Influence of Calcium Foliar Fertilization on Plant Growth, Nutrient Concentrations, and Fruit Quality of Papaya

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ADDITIONAL INDEX WORDS. ***Carica papaya*, morphology, postharvest, disease incidence**

SUMMARY. **Calcium (Ca) is a major plant nutrient that affects cell wall and plasma membrane formation and plays a key role in plant growth, biomass production, and function. Ca can be used to decrease fruit decay and increase firmness and shelf life. Different sources and concentrations of foliar-applied Ca were examined for the effects on nutrient concentration and growth of 'Eksotika II' papaya (*Carica papaya*) plants. Papaya seedlings were established in pots and irrigated with a standard nutrient solution in a net house. Four preharvest sprays were applied as foliar applications with three different sources of Ca {calcium chloride [$CaCl_2$], calcium nitrate [$Ca(NO_3)_2$], and calcium propionate [$Ca(C_2H_5COO)_2$]} at four concentrations (0, 60, 120, and 180 mg·L^{-1}). Plant Ca concentration was unaffected by the different Ca sources. However, increased Ca concentration applied to the leaves enhanced plant accumulation of phosphorous and Ca in the plant, but decreased potassium (K) and magnesium (Mg) concentrations in the tissues. Plants that received Ca at 180 mg·L^{-1} had greater height and diameter than control plants. In a field trial with mature trees, preharvest applications of Ca (0, 4000, and 5400 mg·L^{-1}) in the form of $CaCl_2$ showed that increasing concentrations improved fruit Ca concentration, texture, and flavor; and decreased weight loss, Mg content, and apparent disease incidence of the fruit.**

Papaya is a large perennial plant with a rapid growth rate (Paull and Duarte, 2011). In Malaysia, papaya ranks third in fruit production after durian (*Durio zibethinus*) and banana (*Musa* sp.) (Ali et al., 2010). The cultivar Eksotika II is a high yielding, good quality F_1 hybrid, released by the Malaysian Agricultural Research and Development Institute (MARDI), that is popular in domestic and export markets (Shukor and Shokri, 1997).

Calcium is a fundamental macronutrient for normal plant development (Barker and Pilbeam, 2007) and exogenous applications can reduce fruit decay, and increase firmness and storage life (Eryani- Raqeeb et al., 2009). Ca can be applied to the soil or sprayed directly on the fruit and leaves to increase fruit quality (White and Broadley, 2003). Ca uptake can take place from roots tips, through the fruit cuticle, stomata, or cracks on fruit surfaces (Saure, 2005). Ca deficiency can develop in organs with low transpiration rates, such as fruit (White, 2001).

Foliar application of $Ca(NO_3)_2$ increased plant height and leaf Ca content in parsley [*Petroselinum crispum* (Chondraki et al., 2012)]. In tomato (*Solanum lycopersicum*), foliar sprays with 0.3% $CaCl_2$ increased plant height and fruit per plant, and decreased the incidence of blossom end rot (Rab and Haq, 2012). Calcium nitrate foliar sprays on salt-treated lettuce (*Lactuca sativa*) and endive (*Cichorium endivia*) did not impact plant growth, but reduced blackheart and tip-burn symptoms (Tzortzakis, 2009). Also, foliar sprays of $CaCl_2$ reduced postharvest decay and improved firmness retention in sweet bell pepper [*Capsicum annuum* (Toivonen and Bowen, 1999)].

When Ca sources at six concentrations were applied to the root zone of young 'Eksotika II' papaya, the maximum plant height and stem diameter were reached at 180 and 240 mg·L^{-1} Ca (Madani et al., 2013). Although the Ca content in the plant was unaffected by the different Ca sources, there were significant differences between the control and 300 mg·L^{-1} Ca nutrient solutions (Madani et al., 2013). Furthermore, Qiu et al. (1995) found that $CaCl_2$ sprays applied to the fruit did not increase Ca concentrations in 'Kapoho Solo' papayas grown in Hawaii. However, there are no reports for applications of varying sources of Ca as a foliar spray for papaya under a controlled environment, including the cultivar Eksotika II. Therefore, a study was conducted to evaluate the effect of different sources and concentrations of Ca, sprayed to the fruit and leaves, on papaya nutrient concentrations, plant growth, and fruit quality in a Malaysian environment.

