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Enhancement of Efficacy in Controlling Postharvest Decays and Extending Shelf Life of Mangoes by Combined Pre- and Post-harvest Chemical Applications

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ABSTRACT

To maximize the control of postharvest diseases and extend the shelf life of mangoes, pre-harvest chemical applications in combination with postharvest ones were performed in 2007 in Tianyang County, Guangxi, China. In a small-plot field trial, three fungicide combinations of azoxystrobin (125–250 mg L^{-1}) plus mancozeb (1000 mg L^{-1}) were periodically sprayed on two 10-years-old mango cultivars from initial blooming until harvest. $CaCl_2$ was added to the fungicide mixtures at a concentration of 0.6% (w/v) from fruit set and development. Spray interval from panicle emergence to fruit set was 10 days, while from fruit set to maturity was 15 days. At commercial maturity, mangoes were harvested and drenched in a prochloraz (450 mg L^{-1}) solution for 10 min and packaged in a carton box with ethylene absorbent bags. After 23 or 25 days of storage (29±3°C & 70-85% RH), the percentage of sound fruit and decay-controlled efficacy on two cultivars with both pre- and postharvest chemical applications were significantly higher than those fruit only with pre- or post-harvest treatments. FC-3 (125 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb) was the best pre-harvest fungicide combination, in which the azoxystrobin was at a lower concentration than the other combinations. In a separate demonstration field trial, in which the fungicide combination (167 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb) was applied before harvest, the enhanced efficacies in controlling postharvest decays and extending shelf life of mangoes by combining the pre-harvest chemical applications with the postharvest ones were also confirmed. Three types of diseases (anthracnose, stem end rot & aspergillus rot) were mainly responsible for the rotted mangoes during storage. *Colletotrichum gloeosporioides* was identified as the causal agent of the anthracnose. The three pathogens (*Botryodiplodia theobromae*, *Dothiorella dominicana* & *Phomopsis mangiferae*) were associated with the stem end rot, while the other three (*Aspergillusoryza* var. *oryzae*, *A. niger* & *A. japonicas* var. *aculeatus*) with the aspergillus rot.

Key Words: Chemical application; Disease management; Mango; Postharvest decay; Storage life

INTRODUCTION

Mango is a climacteric fruit generally harvested green, which ripens during the marketing process with an irregular storage period between harvest and consumption (Léchaudel & Joas, 2007). The infections of mangoes by pathogens causing postharvest diseases commonly occur, rendering in long term storage of the fruit difficult under ambient conditions. Among the causal agents of postharvest diseases, fungal pathogens play a major role in postharvest decay of mangoes (Diedhiou *et al.,* 2007). Mango anthracnose and stem end rot are the two most serious postharvest diseases that occur in the main mango-production regions worldwide. The former is caused by *Colletotrichum gloeosporioides* (Akem, 2006) and the latter by multiple fungal species such as *Lasiodiplodia theobromae* (Synonyms: *Botryodiplodia theobromae*, *Diplodia theobromae*) (Sangchote, 1988; Huang *et al.,* 1998; Khanzada *et al.,* 2005; Shahbaz *et al.,* 2009), *Dothiorella dominicana* (Gosbee*et al.,*1997; Xiao *et al.,* 2000) and *Phomosis mangiferae* (Xie *et al.,* 2002). Controlling mango anthracnose and stem end rot diseases are contributed to reducing postharvest decays and extending shelf life of the fruit.

