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Integrated control of powdery mildew on field-grown mango trees by foliar sprays of mono-potassium phosphate fertilizer, sterol inhibitor fungicides and the strobilurin Kresoxym-methyl*

Moshe Reuveni[1], Moshe Harpaz[2] and Reuven Reuveni[3]
[1] *Golan Research Institute, University of Haifa, P.O. Box 97, Qasrine 12900, Israel (Fax: 972-6-6961930);*
[2] *Extension Service, Ministry of Agriculture, Zefat 13100, Israel;* [3] *Dept. of Plant Pathology, ARO, Newe Ya'ar Research Center, P.O. Box 1021, Ramat Yishay 30095, Israel (Fax: 972-4-9836936)*

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Abstract

Foliar sprays of solutions of di-potassium hydrogen orthophosphate, K_2HPO_4 (DKP) and potassium di-hydrogen orthophosphate, KH_2PO_4 (MKP), commercial systemic fungicides, and an alternating treatment with phosphate fertilizer and systemic fungicides inhibited development of the powdery mildew fungus, *Oidium mangiferae*, on flowers and bloom clusters of field-grown mango trees. The effectiveness of the alternation treatments with an appropriate systemic fungicide and 1% solution of mono-potassium phosphate (MKP) in controlling powdery mildew on bloom clusters was similar to that of the commercial treatment with the systemic fungicides. However, application of the systemic fungicides alone, on the same dates on which they were applied in the alternation treatment, without application of the phosphate treatment was significantly less effective in controlling the disease than either the phosphate or the alternation treatment. This indicates that the use of phosphate fertilizer has a significant role in disease control and that it can reduce the number of fungicide treatments necessary against powdery mildew by up to 50%. These results were confirmed in large-scale demonstration trials conducted in commercial orchards in 1994 and 1995. Our 1997 findings also revealed that tank-mix treatments of 1% MKP solution with half the recommended quantity of sterol inhibitor fungicide applied at 14-day intervals provided a protection against powdery mildew comparable with or superior to that given by the standard fungicides-based treatment applied at 7-day intervals. Tank-mix treatments of MKP (1%) with sterol inhibitor at the recommended rate or with the new strobilurin Kresoxym-methyl (BAS 490F, strobi), or the BAS 490F alone, were the most effective, and provided $>$95% protection against *O. mangiferae*, compared with the control. Phosphate solutions were found not to be phytotoxic to plant tissue. These treatments affected the yield of mango trees: a significantly lower yield was observed on control untreated trees, probably because of powdery mildew infection on flowers. The inhibitory effectiveness of phosphate salts makes them a potential major component of an integrated pest management program.

Introduction

Powdery mildew caused by *Oidium mangiferae* Berthet is widely distributed and can be a major foliar disease of field-grown mango trees (Johnson, 1994), on which it can infect leaves, bloom clusters and young fruits. The flowering stage, however, appears to be the most critical for infection; little infection occurs before flower opening or during fruit-set. Infestation of the bloom clusters by powdery mildew causes flowers and young fruits to drop, and may cause a considerable crop loss (Johnson, 1994). Timely applications of effective fungicides, such as benzimidazoles and sterol biosynthesis inhibitors, which can reduce primary inoculum, are the main factors in disease control

*Contribution from the Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel.

in the field. The mild winter temperatures in Israel and highly favorable environmental conditions in the growing regions during the spring season, necessitate four or more applications of systemic fungicides in order to achieve sufficient disease control during the flowering stage. Sulfur sprays must be limited, since they can scorch flowers and young fruit in warm and sunny conditions. Intensive use of fungicides has resulted in resistant races of powdery mildew pathogens on cucumber, grape and cereal crops. These pathogens may survive for several years (Schroeder and Provvidenti, 1969; Schepers, 1985; Steva and Clerjeau, 1990; McGrath, 1996), and their populations might be increased as a result of further applications of ineffective fungicides (Dekker, 1987). The desire to reduce pesticide levels on food crops enhances the need for alternative methods for disease control. Inorganic salts such as sodium bicarbonate (Homma et al., 1981; Horst et al., 1992; Ziv and Zitter, 1992), foliar sprays of potassium silicate (Bowen et al., 1992; Menzies et al., 1992), and mineral or plant oils (Horst et al., 1992) are examples of environmentally friendly means of reducing powdery mildew.