Material and methods

NET HOUSE TRIAL. Seeds of 'Eksotika II' were obtained from the MARDI and germinated in 25-cell polypropylene trays filled with coco peat and paddy husk medium (50:50 v/v).

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
16.3871	inch^3	cm^3	0.0610
1	mmho/cm	dS·m^{-1}	1
28.3495	oz	g	0.0353
1.7300	oz/inch^3	g·cm^{-3}	0.5780
0.001	ppm	mg·g^{-1}	1000
1	ppm	mg·L^{-1}	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Six-week-old papaya seedlings (10 to13 cm height), each having more than four fully expanded leaves and of uniform size, were transplanted into 5-L black polyethylene bags (25 × 20 × 50 cm^3) containing the same medium. The medium had 40.7% organic matter, a bulk density of 0.25 $g \cdot cm^{-3}$, and macronutrient contents of 0.46% nitrogen (N), 0.07% phosphorus (P), 0.86% K, 0.49% Ca, and 0.1% Mg.

The seedlings were arranged in rows with 120 cm between bags and 200 cm between rows. The plants were placed in a net house (10 × 26 m) at University Agriculture Park, Universiti Putra Malaysia (UPM), Serdang, Selangor, Malaysia. Maximum and minimum temperatures in the shelter

Table 1. Effects of three sources of calcium (Ca) at four Ca concentrations sprayed to the foliage 1 mo. after transplanting at 2-week intervals on leaf nutrient concentrations of 'Eksotika II' papaya.

	Macronutrients ($mg \cdot g^{-1}$ dry wt)[z]				
Treatment	**Ca**[y]	**Mg**	**N**	**P**	**K**
Source					
Calcium chloride	11.7 a[x]	8.3 a	15.6 b	5.0 b	60.8 b
Calcium nitrate	12.3 a	8.5 a	18.6 a	6.1 a	71.9 a
Calcium propionate	12.4 a	8.2 a	16.3 b	5.9 ab	58.5 b
Concentration ($mg \cdot L^{-1}$)[z]					
0	11.1	7.4	15.8	2.6	64.9
60	11.6	9.5	16.5	5.9	72.0
120	12.4	8.5	17.1	6.6	62.7
180	13.4	7.7	18.3	7.5	55.5
Significance	Q***[w]	Q***	Q*	Q***	Q*

[z] 1 $mg \cdot g^{-1}$ = 1000 ppm; 1 $mg \cdot L^{-1}$ = 1 ppm.
[y] Ca = calcium; Mg = magnesium; N = nitrogen; P = phosphorus; K = potassium.
[x] Means followed by the same letter in the same column are not significantly different by Duncan's multiple range test at $P \le 0.05$. There were four replications per treatment.
[w] Q*, Q*** = significant quadratic response at $P \le 0.05$ or $P \le 0.001$, respectively.