Many strategies have been reported to control postharvest diseases and/or to extend the shelf life of mangoes. Before harvest, cultural practices such as orchard sanitation (particularly cleaning & pruning) (Diedhiou *et al.*,2007), calcium application (Singh *et al.,*1993) and induction of systemic acquired resistance in mango plants (Yan *et al.,* 2001) have been found to reduce postharvest disease incidences or to extend storage life of mango fruit. The strategies based on postharvest treatments are the most

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common ways of controlling mango fruit decay and extending storage life of the fruit. Dipping mangoes with fungicide solutions are among the most frequently used postharvest treatments for controlling the fruit decays during storage (Spalding & Reeder, 1978; Sangchote, 1988). The Semperflesh-waxed mangoes showed a longer shelf life compared to the non-waxed ones at ambient conditions (Ketsa & Prabhasavat, 1992). Dip treatments of mangoes with appropriate concentrations of calcium salts have also been reported to delay the ripening of the fruit for 3–4 days (Anjum & Ali, 2004). The mangoes showed a marked delay of ripening process by modified atmosphere packaging at lower temperature (Galvis*et al.,* 2005; Niranjana *et al.*, 2009) or at room temperature (Srinivasa *et al.,*2002). Huang *et al*. (2000) reported that the ripening process of mangoes was significantly extended by dip treatments with antagonistic bacterium suspensions under vacuum conditions. Different formulations ofan antagonistic bacterium (*Bacillus licheniformis*) were evaluated on their own and in combination with prochloraz and stroburilin for their ability to reduce mango postharvest anthracnose and stemend rot, indicating that the antagonist was more effective especially in the control of the diseases when fruit were kept in cold storage (Govender & Korsten, 2005). Heat treatments of mango fruit were evaluated for their effectiveness on controlling mango postharvest diseases, and it has been found that combination of hot air (40°C) for 4 h followed by hot water (50°C) for 5 min was the most effective treatment for retarding postharvest diseases (Mansour *et al.,* 2006). Oxalic acid treatments have been found to delay mango fruit ripening and reduce fruit decay incidence compared to the control (Zheng *et al.,* 2007a & b). Besides the pre- and post-harvest treatments, the harvesting methods and storage environments have been reported to influence the storability of mangos (Weor, 2007).

Due to quiescent infection by pathogenic fungi before harvest (Johnson *et al.,* 1991 & 1992; Luo *et al.,* 2004), the effectiveness of pre- or post-harvest treatment alone in suppressing postharvest diseases of mangoes was often poor. Although the pre-harvest application of fungicide(s) has been reported to reduce postharvest anthracnose on mangoes (Dodd *et al.*, 1991), less information is available on the integrated pre- and post-harvest treatments in controlling postharvest mango fruit decays and on extending the storage life of the fruit. The aims of the study were to (1) investigate the pathogens associated with mango postharvest decays in Tianyang County, Guangxi, China and (2) clarify the effectiveness of a combined pre- and post-harvest chemical treatment regime on suppressing post-harvest decays and extending storage life of mangoes under ambient conditions.

MATERIALS AND METHODS

Three fungicides were used for the present study. They were: (1) 25% azoxystrobin (trade name: Amistar) made by Syngenta AG; (2) 80% mancozeb WP by Dow Agro-Sciences; and 45% prochloraz EW (trade name: Sportak) by Bayer CropSciences. The chemicals used for physiological regulations of mangoes were calcium chloride (chemically pure) and potassium permanganate (analytically pure).

Two 10-years-old mango cultivars Tainong No.1 and Red Ivory were used for field trials. The cultivars were favored by consumers in Chinese markets. However, postharvest diseases (especially stem end rot & anthracnose) frequently occurred under traditional cultivation conditions, resulting in a shorter shelf life of the fruit.

Hydrated silicate mineral particles (vermiculate) were immersed in saturated potassium permanganate solution for 30 min and parched at 100°C for 24 h. The dry vermiculate containing potassium permanganate was packaged in non-woven bags (5 g per bag) and used as ethylene absorbent bags.