The effectiveness of phosphate salts in inducing local and systemic protection against powdery mildew pathogens and in controlling the disease has previously been presented for cucumber plants (Reuveni, M. et al., 1993), roses (Reuveni, R. et al., 1994), grapevines (Reuveni, M. and Reuveni, R., 1995a), mango and nectarine (Reuveni, M. and Reuveni, R., 1995b). In the present study, the potential use and the efficacy of foliar sprays of phosphate salt solutions in alternation and in tank-mix with systemic fungicides in controlling powdery mildew in field-grown mango trees were evaluated. In addition, the efficacy of the new strobilurin Kresoxym-methyl (BAS 490F) fungicide and of its mixture with MKP was determined. This fungicide was found to be highly active, in providing a broad-spectrum disease control (Ammerman et al., 1992; Gold and Leinhos, 1995).

Materials and methods

Field experiments in mango, cv 'Tommy Atkins' (planted in 1990 on 13/1 rootstock), cv. 'Keitt' (planted in 1989 on 13/1 rootstock) and cv. 'Kent' (planted in 1987 and 1984) were conducted in their respective commercial orchards, in the southern part of the Golan region of Israel. These cultivars are susceptible to powdery mildew (Johnson, 1994), and the disease has been evident in each of these orchards in recent years. Methods of fertilization and irrigation, and other cultural practices for this crop were as recommended to commercial growers.

Experimental design

Experiments in 1993, 1994 and 1997. Five treatments in 1993 + 1994 and six in 1997 were arranged in a randomized complete block design. Plots consisting of four mango trees were replicated five times in 1993 and 1994. Treatments in 1993 comprised a control, and foliar applications of the systemic fungicide diniconazole (0.04%, 12.5% WP Sumitomo, Japan), two phosphate salts, a 25-mM solution of di-potassium hydrogen orthophosphate (K_2HPO_4, pH 9.3) solution, and a 40-mM solution of potassium di-hydrogen orthophosphate, KH_2PO_4 plus KOH (to give pH 9.3), and a treatment with alternating applications of phosphate (KH_2PO_4 plus KOH) and the fungicide diniconazole. Five foliar sprays of each solution were applied during the bloom season on March 25, April 5, 19 and 29 and on May 9, 1993. In the alternation treatment diniconazole and phosphate (KH_2PO_4 40 mM) were applied only three and two times, respectively, in alternation, starting with diniconazole. Treatments in 1994 comprised a control, and foliar applications of the systemic fungicide diniconazole (0.04%) as a standard treatment at 7-day intervals or at 14-day intervals, for comparison with the alternation treatment, a 60-mM solution of mono-potassium phosphate fertilizer (KH_2PO_4, Rotem Amfert Negev, Israel) at 7-day intervals, and an alternating treatment of this phosphate solution and the systemic fungicide diniconazole (Table 1). Phosphate (fertilizer grade) plus Triton X-100 (0.025%), and the fungicides were sprayed to runoff with a 100-L sprayer.

The 1997 trials were designed with special emphasis on the role of foliar application of mono-potassium phosphate (MKP) in tank-mix with fungicides, in order to reduce the number of applications during the bloom period. Plots each of six mango trees were replicated four times. Six treatments comprised a control, a fungicide-based standard treatment (DMI), a tank mix of an appropriate systemic fungicide at the recommended rate with 1% MKP (TM-1), a tank mix of the systemic fungicide at half the recommended rate (TM-0.5), the new strobilurin Kresoxym-methyl (BAS 490F, BASF AG, Germany) (Strobi-0.015%), and a tank mix treatment of Kresoxym-methyl (0.015%) with

Table 1. Efficacy of foliar spray of mono-potassium phosphate (MKP), systemic fungicides and alternation treatments of phosphate and systemic fungicides on control of powdery mildew on field-grown 'Tommy Atkins' mango trees in 1994

Treatment[1]	Disease rating (0–4)[2]	Infected bloom clusters (%)
Control-untreated	3.7a[4]	100.0a
Diniconazole (0.04%, 7-day)	1.3c	88.0b
KH_2PO_4 60 mM	2.1b	100.0a
Alternation[3]	1.4c	90.0b
Diniconazole (0.04%, 14 d)	2.1b	100.0a

[1] Four foliar sprays of each solution were applied at 7–8-day intervals, during the bloom season starting at the beginning of bloom on March 22, 1994, and continuing until the end of bloom and appearance of young fruits of up to 5 mm (April 24, 1994).
[2] Mean ratings of disease severity on a 0 – 4 scale as described in Materials and methods, as assessed on May 4, 1994 on each of 20 flower clusters of each of two trees in each of five replicate plots per treatment.
[3] In this treatment, diniconazole (0.04%) and phosphate salt (KH_2PO_4 60 mM) were applied only twice each in alternation, starting with diniconazole.
[4] Mean numbers within columns followed by different letters are significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

