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Research Article

Effect of Neutralized Phosphorus Acid on Powdery Mildew and Fruit Quality of Muskmelon (*Cucumis melo* L.) in Greenhouse

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Abstract

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Greenhouse-grown muskmelon (*Cucumis melo* L.) is one of the most high value fruit crops in Taiwan. Powdery mildew, caused by *Podosphaera xanthii*, can infect leaves and vines of muskmelon and result in huge loss of quality and yield. In this study, the efficiency of two concentrations (1 and 2 g L^{-1}) of neutralized phosphorus acid (NPA) applied at two spraying schedules (7- and 14-day intervals) on controlling powdery mildew were compared with triflumizole and a water control in greenhouse. Disease severity of powdery mildew among different treatments were evaluated every 7-d after fruit set. The fresh weight of fruit, flesh thickness and total soluble solid content were evaluated as fruit quality index after harvest. When NPA was applied at a 7-d interval, the efficiency on controlling powdery mildew were not significantly different ($P = 0.05$) with triflumizole. In contrast, when NPA was applied at 1 g L^{-1} at 14-d interval, the disease severity was not significantly different with the non-treatment control. Overall, the 7-d spraying schedule has a better control on powdery mildew no matter what concentration of NPA was applied. In the fruit quality analysis, NPA sprayed at 2 g L^{-1} at 14 days and 1 g L^{-1} at 7 days significantly increased the fresh weight of fruits when compared with untreated control. However, there was no significant differences ($P = 0.05$) between treatments on the flesh thickness and total soluble solid content of muskmelon except for applying NPA at 2 g L^{-1}/14-d in the second trial.

Key words: *Cucumis melo* L., Muskmelon, Neutralized phosphorus acid (NPA), Powdery mildew, Non-fungicide control.

INTRODUCTION

Greenhouse-grown muskmelon (*Cucumis melo* L.) is a high value crop in Taiwan. Powdery mildew, caused by *Podosphaera xanthii* (Castag.) Braun & Shishkoff, is a major disease which can infect leaves, vines and decrease the fruit quality and yield in muskmelon production (McCreight *et al*. 1987). In most cucurbit crops, application of fungicides is the major practice for managing powdery mildew (McGrath 2007). In recent years, many

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studies are seeking alternative methods for managing powdery mildew due to increasing concerns of environmental sustainability, food safety, and necessity to reduce the application of fungicides (McGrath 2001; Mkhize *et al*. 2013). Several alternative methods have been reported effectively control of the powdery mildew on cucurbit in greenhouse and application of phosphorus salts is one of the methods (Keinath & DuBose 2012). Phosphorus acid has been found to induce resistance of crops and has been used for protecting plants against several plant pathogens (Guest 1984; Panicker & Gangadharan 1999).

Phosphites is an alkali metal salt of phosphorous acid which is also a source of plant phosphorus nutrition or an agricultural fungicide (McDonald *et al*. 2001). Recent research showed that phosphites or phosphorus acid confer induced resistance in plants and provide systemic protection against many plant pathogens (Choudhary *et al*. 2007). Some studies showed that phosphites confer resistance against *Phytophthora infestans* and *Fusarium solani* in potato (Lobato *et al*. 2008). Other reports also demonstrated the efficiency on controlling powdery mildew by foliar sprays of phosphate salts on different crops, such as cucumber (Reuveni *et al*. 1996), nectarine, mango, and grapevines (Reuveni & Reuveni 1995).

Defense mechanisms of crops conferred by phosphites includes direct and indirect pathways. High level concentration of phosphate at the infection site could directly reduce fungal growth (Smillie *et al*. 1989). Indirect pathway is the stimulation of systemically acquired resistance and prevention of infection by fungal pathogens (Percival *et al*. 2009; Bock *et al*. 2012). Furthermore, several studies indicated the production and accumulation of phenolic compounds and phytoalexin which can reduce disease severity (Saindrenan *et al*. 1988; Danie & Guest 2006). The control of Phytophthora disease in avocado and pineapple, potato tuber rots, and maize downy mildew were demonstrated related with the accumulation of phenolic compounds after application of phosphorus acid (Pegg *et al*. 1990; Panicker & Gangadharan 1999; Johnoson *et al*. 2004). Application of phosphites can also increase pectin content in periderm and cortex tissue in potato tubers (Olivieri *et al*. 2012). On cauliflower, potassium phosphonate can activate β-1,3-glucanase and induced localized resistance to downy mildew (Bécot *et al*. 2000).