Two field trials were designed as follows. The first one was a small-plot field trial which was divided into two phases before harvest. The first phase started from initial blooming until fruit set, in which three combinations of 25% azoxystrobin plus 80% mancozeb at different concentrations were separately sprayed three times on the panicles of two mango cultivars (Tainong No.1 & Red Ivory) at 10-days-intervals. The first fungicide application was performed on March 13, 2007. The fungicide combinations (FC) used before harvest were: FC-1 (250 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb); FC-2 (167 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb); and FC-3 (125 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb). The mango trees without fungicide application were used as control. The second phase started from fruit set until commercial maturity. In this phase, $CaCl_2$ was added to the fungicide mixtures at a concentration of 0.6% (w/v). Three sprays of the $CaCl_2$-amended fungicide mixtures were separately performed on the developing fruit of cv. Tainong No.1 and four on those of cv. Red Ivory at 15-days-intervals. Each treatment consisted of three 10-years-old mango trees with three replicates (one tree per replicate). The average numbers of mangoes produced by each of the mango trees was greater than 150.

The mature green mangoes of cvs. Tainong No.1 and Red Ivory were harvested on May 30 and June 12, 2007, respectively. Pedicels remained attached to the fruit as long as possible when picked. Before conducting postharvest treatments, the pedicels were cut back to a length of 1 cm. The mangoes were gently washed with tap water. After air-drying, postharvest treatments were carried out as follows: (1) The mangoes of FC-1 were drenched in a 45% prochloraz (450 mg L^{-1}) solution for 10 min (regime A). (2) The mangoes of FC-2 were drenched in the prochloraz solution for 10 min (regime B). (3) The mangoes of FC-3 were drenched in the prochloraz solution for 10 min (regime C). (4) The mangoes of FC-2 were only washed with tap water (regime D). (5) The mangoes from the trees lacking pre-harvest chemical application were drenched in the

prochlorazsolutionfor10 min (regime E). (6) The mangoes from the trees lacking pre-harvest chemical application were drenched in tap water and used as control (regime F).

After air-drying, the mangoes from the same tree were packaged together in a cartonbox (40 mangoes per box for cv. Tainong No.1 & 60 for cv. Red Ivory). The ethylene absorbent bags were placed in the boxes with mangoes of regimes A, B, C and E (approximately one bag of ethylene absorbent for 1 kg of mangoes), respectively. The boxes were deposited in a storeroom under ambient conditions (29±3°C & 70–85% RH). The effectiveness of the combined pre- and post-harvest chemical applications on suppressing postharvest decays and on extending shelf life of the mangoes were separately investigated after 16–23 days of storage for cv. Tainong No. 1 and 16–28 days for cv. Red Ivory. Disease severity, expressed as a percentage of infected area over the total fruit surface area, was divided into five ratings: 0=no symptom, 1=less than 5% surface area infected, 3=5–15% surface area infected, 5=16–25% surface area infected, 7=26–50% surface area infected, 9=more than 50% surface area infected. The percentage of sound fruit, disease index and decay-controlled efficacy were calculated with the following formulae.

Percentage of sound fruit=(No. of 0-rating mangoes/No. of mangoes examined)×100%

Disease index = [100×∑(No. of affected mangoes × corresponding disease severity)]/(No. of mangoes examined×9).

Decay-controlled efficacy = (disease index of the control–disease index of each treatment)/disease index of the control ×100%.

The second field trial was a demonstration trial with 100 mango trees. The first phase of pre-harvest chemical applications started from initial blooming until fruit set, in which the fungicide mixture (167 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb) was sprayed three times on the panicles of the 10-years-old mango trees (cv. Red Ivory) at 10-days-intervals. The first fungicide application was performed on March 13, 2007. The second phase of chemical applications started from fruit set until commercial maturity, in which $CaCl_2$ was added to the fungicide mixture at a concentration of 0.6% (w/v) and 4 sprays of the $CaCl_2$-amended fungicide mixture were performed on the developing fruit at 15-days-intervals. Totally 2500 kg of the mature green mangoes were harvested on June 12, 2007. After being carefully washed with tap water, the fruit were immersed in the prochloraz solution for 10 min, air-dried, and packaged in a carton box (20–25 kg per box). The mangoes from the trees without pre-harvest chemical applications were only washed with tap water and used as control. Ethylene absorbent bags were placed in each box (approximately one bag of ethylene absorbent for 1 kg of the fruit) except the control. The treated fruits were deposited in a storeroom at 29±3°C and 71–91% RH. After 20 days of storage, the percentage of sound fruit, disease index and disease-controlled efficacy were investigated as described above. After 22 days of storage, sound fruit samples both with and without chemical applications (1.5 kg per treatment) were sent to the Quality Supervision and Testing Center of Subtropical Fruit and Vegetable, Ministry of Agriculture, China, for quality analysis.