1% MKP (TM-S). The fungicide-based standard treatment (DMI) was applied four times at 7-day intervals at the following order: diniconazole (0.04%), diniconazole, myclobutanil (0.05%) and myclobutanil. All the other treatments were applied twice with a 14-day interval (Figure 1). These treatments were further evaluated in 1997 on large-scale demonstration plots of a commercial 'Kent' orchard (ca. 0.5 acre for each treatment plot). In this trial, all treatments were applied twice (on April 24 and May 8, 1997) during the bloom period. DMI fungicides diniconazole (0.04%) and myclobutanil (0.05%) were applied as standard (DMI) and all other treatments as described for the previous experiment. In both trials, MKP solutions plus Triton X-100 (0.025%), and fungicides were sprayed with a 2000-L speeder type sprayer (1800 L/ha).

Observations in large-scale demonstration plots

Treatments in three large-scale demonstration plots in commercial orchards were conducted during the 1994 and 1995 seasons, in the Golan region. Four treatments, comprising control, diniconazole (0.04%) mono-potassium phosphate (MKP, 50 mM) plus Triton X-100 and an alternation treatment of MKP with the fungicide, were applied three times at 14-day intervals during the bloom season of 1994 starting on March 28, at the beginning of bloom and continuing until the end of bloom on April 23, 1994. In the alternation treatment, diniconazole was sprayed once and MKP was sprayed twice starting with MKP. Each demonstration plot treatment (ca. 0.25 acre) was replicated twice (Table 2). The 1995 demonstration trials included three treatments in which diniconazole (0.04%) was applied twice (at 14-day intervals) during the bloom season and compared with the alternation treatment of the fungicide with MKP (1%) plus Triton X-l00 and control. In the first trial diniconazole was applied on April 9 and 23, 1995 and in the second trial on April 12 and 16, 1995. Each treatment was applied to ca 0.5 acre for each plot treatment in the respective orchards (Table 3). In all these trials, phosphate solutions and fungicide were sprayed according to commercial practice with a 2000-L sprayer (1500 L/ha).

Assessment of powdery mildew on flower clusters

Flower clusters which were naturally infected with powdery mildew fungus were rated at the end of the bloom seasons. Ten bloom clusters were randomly selected from each of the center trees in each replicate plot, and were rated for disease severity; on a 0–4 scale: 0 = no powdery mildew colonies observed on tissue, 1 = 1–10%, 2 = 11–25%, 3 = 26–50% and 4 $\geq$ 50% of the selected clusters infected with powdery mildew. In addition the percentage of infected bloom clusters was determined.

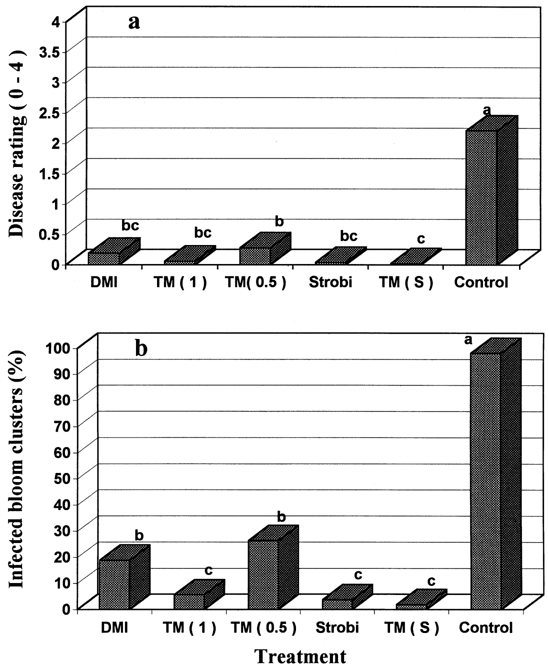

Figure 1. Efficacy of foliar sprays of sterol inhibitor fungicides, stobilurin BAS 490F fungicide and of their tank mixes with mono-potassium phosphate, in control of powdery mildew on field-grown 'Kent' mango trees in 1997. Four foliar sprays of systemic fungicides (DMI) at 7-day intervals and two applications of BAS 490F (strobi) or of tank mixes of MKP with strobi (TM-s) or with the recommended concentration (TM 1) or half the recommended concentration (TM 0.5) of DMI, were applied at 14-day intervals during the 1997 bloom season. Disease was rated in the end of the bloom season on each of 10 bloom clusters of each of four center trees of each replicate plot and treatment, as described in M & M. Different letters on bars indicate a significant difference ($P < 0.05$) between treatment means according to Duncan's Multiple Range Test.

