003).

Conclusions

Bicarbonate salts and other alternative organic products with fungicidal effect on apple cultivars, such as potassium bicarbonate, sulfur, potassium bicarbonate with sulfur, potassium bicarbonate with potassium silicate, potassium silicate, lime sulfur, cooper ammonium phosphate, significantly reduced attack grade of apple scab and mildew mildew on leaves and fruits and increased yield. Potassium bicarbonate used alone reduced apple scab and powdery mildew, being as effective as wettable sulphur, but was more effective in combination with wettable sulphur applied immediately after each rain. Mixture between potassium bicarbonate and potassium silicate was as effective as the mixture between potassium bicarbonate and wettable sulphur for reducing attack degree of apple scab and powdery mildew diseases, thus it can be concluded that

Table 5. Influence of different products used in organic apple growing on apple yield (kg/tree)

Treatment / Cultivar	'Elstar'	'Pinova'	'Golden Delicious'	'Luna'	'Topaz'	'Sirius'	Mean treatment
Control	6.6 [c]	9.7 [b]	9.6 [b]	10.2[b]	11.0 [ab]	11.3 [ab]	9.7 [N]
Potassium bicarbonate + Potassium silicate	9.3 [b]	13.2 [a]	11.9 [ab]	14.1[a]	11.7 [ab]	11.5 [ab]	12.0 [M]
Lime Sulphur	7.4 [b]	9.9 [b]	10.6 [ab]	13.0[a]	10.3 [ab]	10.3 [ab]	10.3 [N]
Potassium Bicarbonate + Thiovit jet	13.1 [a]	13.4 [a]	13.9 [a]	14.3[a]	12.3 [a]	11.8 [ab]	13.1 [L]
Potassium silicate	9.5 [b]	9.3 [b]	9.5 [b]	13.7[a]	11.0 [ab]	11.0 [ab]	10.7 [N]
Thiovit jet	9.2 [b]	9.5 [b]	9.3 [b]	13.0a	10.9 [ab]	10.7 [ab]	10.4 [N]
Potassium bicarbonate	8.9 [b]	9.4 [b]	9.5 [b]	11.0[ab]	11.1 [ab]	11.0 [ab]	10.2 [N]
Cooper ammonium phosphate	8.8 [b]	9.7 [b]	9.3 [b]	11.0[ab]	10.9 [ab]	11.0 [ab]	10.1 [N]
Mean cultivar	9.1 [C]	10.5 [B]	10.5 [B]	12.5[A]	11.2 [B]	11.1 [B]	
LSD 5% cultivar				1.0-1.2			
LSD 5% treatment				1.2-1.4			
LSD 5% int. cv. × tr.				3.0-3.8			

Note: Different letters between cultivars denote significant differences (Duncan test, $p < 0.05$)

potassium silicate potentiates the action of potassium bicarbonate. Wettable sulphur proved to be less effective in scab and powdery mildew control than lime sulphur. The advantage displayed by cooper ammonium phosphate is the efficiency, similar or better, to the potassium silicate, wettable sulphur and potassium bicarbonate, with a cooper doses of ten times lower per hectare, meaning lower price for attack control and longer lasting effect.

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