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Development of improved disease management for powdery mildew on mango trees in Israel

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ABSTRACT

Powdery mildew, caused by *Pseudoidium anacardii* (formerly *Oidium mangiferae* Berthet), attacks panicles, young fruits, and leaves of mango trees; it may cause considerable crop loss. Mango is the only known host of this pathogen. Disease management in Israel has not been investigated extensively; it is based on field observations by the Agricultural Extension Service, which instructs growers to spray at 14-d intervals, starting from the beginning of bloom when the first flowers appear in the orchard, or after rain events; rain events during flowering promote development of the disease. The present study found that fungicides applied to panicles at 10-d intervals after they reached a length of 5 or 10 cm improved disease control compared with spraying at 14-d intervals. Earlier applications did not improve disease control; later applications, beginning at the first-open-flower stage, were less effective. Foliar sprays applied before rain events provided better disease control than spraying after the rain. In Israel, about 30 fungicides against mango powdery mildew are registered, but no comparative trials for fungicide efficacy have been conducted in recent years. Efficacy trials showed that the most effective fungicides were penconazole, myclobutanil, tetraconazole, and an improved formulation of mineral oil. A tank mixture of systemic fungicide with a reduced sulfur content (up to 60%) was as effective as, or slightly more so than each component applied alone, and provided 70–90% protection compared with control untreated trees. QoI fungicides (strobilurins) were less effective and less consistent. Where there was an existing infection on panicles, two consecutive applications of sulfur or mineral oil, combined with systemic fungicides, suppressed the fungus and inhibited powdery mildew development. The main findings of the present study were implemented by growers and currently are used to develop improved disease management.

1. Introduction

Mango (*Mangifera indica* L.) powdery mildew caused by the fungus *Pseudoidium anacardii* (formerly *Oidium mangiferae* Berthet) (Braun and Cook, 2012) is widely distributed and can be a major foliar disease of field-grown mango trees (Félix-Gastélum et al., 2013; Johnson, 1994; Joubert et al., 1993; Nasir et al., 2014; Nelson, 2008; Prakash and Srivastava, 1987; Reuveni et al., 1998; Schoeman et al., 1995). It can infect leaves, panicles, and young fruits, but the flowering stage appears to be the most vulnerable to infection, and little infection occurs before flower opening or during fruit set. The bloom period is relatively long, and infestation of the bloom clusters by powdery mildew, which causes flowers and young fruits to drop, may therefore cause a crop loss of up to 90% (Johnson, 1994; Misra, 2001; Nelson, 2008; Nofal and Haggag, 2006; Ploetz, 2004; Sarwar, 2015; Shukla and Adak, 2016). Disease development in the orchard is influenced mainly by temperature, humidity, and wind dispersal of conidia (Joubert et al., 1993; Nasir et al., 2014; Schoeman et al., 1995). The fungus overwinters on leaves, as dormant mycelia that serve as primary inoculum in the following year, when secondary infection is induced by conidia they produce.

Timely applications of effective fungicides, such as sterol biosynthesis inhibitors and strobilurins, which can reduce the primary inoculum, are the main means of disease control in the field (Joubert et al., 1993; Lonsdale and Kotze, 1993; Nasir et al., 2014; Reuveni et al., 1998). In Israel, mild winter temperatures and highly favorable environmental conditions in the growing

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regions during the spring necessitate 8 or more applications of systemic fungicides to achieve sufficient disease control during the flowering stage. Experience with *P. anacardii* led the present authors to hypothesize that intensive use of some DMI or strobilurin fungicides may have reduced their efficacy in controlling *P. anacardii* in mango orchards in important growing areas in northern Israel.

Disease management recommended by Israel's Agricultural Extension Service includes foliar applications of fungicides at 14-d intervals from the beginning of bloom. In recent years, their recommendations were to begin spraying when the first flowers appeared in the orchard (Agricultural Extension Service of Israel, personal communication). These recommendations were based on observations, but hitherto there was no experimental program. Furthermore, following Palti et al. (1974) and Joubert et al. (1993), who reported that rain events during the flowering period enhanced powdery mildew infection, it was recommended that Israeli growers add a foliar spray immediately after a rain event. However, no experiments were conducted to evaluate the effect of spraying, either before or after a rain event. The recommendations also were based on the use of some ineffective fungicides, chosen from the list of more than 30 fungicides registered in Israel. The effectiveness of these recommendations and of the fungicides has not been re-investigated for several years, therefore growers have been forced to use up to 8–10 foliar applications of fungicides during the season – with unsatisfactory results.

Fungicides are combined in mixtures, mainly in order to widen their spectrum, extend the duration of their antifungal activity, and delay or reduce the emergence of resistant strains (Gisi, 1996). Mixtures of fungicides usually are used, which may have differing or identical modes of action, varied formulations, and differing natures and sources (Gisi, 1996). Mixtures of DMI fungicides with sulfur have been introduced for various crops, to improve efficacy and reduce the risk of development of resistant strains of powdery mildew fungi (Galet, 1996; Reuveni, 2001). However, although this approach significantly reduces the sulfur rate, it has not been evaluated in Israel against mango powdery mildew.