An arc-sin transformation was performed on data of ordinal or interval scale. Analysis of variance (ANOVA) using the SAS GLM procedure was used on the transformed data. Duncan's Multiple Range Test was applied to determine whether differences between treatments were significant.

Effects on yield. The first selective harvest in the experimental plot was made on August 5, and the remaining fruits were harvested on September 3, 1997. Fruits were harvested from the four central trees of each of the four replicate plots of each of the six treatments. The average yield (kg/tree) and number of fruits per tree in each treatment were determined.

Results

Symptoms of powdery mildew on mango trees were initially observed only on inflorescences of untreated control trees; five foliar sprays of the phosphate solutions significantly inhibited development of powdery mildew on inflorescences. Treatment with the systemic fungicide diniconazole was more effective than that with phosphates, and completely inhibited the fungus. However, an alternating treatment of diniconazole with KH_2PO_4 plus KOH (pH 9.3) significantly inhibited powdery mildew and was similar in its effect to the sterol inhibitor fungicide. The number of infected bloom clusters on control, K_2HPO_4, KH_2PO_4, dinnconazole and alternation treated plants was 41.7, 9.1, 4.3, 0.0 and 1.3, respectively. The KH_2PO_4 solution seems to be more efficient than K_2HPO_4 in controlling the disease.

More pronounced results for the alternation treatment were however, obtained during the bloom period of 1994, in which disease severity was much higher than that observed in 1993. The disease ratings clearly indicated that spraying of mono-potassium phosphate fertilizer (MKP 60 mM), in alternation with diniconazole, significantly inhibited powdery mildew; it was similar in its effect to the commercial fungicide-based treatment (Table 1). Spraying of the systemic fungicide at 14-day intervals (on the same dates as in the alternation treatment) was significantly less effective than the alternation treatment; it was similar in its effect to the phosphate fertilizer alone (Table 1). These data clearly indicate that the phosphate treatment has a role in retarding powdery mildew, particularly when applied in alternation with the systemic fungicides.

Similar findings on the inhibitory effect of mono-potassium phosphate in alternation treatment were obtained in large-scale demonstration trials conducted in commercial orchards in 1994 (Table 2) and 1995 (Table 3). Results obtained from these orchards confirmed those obtained in 1994, and clearly demonstrated that the effectiveness of the alternation treatment, in which there was a reduction of at least 50% of the fungicide applications, was similar to (Tables 2 and 3) or even better than (Table 3) that of the commercial treatment which included applications of the sterol inhibitor fungicide only. This was expressed by a significant reduction in both the number of infected inflorescences and the severity of powdery mildew on bloom clusters, as compared with non-treated control trees (Tables 2 and 3).

Table 2. Efficacy of foliar spray of mono-potassium phosphate (MKP), systemic fungicides and alternation treatments of phosphate and systemic fungicides on control of powdery mildew on large-scale demonstration plots of field-grown 'Keitt' mango trees in 1994

Treatment[1]	Disease rating (0–4)[2]	Infected bloom clusters (%)
Control-untreated	3.42 ± 0.07	100.0 ± 0.0
Diniconazole (0.04%)	0.43 ± 0.03	36.3 ± 1.9
KH_2PO_4 (50 mM)	1.61 ± 0.10	82.5 ± 2.6
Alternation	0.54 ± 0.06	53.6 ± 3.8

[1] Three foliar sprays of each solution were applied at 14-day intervals, during the bloom season of 1994, as described in Materials and methods. In the alternation treatment, diniconazole (0.04%) was sprayed once and MKP (KH_2PO_4 50 mM) was sprayed twice, in alternation, starting with MKP.
[2] Mean ratings ± SE of disease severity on a 0–4 scale as described in Materials and methods as assessed on May 2, 1994 on each of 10 flower clusters of each of four trees in each of two replicate demonstration plots per treatment.