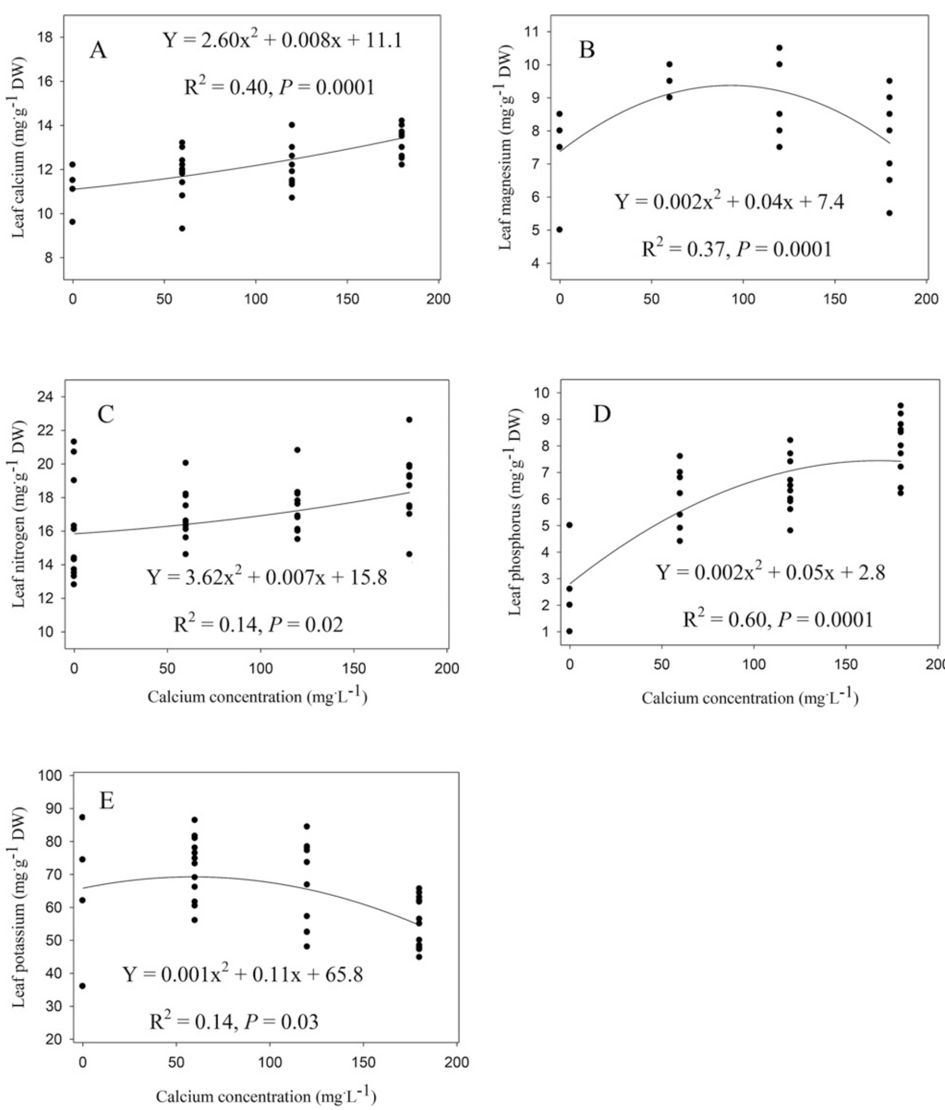

Fig. 1. Papaya leaf calcium (A), magnesium (B), nitrogren (C), phosphorus (D), and potassium (E) concentrations for plants treated with foliar applications of calcium (Ca) at four concentrations (0, 60, 120, and 180 $mg \cdot L^{-1}$) with three sources of Ca as calcium chloride ($CaCl_2$), calcium nitrate [$Ca(NO_3)_2$], and calcium propionate [$Ca(C_2H_5COO)_2$]. Each treatment had four replicates; 1 $mg \cdot L^{-1}$ = 1 ppm, 1 $mg \cdot g^{-1}$ = 1000 ppm.

Table 2. Effects of three sources of calcium (Ca) at four Ca concentrations sprayed to the foliage 1 month after transplanting at 2-week intervals on stem growth of 'Eksotika II' papaya.