To ascertain the pathogens causing post-harvest decays of mangoes during storage, diseased mangoes were first picked up and their symptoms recorded. The affected mangoes were categorized based on their symptoms prior to pathogen isolations. Pathogen isolations were carried out as follows. The diseased peels were cut out into 0.5×0.5 cm pieces and dipped in 75% ethanol solution for 10 s and transferred to 0.1% $HgCl_2$ solution for 6 min. Subsequently, the samples were rinsed twice with sterilized water and separately blotted on the inside surface of a sterilized Petri dish with a tweezer for removal of excess water. Five to seven pieces of the surface-sterilized diseased tissue were then placed onto a potato dextrose agar (PDA) plate (9 cm in diameter) containing 200 g of potato, 15 g of glucose, 0.1g of penicillin and 17 g of agar in 1000 mL of water (pH 6.5) and incubated at room temperature (28–32°C) for 3–7 days. Once mycelia were observed from the sample isolations, mycelia plugs from the leading edges of colonies were separately transferred to a new PDA plate and incubated until sporulation at the room temperatures.

Pathogenicity tests of the isolated fungal cultures were performed based on Koch's postulates. A healthy mango fruit was wounded with a puncher (5 mm in diameter) and a mycelial plug (5 mm in diameter) was placed on the wound of the fruit. The fruit inoculated only with a pure PDA plug was used as the control. Three replicates were set up for each fungal isolate. The inoculated mangoes were kept in a moist chamber at 25–28°C for 3–5 days. Reisolations of the pathogens from the diseased tissues of the inoculated fruit were performed as mentioned above. Morphological identity between the inocula and the re-isolated cultures was confirmed by microscopic examination.

Pathogen identifications were carried out mainly by morphological examination under a light microscope as well as disease symptoms. In the case of an unfamiliar fungal pathogen, its identification was performed by molecular analysis of rDNA-ITS (internal transcribed spacer) sequences (Xie *et al*., 2010) as well as spore morphology and disease symptoms.

Data obtained from the experiments on percentage sound fruit and decay-controlled efficacy during storage of the fruit, were used for analysis of variance (ANOVA) using SAS software (SAS Institute, version 6.08, Cary, NC). Comparison of means was performed using Duncan's Multiple Range Test at $P = 0.05$. Each of the percentage data was subjected to an arcsine transformation before statistical analysis.

RESULTS

In the small-plot field trial, significant enhancement of efficacy in controlling post-harvest decays and extending shelf life of mangoes by combined pre- and post-harvest chemical applications was observed (Table I). For cv. Tainong No.1, no significant differences among regimes A, B, C and E were observed after 16 days of storage in the percentage of sound fruit and disease-controlled efficacy at a significance level of P=0.05. The percentages and disease-controlled efficacies of regimes A, B, C, D and E were significantly higher than that of the control (regime F). As the storage period extended to 20 days, the percentages of sound fruit and disease-controlled efficacies of regimes A, B and C with both pre- and post-harvest chemical applications were 97.5–98.3% and 95.4–97.5%, respectively which were significantly higher than those of the regime E only with the pre-harvest chemical applications and those of the regime F only with the post-harvest chemical applications. As the storage period extended to 23 days, the percentages of sound fruit and disease-controlled efficacies of regimes A, B and C only slightly decreased to 95.0–96.7% and 95.0–97.3%, respectively as compared to a marked decline in the percentages of sound fruit and disease-controlled efficacies of regimes D and E. The disease indices of regimes A (0.7), B (0.5) and C (0.9) slightly rose to 3.2, 1.9 and 3.5, respectively as the storage period extended to 23 days. On the other hand, the disease indices of regimes D (4.4) and E (1.4) increased to higher levels (24.9 & 20.3, respectively) at the extended storage period. In contrast, the disease index of the regime F (control) was 28.1 after 16 days of storage and increased to 71.6 as the storage period extended to 23 days (Table I), showing a significantly enhanced efficacy in controlling post-harvest decays of mangoes by combining the pre-harvest chemical applications with the post-harvest ones.