Table 3. Efficacy of foliar spray of systemic fungicide and alternation treatments of mono-potassium phosphate (MKP), and systemic fungicide on control of powdery mildew on large-scale demonstration plots of field-grown mango trees in 1995

Treatment[1]	Trial 1		Trial 2	
	Disease rating (0–4)[2]	Infected bloom clusters (%)	Disease rating (0–4)	Infected bloom clusters (%)
Control-untreated	0.75 ± 0.05	70.5 ± 4.3	3.51 ± 0.08	100.0 ± 0.0
Diniconazole	0.25 ± 0.04	24.2 ± 2.7	0.93 ± 0.11	77.3 ± 7.0
Alternation	0.12 ± 0.02	12.5 ± 1.1	1.24 ± 0.13	89.5 ± 4.8

[1] Two foliar sprays of diniconazole 0.04% solution were applied at 14-day intervals, during the bloom season on April 9 and 23, (trial 1 on 'Keitt') and on April 12 and 16, 1995 (trial 2 on 'Kent'). In the alternation treatment, each solution, of diniconazole (0.04%) or MKP (KH_2PO_4 1%), was sprayed once at 14-day interval, in alternation.
[2] Mean ratings ± SE of disease severity on a 0–4 scale, as described in Materials and methods, as assessed on May 5, 1995 on each of 20 flower clusters of each of 10 trees per demonstration plot of each treatment.

The role of mono-potassium phosphate (MKP) fertilizer in accelerating disease inhibition when it was tank mixed with fungicide was further evaluated in 1997. Our results show that four applications of sterol inhibitor fungicide at weekly intervals, were needed to provide 81.0% protection against powdery mildew compared with non-treated control trees (Figure 1). However, two applications of the tank mix treatment of MKP (1%) and the systemic fungicide (at the recommended rate), significantly accelerated the inhibitory effect and provided 94.3% protection against the mildew (Figure 1). Moreover, two applications of MKP (1%) in a mixture with half the recommended concentration of systemic fungicide were as effective as the standard treatment of four applications of fungicide. Two applications of the strobilurin fungicide Kresoxym-methyl (BAS 490F, strobi) were more effective than the standard treatment, and a tank mix with MKP (1%) was slightly better, but not significantly so (Figure 1). The use of the same treatments on large-scale plots in another orchard confirmed these findings. Two applications of sterol inhibitors at 14-day intervals during the bloom season provided the lowest protection (34.7%) as compared with control. However, the tank mix treatment of MKP (1%) with half the recommended concentration of sterol inhibitor fungicide was more effective than the standard treatment alone and provided 56.0% protection, as compared with control. A tank mix of MKP (1%) with sterol inhibitor or with strobi, or strobi alone were the

Table 4. Effect of foliar sprays of MKP and fungicides on yield and number of fruits in mango trees

Treatment[1]	Number of fruits/tree[2]	Yield (kg/tree)	Mean fruit weight (g)
DMI Fungicides	59.8ab[3]	22.3ab	373
Tank mix (1)	72.2a	26.4a	366
Tank mix (0.5)	57.5ab	21.3ab	370
Strobi	56.0ab	21.7ab	387
Tank mix (s)	66.6ab	25.2a	378
Control	49.6b	18.2b	370

[1] See footnote in Figure 1.
[2] Fruits were harvested on August 5 and September 3, 1997 from each of four center trees of each of four replicate plots. Total numbers of fruits and their weights per tree and per treatment were determined.
[3] Mean numbers within columns followed by different letters are significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

most effective treatments; they provided similar levels of protection of 86.0, 95.0 and 84.0%, respectively, against *O. mangiferae*, as compared with control.

Throughout all our experiments and large-scale demonstration trials, no phytotoxicity to plant foliage was observed as a result of foliar applications of these compounds.

Effect on yield Foliar applications of the tank-mix treatments of MKP and sterol inhibitors or with strobi at the recommended rate resulted in the highest yield as expressed by weight and number of fruits per plant (Table 4). The mean fruit weight was similiar under all treatments. Lower numbers, but not significantly so, were recorded on trees of the other treatments, but there were significant reductions on trees of the control treatments (Table 4).

Discussion

This study demonstrated that a fertilizer compound such as MKP (KH_2PO_4) is an environmentally friendly potential means for controlling powdery mildew on bloom clusters of field-grown mango trees, and confirmed our previous findings on the capability of phosphates in controlling powdery mildew on cucumber (Reuveni M. et al., 1995), grapevines (Reuveni, M. and Reuveni, R., 1995a), roses (Reuveni, R. et al., 1994), apple and nectarine (Reuveni M. and Reuveni, R., 1995b). Phosphate spray induces local and systemic protection against *S. fuliginea* (Reuveni, M. et al., 1993) and various diseases in cucumber (Mucharromah and Kuc', 1991) and *Exserohilum turcicum* and *Puccinia sorghi* in maize (Reuveni, R. et al., 1996).