Treatment	Stem growth Ht (cm)[z]	Diam (mm)[z]
Source		
Calcium chloride	145.8 a[y]	28.1 a
Calcium nitrate	148.9 a	27.5 a
Calcium propionate	144.5 a	27.7 a
Concentration ($mg \cdot L^{-1}$)[z]		
0	131.2	25.9
60	148.4	27.7
120	151.4	27.5
180	154.6	29.8
Significance	Q**[x]	Q**

[z]1 cm = 0.3937 inch; 1 mm = 0.0394 inch; 1 $mg \cdot L^{-1}$ = 1 ppm.
[y]Means followed by the same letter in the same column are not significantly different by Duncan's multiple range test at $P \leq 0.05$. There were four replications per treatment.
[x]Q** = significant quadratic response at $P \leq 0.01$.

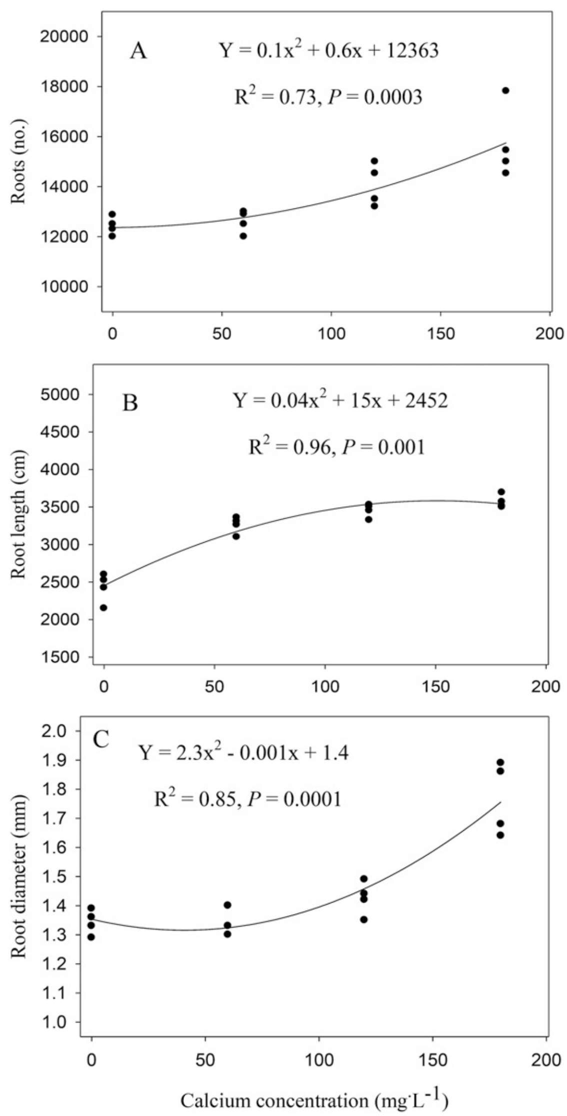

Fig. 2. Papaya total root number per tree (A), total root length per tree (B), and average root diameter per tree (C) for plants treated with four calcium concentrations (0, 60, 120, and 180 $mg \cdot L^{-1}$) when calcium chloride ($CaCl_2$) was used as a source for a foliar spray. Each treatment had four replicates; 1 $mg \cdot L^{-1}$ = 1 ppm, 1 cm = 0.3937 inch, 1 mm = 0.0394 inch.

were 35 and 23 °C, respectively. Relative humidity was between 80% and 90% and photosynthetically active radiation was 700–800 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

The plants were fertilized with a standard nutrient solution containing the following concentration of macronutrients (mM): N 21.0, P 1.48, K 6.92, Ca 6.0, Mg 5.0, sulfur 0.28; and micronutrients (µM): iron 23.0, zinc 7.0, manganese 6.0, copper 11.0, boron 24.0, and molybdenum 39.0 (Mardi, 2009). Ca was supplied as $Ca(NO_3)_2$ in the nutrient solution. The electrical conductivity and pH of the solution were maintained at 2.5 $dS \cdot m^{-1}$ and 6, respectively, throughout the experiment. A total volume of 600 $mL \cdot d^{-1}$ of the nutrient solution was applied to each polyethylene bag, using an automatic drip irrigation system.