However, concentrations and spraying schedules of phosphites may affect their efficiency against diseases as well as the growth of crops (Bock *et al*. 2012). Previous study showed that application of phosphites at least three times could offer better protection against apple and pear scab (Percival *et al*. 2009). Also, different concentrations of phosphites showed different growth inhibition on potato pathogens (Lobato *et al*. 2010). In conventional practice, muskmelon is cultivated on the ground in fields (Ibarra *et al*. 2001). In order to produce high quality muskmelon, greenhouse production technology has been widely applied (Rodriguez *et al*. 2007; Cantliffe *et al*. 2009). In Taiwan, vertical cultivation of muskmelon in greenhouse creates a high planting density and low ventilation environment in which muskmelon is very susceptible to powdery mildew (Wang *et al*. 2004). Application of phosphorus acid maybe an alternative option to reduce the loss caused by powdery mildew in greenhouse-grown muskmelon and to reduce the application of fungicides. However, information on effective concentrations of phosphorus acid and spraying schedules is still limited. Also, most studies only focused on evaluating the efficiency of disease control but ignored the effect of phosphorus acid on fruit quality. The objectives of this study are: (1) to evaluate the efficiency of different treatments of neutralized phosphorus acid (NPA) on controlling powdery mildew, and (2) to investigate the fruit quality of muskmelon after application of NPA under vertical cultivation model in the greenhouse.

MATERIALS AND METHODS

Variety and cultivation of muskmelon

Two trials were conducted in the greenhouse at Fengshan Tropical Horticultural Experiment Branch, Taiwan Agricultural Research Institute, Kaohsiung City, during the 2009 and 2010 fall growing seasons, respectively. Muskmelon (*Cucumis melo* L.) cv. 'Honey world' seeds used in this study were obtained from Know-You Seed Co. Ltd., Taiwan. Seeds were sown in 50-well pots (4.5 cm diameter per well) containing peat moss for 25 d. Then, seedlings were transplanted to cultivation containers (8 m in length, 30 cm in width and 30 cm in depth). In each container, peat moss and coconut fiber were mixed (1 : 1; v/v) as cultural substrate. Two containers were laid side by side and set up 30 cm above ground. Plant density was 7.4 plants m^{-2} with 45 cm between plants and 30 cm between rows. Vertical trellis was used for vine growing. Top leaves and shoots of the main vine were trimmed when the plant has more than 30 internodes. Only 28 leaves were retained during fruit development and secondary vines grew between 13th to 16th nodes of the main vine was kept for the fruit set. After successful fruit set, only one fruit per plant was developed and secondary vines without fruits were trimmed off. To fertilize the plants, Yamazaki nutrient solution was applied in the dripping irrigation system during the growth period of both trials (Yamazaki 1982). In the 2012 trial, 200 g of biotech organic fertilizer No.1 (Taiwan fertilizer Co. Ltd., Taiwan) was applied before planting and blooming. Total cultivation period was 85 d since seeds were sown and the fruit development period was 42 d after hand pollination.

Effect of neutralized phosphorus acid on powdery mildew

The effect of neutralized phosphorus acid (NPA) on disease severity of powdery mildew was assessed 13 d after hand pollination in each year. Phosphorus acid was neutralized with potassium hydroxide by dissolving equal weight of both chemicals in water (1 : 1; w/w) (Ann 2001). Six treatments were compared in this study, including (1) tap water as non-treatment control, (2) NPA at 2 g L^{-1} at 7-d interval, (3) NPA at 2 g L^{-1} at 14-d interval, (4) NPA at 1 g L^{-1} at 7-d interval, (5) NPA at 1 g L^{-1} at 14-d interval, and (6) 30% triflumizole WP (Soda Co. Ltd., Japan) 3,000× at 7-d interval. Trials were randomized completely block designed (RCBD) with four plants in each replicate and three replicates in each treatment. For the evaluation of disease severity, eight leaves from the lower node parts (no. 5th to 8th) and middle node parts (no. 13th to 16th) of the main vine were investigated. The disease severity was scored using a 0-4 scale, where 0 means healthy leaves; 1 = diseased area is less than 25% of the leaf; 2 = diseased area is between 26–50% of the leaf; 3 = diseased area is between 51–75% of the leaf; and 4 = diseased area is higher than 75% of the leaf. The disease severity was calculated using the following equation:

$$\text{Disease severity (\%)} = [\Sigma(N_{0\text{-}4} \times n)/(N \times 4)] \times 100$$

Where $N_{0\text{-}4}$ represents the disease severity of each leaf; n = the number of leaves in each disease severity; and N = the number of total leaves assessed. Each plant was assessed at a 7-d interval. For 7-d interval treatments, NPA and triflumizole were applied at 14th, 21th, 28th, and 35th d after hand pollination. For the 14-d interval treatments, NPA was applied on 14th and 28th day after hand pollination.