The main objective of the present study was to develop an improved and effective disease management regime for control of powdery mildew in mango trees in Israel; such a regime should take into account: the phenological stage (e.g., applications before bloom); rain events; effective fungicides registered in Israel, applied at appropriate intervals; and tank mixtures with a reduced sulfur rate, applied either as preventive or as curative for the control of existing fungus on mildewed tissue.

2. Materials and methods

2.1. Fungicides

The following DMI fungicides, registered for use against mango powdery mildew in Israel, were tested: cyproconazole (Atemi Extra, 100 SL, Syngenta, Switzerland); diniconazole-M (Marit, 12.5% WP, Sumitomo, Japan); myclobutanil (Systhane, 240 EC, Dow AgroSciences, France); penconazole (Ofir, 2000, 200 EW, Syngenta, Switzerland); tetraconazole (Domark, 100 SC, Isagro, Italy); and triadimenol (Shavit, 250 EC, Adama Makhteshim, Israel). Also tested were: strobilurins – (QoI) kresoxim-methyl (Stroby 50, 500 WG, BASF, Germany) and trifloxystrobin (Flint 50, 500 WG, Bayer, Germany); ready mixtures – kresoxim-methyl (100 SC) plus boscalid (200 SC) (Collis, BASF, Germany), meptyldinocap (11.3% SC) plus myclobutanil (4.8% SC) (Sheriff Super, Dow AgroSciences, France), and tetraconazole (1% WP) plus sulfur (40% WP) (Domark Combi, Isagro, Italy). Included for comparison were: Meptyldinocap (Karathane Star 350 EC, Dow AgroSciences, France); mineral oil (E.O.S., 822 MO, Zicos, Greece); a ready mixture of improved formulation of mineral oil (88%) plus D-Limonene (12%) (Ultrapaz, Agrimor, Israel); and Heliosulfur (70 SC, Action-Pin, France).

2.2. Experimental design of field trials

Eight field trials in mango cvs. 'Keitt' and 'Sheli' were conducted in their respective commercial orchards in the Upper Galilee region of Israel, in 2012 and 2013. These cultivars are susceptible to powdery mildew (Johnson, 1994; Reuveni, unpublished results), which was clearly observed in all of these orchards in recent years. The 8 trials comprised: 3 for disease management, 2 for efficacy of tank mixtures, one for efficacy of fungicides registered in Israel, and 2 for suppression of existing powdery mildew.

Methods of fertilization and irrigation and other cultural practices for this crop were as recommended for commercial growers by the Agricultural Extension Service of Israel's Ministry of Agriculture and Rural Development. Fungicides were sprayed to runoff with a Turbo 400 (100-L, 1400 kPa) gun sprayer (Degania Sprayers, Israel), at spray volumes of 800–1000 L/ha, according to the size of the trees, and at the time intervals specified for each trial. Untreated trees served as controls. In all trials, treatments were arranged in a randomized complete block design. Plots containing 1–3 mango trees at similar phenological stage were selected and 4 replications were used.

2.3. Effects on powdery mildew development, of fungicide application at various intervals, phenological stages, and before or after rain events

Three trials were conducted in 2012 and 2013 in order to determine the optimal interval between applications, the best phenological stage for beginning fungicide applications, and whether fungicides should be applied before or after rain events. In 2012 Trials 1 and 2 were conducted in 2 separate orchards of cv. 'Keit' in the Upper Galilee region; treatments included comparison between a tank mix of the sterol inhibitor penconazole at a concentration of 0.015% (v/v) and Heliosulfur at 0.2% (v/v), on the one hand, and, on the other hand, a standard that included alternations of various fungicides (as recommended to growers in commercial orchards), and control untreated trees.

Trial 1 included 8 treatments, in plots containing 2 trees in 4 replications. Foliar applications of fungicides began on March 13 when the panicles reached a length of 5 cm, on March 23 when they were 10 cm long, or on April 1 when the first flowers opened (Table 1).

Trial 2 also included 8 treatments in plots containing 2 trees in 4 replications. Sprays were applied on March 23 and 26, and April 5, at similar phenological stages to those in Trial 1 (Table 2). With the exception of the standard treatment, which included different fungicides applied in alternation, treatments in Trial 2 were similar to those applied in Trial 1 (Table 2).

Trial 3 was conducted in 2013 in a different orchard and repeated some of the treatments examined in 2012. It also included a foliar spray applied at bud break: Penconazole at 0.015% (v/v) was sprayed in each treated stage at 10-d and 14-d intervals starting on March 7 at bud break, on March 14 when panicles reached a length of 5 cm, and on March 21 when they reached a length of 10 cm, and control untreated trees. A standard treatment included alternation of various fungicides (Table 3). This trial included 7 treatments in plots containing one tree, in 4 replications.

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