Foliar Ca applications started 1 month after transplanting. Treatments included three sources of Ca: $CaCl_2$, $Ca(NO_3)_2$, and $Ca(C_2H_5COO)_2$ at four concentrations of Ca (0, 60, 120, and 180 $mg \cdot L^{-1}$). Four replicates of the treatments were used for this experiment. Treatments were applied four times every 2 weeks as foliar sprays using a manual 16-L knapsack sprayer with a solid cone nozzle, nozzle cap (June Chong®, Johor, Malaysia) at 0.70–0.85 $L \cdot min^{-1}$. Sprays were applied until runoff, and 0.03% Tween 20 (Sigma-Aldrich®, St. Louis, MO) was used as a surfactant to maximize Ca absorption. The potting medium was covered with polyethylene to avoid residual runoff of Ca into the medium.

The ideal time for leaf sampling from fruit trees for nutrient analysis is during midseason of plant growth (Jones, 2001) or specifically for papaya, at 3- to 4-month-old leaves from a new flush (Motsara and Roy, 2008). In each replicate, two fully matured leaves were harvested at the seventh and eighth leaves from the apex of each plant, and then combined to create one sample for nutrient measurement. Leaf samples were placed in the tap water for 10 min and then washed twice in distilled water. Leaf samples were oven dried at 70 °C for dry weight determination and ground to pass a 2-mm sieve. The samples were digested with 5 mL of 98% sulfuric acid (H_2SO_4) and then 2 mL of 50% hydrogen pyroxide (H_2O_2) until clear. K, Ca, and Mg in the solution were analyzed using an atomic absorption spectrometer (model 3110; Perkin