Evaluation of fruit quality

After the last assessment of disease severity, fruits were harvested and the fruit weight (g), flesh thickness (cm) and total soluble solid (°Brix) were used to evaluate the fruit quality. For ripening after harvest, the harvested fruit was stored at room temperature for 4 d and total soluble solid was measured.

Statistical analysis

The disease severity and fruit quality data were subjected to analysis of variance using the SAS-EG (SAS Enterprise Guide 4.1 system). Treatment means separation was performed using the least significant difference (LSD) at P = 0.05.

RESULTS AND DISCUSSION

The first assessment of disease severity of powdery mildew was carried out 13 days after hand pollination in both trials. The disease severity was not significantly different among all treatments in the first and the second assessments of both trials. At the 27th day, application of NPA at 1 g L^{-1} at 7-d interval and triflumizole significantly (P = 0.05) reduced the disease severity of powdery mildew when compared with the non-treatment control in both trials. As the disease pressure increased between 34th to 41th day, only NPA applied at 7-d interval consistently and significantly reduced the disease severity of powdery mildew in both trials. Also, the efficiency on controlling powdery mildew on muskmelon was not significantly different with triflumizole when NPA was applied at both concentrations at 7-d interval (Fig. 1 and 2). However, in the 14-d interval treatments, only NPA applied at 2 g L^{-1} significantly controlled the expansion of powdery mildew in the second trial. This result revealed that the application schedule is more crucial than the concentration when applying NPA for the control of powdery mildew (Fig. 3).

Effect of NPA on the fruit quality of muskmelon was evaluated. In the 2012 trial, the fruit weight in all treatments were higher than that in 2009 trial due to an extra application of biotech organic fertilizer. Besides, the fruit weight is significantly higher (P = 0.05) than water control when NPA was applied at 2 g L^{-1} at 14-d interval or at 1 g L^{-1} at 7-d interval in both trials (Table 1). The NPA treatments were obviously promoted fruit development except for NPA treated at 1 g L^{-1} at 14-d interval in which the fruit weight was not significantly different with that of the non-treated control. Compared with the triflumizole, the

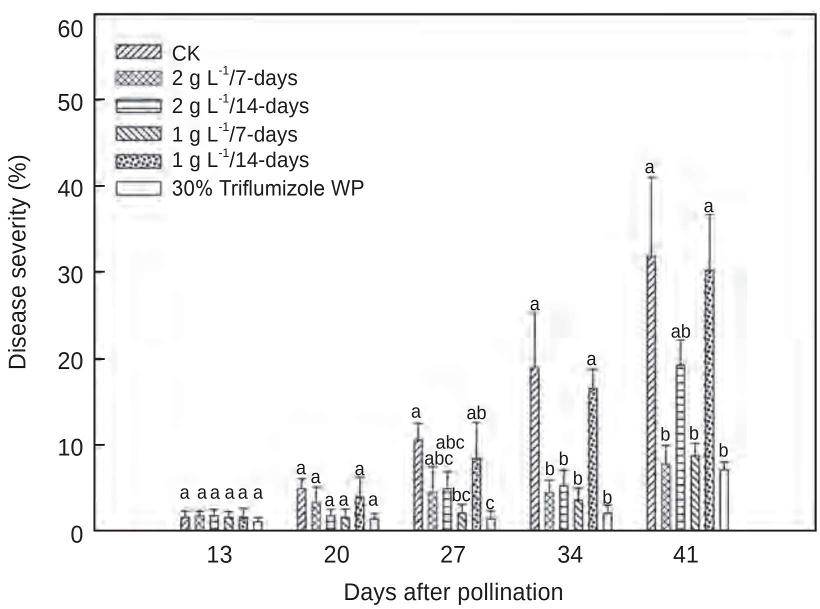

Fig. 1. Effect of different NPA treatments on powdery mildew of muskmelon after pollination in 2009.