For cv. Red Ivory, the percentages of sound fruit and decay-controlled efficacies of regimes A, B and C were significantly higher than those of regimes D and E during the whole storage period. The percentages of sound fruit and decay-controlled efficacies of regimes A, B and C were statistically at par with each other during storage. All the percentages of sound fruit of the regimes A, B, C, D and E were significantly higher than that of the regime F (the control). The disease indices of the regimes A, B and C increased from 0 to 8.5, 0 to 9.8 and 0.1 to 8.3, respectively as the storage period extended to 28 days. In contrast, the disease indices of the regimes D and E markedly increased from 3.3 to 42.3 and 4.0 to 32.8, respectively after the extended storage period. The control had the highest disease index during the whole storage period (Table II).

After 20 days of storage, the percentage of sound fruit, disease index and decay-controlled efficacy of the mangoes combining the pre-harvest chemical applications with the post-harvest ones were 98.2%, 1.1 and 96.8%, respectively as compared to a significantly lower percentage of sound fruit (50.7%) and significantly higher disease index (34.2) in the control (Table II).

A similar enhanced efficacy of the combined pre- and post-harvest chemical applications in controlling post-harvest decays and extending the shelf life of the mangoes could also be confirmed in the demonstration field trial with 100 test mango trees (Fig. 1). After 22 days of storage, the nutritional contents were compared between the mango fruit with pre- and post-harvest chemical applications and those without such chemical applications (Table III). Among 6 nutritional contents tested, the contents of total soluble solids, total acids and vitamin C in the fruit with pre- and post-harvest chemical applications were higher than those without such chemical applications (control). On the other hand, the contents of total soluble sugars, crude cellulose and vitamin A in the fruit with pre- and post-harvest chemical applications were lower than the control.

Three types of fungal diseases were found to be associated with the rotted mangoes during storage. The first one was the anthracnose caused by *Colletotrichum gloeosporioides*. The second was the stem end rot caused by multiple fungal species, including *Botryodiplodia theobromae*, *Dothiorella dominicana* and *Phomopsis mangiferae*. The third was the aspergillus rot caused by *Aspergillusoryza* var. *oryzae*, *A. niger* and *A. japonicus* var. *aculeatus*. Of the mango stem end rot pathogens, *B.*

Fig. 1: After 20 days of storage showing significant suppression of postharvest decay of the mango fruits (cv. Red Ivory) with combined pre and postharvest chemical applications. A, The mangoes lacking pre and postharvest chemical applications are taken as control. B, The mangoes with the following pre and postharvest treatments: A fungicide mixture (167 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb) was sprayed three times on the panicles of the 10-years-old mango trees at 10-days-intervals. From fruit set until harvest, $CaCl_2$ was added to the fungicide mixture at a concentration of 0.6% (w/v) and 4 sprays of the $CaCl_2$-amended fungicide mixture were performed on the developing fruit at 15-days-intervals. After being harvested, the fruits were immersed in a prochloraz solution (450 mg L^{-1}) for 10 min, air-dried and packaged in a carton box with ethylene absorbent bags

Table I: Enhanced efficacies of the combined pre and postharvest chemical applications in controlling fruit decays of cv. Tainong No.1