Although systemic fungicides, applied as foliar sprays, were more effective than salt solutions in controlling powdery mildew on mango, the necessary number of fungicide applications was reduced by 50% when they were alternated with phosphate sprays. It should be noted that better protection against the pathogen was obtained from the alternation treatments than from phosphates alone. This alternation treatment yielded similar protection to that obtained from the commercial application of systemic fungicides, and therefore it offers environmentally friendly possibilities for disease control, with reduction of pesticide use by at least 50%, whether expressed as the number of treatments or as the total dosage per season. These data clearly indicate that phosphates have a role in this inhibition (Table 1).

Sodium bicarbonate has effectively controlled powdery mildew diseases on various crops (Homma et al., 1981; Horst et al., 1992; Ziv and Zitter, 1992). Inhibition of conidial formation and germination of *Sphaerotheca fuliginea* has been reported in cucumbers (Homma et al., 1981), and collapse of hyphal walls and shrinkage of conidia and conidiophores of the fungus have been observed as result of potassium bicarbonate treatment (Homma and Arimoto, 1990). Similiar damage has been seen on hyphae and conidia of *Levellula taurica* Lev. Arm, the causal organism of powdery mildew of peppers (Reuveni, R. et al., unpublished data), and of the powdery pathogens of apples and grapevines (Reuveni, M. et al., unpublished data). These previous findings and observations may explain the inhibitory properties of phosphate found in our present study, in which mango trees, naturally infected with powdery mildew, were tested. Application of silicon in combination with potassium and PO_4 has also been reported to reduce the number of powdery mildew colonies on cucurbits and grape leaves (Bowen et al., 1992; Menzies et al., 1992).

The mode of action of foliarly applied phosphate salts in controlling powdery mildew fungus has not been clearly determined. Foliar sprays of MKP on mildewed tissue bearing sporulating colonies of *O. mangiferae on* field-grown mango bloom clusters suppressed the fungus as evidenced by hyphal deformation and shrinkage of conidia and conidiophores, as observed by microscopic examination. No visible damage was observed on the host organs as result of phosphate application, and it is more likely that a direct effect on the fungus, may play an important role in the protection mechanism. This possibility should be further investigated.

It seems that the mode of action of MKP is different from that of sterol inhibitor fungicides (Koller and Scheinpflug, 1987) or the strobilurin BAS 490F (Ammerman et al., 1992; Gold and Leinhos, 1995). Spraying MKP in alternation with fungicides or the use of its mixtures with fungicides may reduce the development of fungicide-resistant populations of *O. mangiferae*. Mixtures of fungicides or antifungal compounds are used in order to widen the spectrum and ensure a longer duration of antifungal activity; or to exploit synergistic interaction between the compounds, by which the overall activity can be increased or the amounts used can be reduced without loss of activity; and to delay or reduce the process of selection of resistant strains (Gissi, 1996). Synergy, which is a common phenomenon in fungicide mixtures, may occur between antifungal compounds of different natures and sources, or between fungicides with different or identical modes of action and in different formulations (Gisi, 1996). The increased protection provided by MKP when used in mixtures with reduced rates of fungicides or with their recommended rates, but with reduced number of applications, compared with the recommended rates for standard fungicide-based treatments (Figure 1), suggests a possible synergistic interaction. This is the first report to present such a phenomenon of MKP activity under field conditions and to confirm our preliminary observations on apple trees (Reuveni, M. et al., unpublished). Since MKP alone was not included in 1997 experiments, the possible additive effect could also be considered. Further study is needed to demonstrate the synergistic or additive interaction of the MKP in mixtures with these fungicides, in controlling powdery mildew. In addition to their inhibitory effect against powdery mildew, these treatments also affected the yield of mango trees: a significantly lower yield was observed on untreated control trees (Table 4). However, this observed reduction of yield was not through the mean weight of the fruits but reflected reduced numbers, probably because of the powdery mildew infection on the flowers. On the basis of these data the tank mix treatment is presently being recommended as a routine strategy for the control of powdery mildew on mango trees in the northern region of Israel.

The present data based on observations in experimental and large-scale demonstration plots, together with our above-mentioned previous findings on the control of powdery mildew in various crops make MKP an attractive compound for practical agronomic use against *O. mangiferae* in mango orchards, and provide further support for the role of phosphate foliar fertilizers as a component in an integrated pest management program (Reuveni, R. and Reuveni, M., 1998).

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