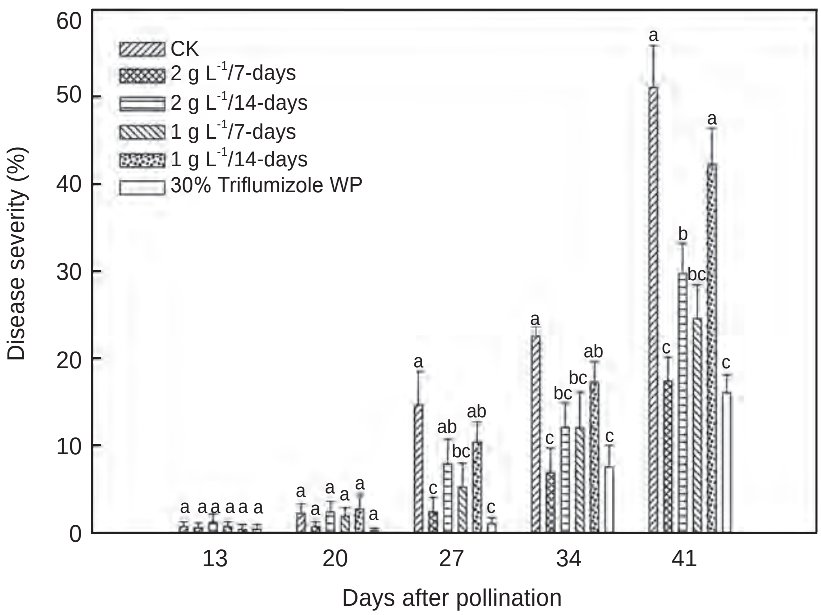

Fig. 2. Effect of different NPA treatments on powdery mildew of muskmelon after pollination in 2012.

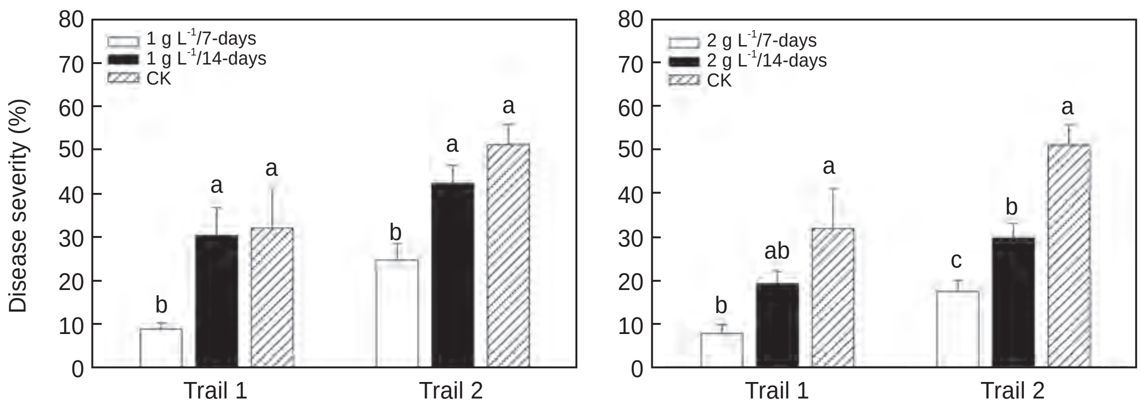

Fig. 3. Effect of different NPA spraying schedules on powdery mildew in both trials.

fresh weight of muskmelon was significantly higher when NPA was applied at 2 g L^{-1} at 14-d interval in both trials. For the flesh thickness and total soluble solids, there were not significant differences among all treatments in the first trial. However, application of NPA at 2 g L^{-1} at 14-d interval significantly increased the flesh thickness of muskmelon in the second trial.

The fruit weight of muskmelon increases rapidly after pollination and increases slightly before harvest (Lingle & Dunlap 1987; Miccolis & Saltveit 1991). Therefore, effective control of powdery mildew during early to middle period of fruit development after pollination is important. Previous studies indicated that defense mechanisms of crops conferred by phosphites include direct and indirect pathways (Smillie *et al*. 1989; Percival *et al*. 2009; Bock *et al*. 2012). Induction of defense mechanism could result in production of pathogenesis-related (PR) proteins and accumulation of phe-

Table 1. Effect of various NPA treatments on fruit quality of greenhouse-grown muskmelon.