Regime	16 d			20 d			23 d		
	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)
A	98.3a	0.7	97.4a	98.3a	1.5	96.8a	95.8a	3.2	95.5a
B	99.2a	0.5	97.9a	98.3a	1.1	97.5a	96.7a	1.9	97.3a
C	98.3a	0.9	96.9a	97.5a	2.1	95.4a	95.0a	3.5	95.0a
D	94.2b	4.4	84.2b	76.7c	14.8	67.7b	67.5b	24.9	65.5b
E	97.5ab	1.4	94.5ab	86.7b	8.0	82.5b	62.5b	20.3	71.0b
F(control)	59.2c	28.1		34.5d	45.8		2.5c	71.6	

Table II: Enhanced efficacies of the combined pre and postharvest chemical applications in controlling fruit decays of cv. Red Ivory

Regime	16 d			20 d			25 d			28 d		
	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)	Sound fruit (%)	Disease index	Decay-controlled efficacy (%)
A	100.0a	0.0	100.0a	100.0a	0.0	100.0a	95.0a	2.7	97.0a	89.4a	8.5	91.2a
B	100.0a	0.0	100.0a	99.4a	0.1	99.8a	96.7a	2.0	97.7a	87.8a	9.8	89.9a
C	99.4a	0.1	99.8a	99.4a	0.2	99.5a	97.8a	0.5	99.4a	88.3a	8.3	91.3a
D	96.1b	3.3	89.2b	82.2b	11.5	70.0b	66.7b	25.3	71.4b	46.1b	42.3	56.0c
E	95.0b	4.0	86.9b	83.3b	13.1	66.5b	73.9b	21.8	75.5b	55.0b	32.8	66.0b
F(control)	48.9c	31.1		47.8c	37.9		1.7c	88.5		0.0c	96.2	

Note: In Tables I & II, three fungicide combinations were used before harvest. They were: FC-1 (250 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb), FC-2 (167 mg L^{-1} azoxystrobin plus 1000 mg L^{-1}mancozeb), and FC-3 (125 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb). Five postharvest treatments were designed: Regime A, the mangoes of FC-1 were drenched in the prochloraz solution; Regime B, the mangoes of FC-2 were drenched in the prochloraz solution; Regime C, the mangoes of FC-3 were drenched in the prochloraz solution; Regime D, the mangoes of FC-2 were only washed with tap water; Regime E, the mangoes from the trees lacking pre-harvest chemical application were drenched in the prochloraz solution; Regime F, the mangoes from the trees lacking pre-harvest chemical application were drenched in tap water. The lowercases in the same column represent a significance level of $P=0.05$

Table III:Comparison of nutritional content between the mango fruit with pre and postharvest chemical applications and those without the chemical applications

Treatment	Total soluble solids (%)	Total acids (g kg^{-1})	Total soluble sugars (%)	Crude cellulose (%)	Vitamin A (μg 100 g^{-1})	Vitamin C (μg 100 g^{-1})
Chemical application	11.6	1.11	7.8	0.25	148	17.37
Control	11.1	0.94	9.6	0.5	170	13.75

Note: Values in the tables are the averages of two replicates

theobromae and *D. dominicana* were the most frequently isolated species that could cause complete rot of a fruit within a relative shorter time. The stem end rots caused by *P. mangiferae* commonly occurred at a later stage during storage. The isolated fungal species showed different degrees of virulence on healthy mangoes in the pathogenicity tests based on Koch's postulates.

DISCUSSION

Multiple fungal pathogens are known to be the causal agents of mango post-harvest diseases (Akem, 2006). In the present study, anthracnose caused by *C. gloeosporioides* and stem end rot by three fungal pathogens viz., *L. theobromae*, *D. dominicana* and *P. mangiferae*, were found to be the main post-harvest diseases in the experimental mango fruit sourced from Tianyang County, Guangxi, China. Besides the two diseases (anthracnose & stem end rot), mango fruit rots caused by three*Aspergillus* species (*A.oryza* var. *oryzae*, *A. niger* & *A. japonicus* var. *aculeatus*) were also observed. The mango anthracnose and stem end rot pathogens mentioned above have been reported, showing quiescent infection in mango plants/fruit (Johnson *et al.,* 1991 & 1992; Liu *et al.,* 1999; Luo *et al.,* 2004). The efficacies of fungicides for controlling mango stem end rot after harvest were often poor compared to mango anthracnose (data not shown). Quiescent infection by *C. gloeosporioides* commonly occurred in the peel tissue on immature mangoes, while mango stem end rot pathogen(s) frequently existed in mango seeds/pulps as well as peels, making a post-harvest fungicide application less effective.