	Trial 1			Trial 2		
Treatment	Fruit fresh weight (g)	Fruit flesh thickness (cm)	Total Soluble Solid (°Brix)	Fruit fresh weight (g)	Fruit flesh thickness (cm)	Total Soluble Solids (°Brix)
CK	1183.8 c[z]	3.2 a	12.0 a	1323.3 d	3.5 b	11.0 a
2 g L^{-1}/7-day	1263.2 bc	3.2 a	12.0 a	1476.7 ab	3.8 b	12.1 a
2 g L^{-1}/14-day	1439.1 a	3.4 a	12.3 a	1581.7 a	4.1 a	11.5 a
1 g L^{-1}/7-day	1346.4 ab	3.1 a	12.3 a	1535.0 ab	3.8 b	12.2 a
1 g L^{-1}/14-day	1235.0 bc	3.2 a	12.0 a	1346.7 cd	3.8 b	12.1 a
30% Triflumizole WP	1259.4 bc	3.1 a	12.6 a	1445.0 bc	3.7 b	11.0 a

[z] Means in each column followed by different letters are significantly different according to Fisher's LSD test at 5%.

nolic compounds or phytoalexins which may not persist for a long time (Choudhary *et al*. 2007; Mkhize *et al*. 2013). In this study, NPA applied at 7-d interval significantly reduced the disease severity of powdery mildew on muskmelon no matter what concentration was applied. However, the efficiency on controlling powdery mildew was significantly lower when NPA was applied at 14-d interval than that applied at 7-d interval. This result indicates a short term defense mechanism is involved in against powdery mildew after application of NPA.

Bock *et al*. (2012) reported applying phosphites at 2-week interval slightly increase the fruit weight in some pecan cultivars. In this study, NPA treatments could significantly increase fruit weight except for those treated with 1 g L^{-1} at 14-d interval in which the fruit weight was not significantly different with the non-treated control. The fresh weight of muskmelon was significantly higher when NPA was applied at 2 g L^{-1} at 14-d interval than that of triflumizole. For the flesh thickness and total soluble solids, no significant differences were found among all treatments in the first trial. However, application of NPA at 2 g L^{-1} at 14-d interval significantly increased the flesh thickness of muskmelon in the second trial. Apparently, application of NPA did not consistently affect the flesh thickness and total soluble solids of muskmelon in this study. Li *et al*. (2012) reported that the amount of irrigation water could significantly affect the flesh thickness and total soluble solids in greenhouse conditions. In these two trials, all treatments used the same dripping irrigation schedule and showed no significant differences among treatments except for 2 g L^{-1} at 14-d interval of NPA.

This study demonstrated that application of NPA significantly reduced the disease severity of powdery mildew on muskmelon in greenhouse and showed NPA as a potential alternative for chemical fungicide. Based on the results, weekly application of NPA at 1 g L^{-1} has more advantages on the fruit quality and offers a promising control of powdery mildew on muskmelon in greenhouse.

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中和亞磷酸對洋香瓜白粉病與果實品質之影響

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摘要

林楨祐、陳甘澍、黃雅穗、羅惠齡、洪爭坊。2016。中和亞磷酸對洋香瓜白粉病與果實品質之影響。台灣農業研究 65(3):261–268。

溫室甜瓜 (*Cucumis melo* L.) 為台灣高價值的水果之一，*Podosphaera xanthii* 引起的白粉病，可感染甜瓜的葉和藤蔓並造成品質和產量的下降。本研究比較不同中和亞磷酸和賽福座殺菌劑對設施內直立式洋香瓜栽培的影響，以兩種濃度 (1 g L^{-1} 和 2 g L^{-1}) 之中和亞磷酸，並搭配兩種噴施間期 (每 7 天 1 次和每 14 天 1 次)，於著果期間每 7 天評估各處理組的罹病程度，並於採收後調查果實鮮重、果肉厚度與總可溶性固形物。結果顯示在不同施用濃度下，每 7 天噴施中和亞磷酸對白粉病的防治效果與賽福座殺菌劑沒有顯著的差異 (P = 0.05)。然而，每 14 天噴施中和亞磷酸 1 g L^{-1} 則無法有效地降低白粉病罹病度。在各單一濃度下比較每 7 天或 14 天噴藥間期的影響，每 7 d 噴藥間期對白粉病罹病程度有較佳的控制效果。在果實品質方面，每 7 天噴施中和亞磷酸 1 g L^{-1} 和每 14 天噴施 2 g L^{-1} 皆顯著增加果實的鮮重。整體而言，施用中和亞磷酸對果肉厚度與可溶性固形物的含量並無顯著提升，僅在第 2 次的試驗中，每 14 天噴施中和亞磷酸 2 g L^{-1} 則有較佳的果肉厚度。因此，考量設施內洋香瓜果實品質的提昇和白粉病的控制，以每 7 天噴施中和亞磷酸 1 g L^{-1} 之處理應為較佳的選擇。

關鍵詞：洋香瓜、中和亞磷酸、白粉病、非農藥防治。

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