Many approaches have been applied to management of mango post-harvest decays and to extension of mango storage life (Spalding & Reeder, 1978; Ketsa & Prabhasavat, 1992; Singh *et al.,*1993; Sangchote, 1998; Huang *et al.*, 2000; Yan *et al.,* 2001; Srinivasa *et al.,* 2002; Anjum & Ali, 2004; Galvis *et al.,* 2005; Govender & Korsten, 2005; Mansour *et al.,* 2006; Zheng *et al.,* 2007a & b; Weor, 2007; Niranjana *et al.*, 2009), which could be

divided into three types: (A) antimicrobal technology; (B) physiological regulation of mango plants/fruit; and (C) environmental improvement. Most of these approaches were based on pre- or post-harvest treatments alone. In the present study, an approach that integrated pre-harvest treatments with the post-harvest ones was applied to control of mango post-harvest decay and to prolongation of the fruit storage life. The percentage of sound fruit and decay-controlled efficacy on the fruit with pre- and post-harvest chemical applications were significantly higher than those with pre- or post-harvest chemical applications alone (Tables I & II), suggesting that factors contributing to a higher decay-controlled efficacy of mangoes during storage exist in both pre- and post-harvest stages. A successful management of mango post-harvest diseases needs a full consideration to both pre- and post-harvest factors influencing pathogen infection and disease development as well as physiological regulation of fruit development.

Calcium application has been reported to be an effective means of extending the storage life of mangoes (Singh *et al.*, 1993; Anjum & Ali, 2004). On the other hand, ethylene is known as ripening hormone that plays a regulatory role in many processes of plant growth and development. For the reason, ethylene absorbents such as potassium permanganate have been frequently used for retaining freshness of climacteric fruits (Scott *et al.*, 1970; Ishaq *et al.*, 2009). The results in the present study clearly showed that the combined pre- and post-harvest chemical applications led to a marked reduction in disease index and a significant enhancement in the percentage of sound fruit and disease-controlled efficacy during storage. Two reasons for the extended storage life of the mangoes with pre- and post-harvest chemical applications could be considered as follows: (i) the pre-harvest application of the fungicide mixture (azoxystrobin plus mancozeb) and post-harvest application of prochloraz might be responsible for the increased effectiveness on suppressing the post-harvest decays; and (ii) the pre-harvest application of calcium chloride and post-harvest application of ethylene absorbent might be contributed to delaying the ripening process in mango fruit by lowering the rate of fruit respiration. Although the storability of mangoes could be significantly enhanced by combined pre-harvest chemical applications with post-harvest ones in the present study, the optimization of both pre- and post-harvest treatments such as extensive screening of chemical combinations and the determination of optimum chemical concentrations and treatment time, remains to be studied. Furthermore, the residual levels of related chemicals in the mangoes should be clarified before the technology is practically used in mango production.

In conclusion, the efficacy of controlling post-harvest decays and extending shelf life of mangoes could be significantly enhanced by combined pre- and post-harvest chemical applications. No significant difference in enhancing storability of fruit existed among three chemical combinations used in pre-harvest treatments. FC-3 (125 mg L^{-1} azoxystrobin plus 1000 mg L^{-1} mancozeb) was the best pre-harvest fungicide combination, in which the azoxystrobin was at a lower concentration as compared to other two pre-harvest chemical combinations (FC-1 & FC-2).

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