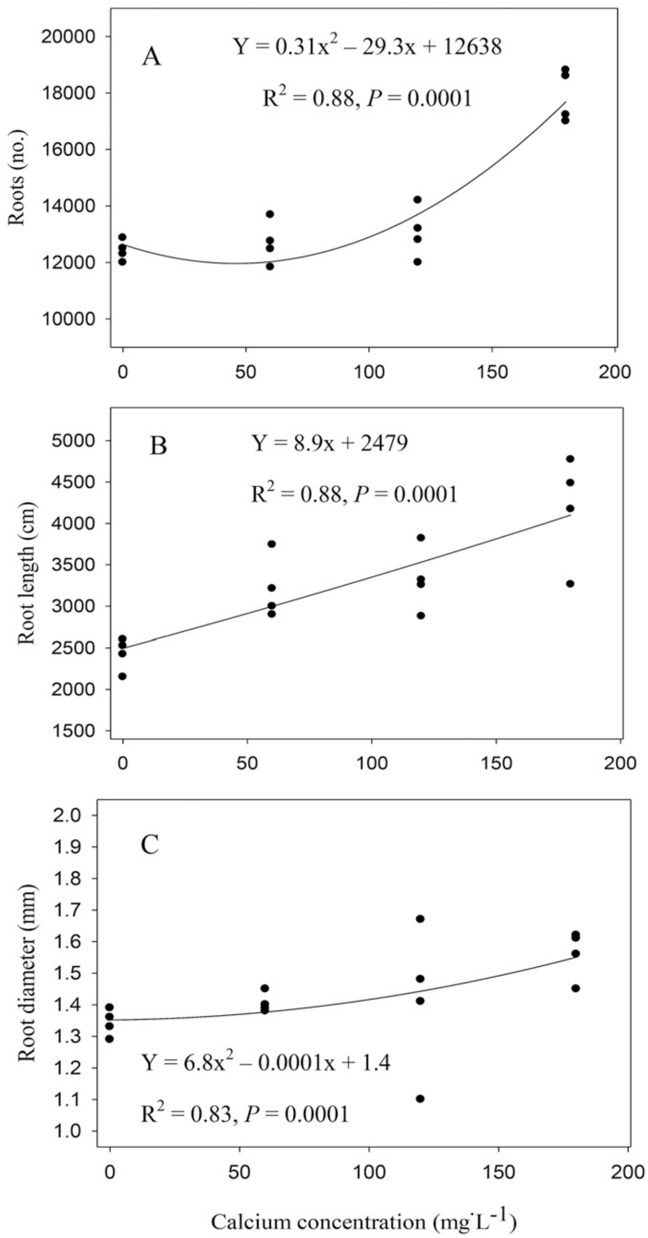

Fig. 3. Papaya total root number per tree (A), total root length per tree (B), and average root diameter per tree (C) for plants treated with four calcium concentrations (0, 60, 120, and 180 mg·L^{-1}) when calcium nitrate [$Ca(NO_3)_2$] was used as a source for a foliar spray. Each treatment had four replicates; 1 mg·L^{-1} = 1 ppm, 1 cm = 0.3937 inch, 1 mm = 0.0394 inch.

Elmer, Palo Alto, CA). N and P were analyzed using an auto analyzer (model 403, Perkin Elmer).

Plant growth variables were measured at 100 d after transplanting. Stem height was measured from the media line to the apical bud of each plant. Stem diameter was measured at 10, 60, and 120 cm from the base of the plant, and the average calculated. Roots were carefully washed to remove the media, and total root number, total root length, and average root diameter were measured using a root scanner image analyzer (Seiko; Epson Corp., Nagano, Japan) and WinRHIZO ProV 2007 software (Regent Instruments, QC, Quebec, Canada).

For this experiment, three sources of Ca at four concentrations were arranged as a factorial in a completely randomized design with four replications. Data were subjected to a two-way analysis of variance (ANOVA) to determine if interactions existed between fertilizer source and rate. Duncan's multiple range test at $P \leq 0.05$ was used to separate means for Ca source. The effect of Ca concentration on papaya growth features was analyzed by regression (SAS version 8.2; SAS Institute, Cary, NC).

Field trial. 'Eksotika II' papaya plants (8-month old, about 2.2 m height) were selected in 2013 for a field trial at UPM with two plants per treatment per block. Each plant received 200 g 12N–5.2P–14.2K solid fertilizer (Hextar Fertilizer, Selangor, Malaysia) applied monthly around the canopy periphery, and the plants were irrigated at 4 d intervals.

Ca concentration treatments (0, 4000, and 5400 mg·L^{-1}) in the form of $CaCl_2$ were applied to the leaves and fruit beginning on 15 Jan. 2013 (3 weeks after anthesis), with the final spray on 28 Mar. (2 d before fruit harvest). Fruit development takes about 3 months from anthesis to color-break in this environment. Papaya leaves and fruit were treated with $CaCl_2$ using a knapsack sprayer. Tween 20 (0.03%) was used as a surfactant. The base of each tree was covered with polyethylene to avoid runoff of Ca into the soil. Sprayings were done every 2 weeks for six applications. Fruit with uniform size and shape were harvested at ripening index 2 (green with a trace of yellow), washed with water and allowed to air dry before being packed in commercial boxes (EXOTIC STAR®; Kajang, Selangor, Malaysia) and stored 3 weeks at 12 ± 2 °C and 85% to 90% relative humidity.

For Ca and Mg analyses, eight samples of peel and pulp tissue were taken separately for each treatment after 3 weeks in storage. Samples were taken from the middle side of each fruit and then dried at 70 °C in an air-circulating oven. The procedure for mineral analysis (Ca and Mg) was as previously described. For determining weight loss, eight fruit in each treatment were marked and weighed before and after 3 weeks in storage. The results were expressed as percentage loss of initial weight. Apparent disease incidence was measured as the percentage of fruit showing disease symptoms out of the total number of fruit in each treatment. Apparent disease incidence also was measured after 3 weeks in storage, with 24 fruit in each treatment (six fruit per block).

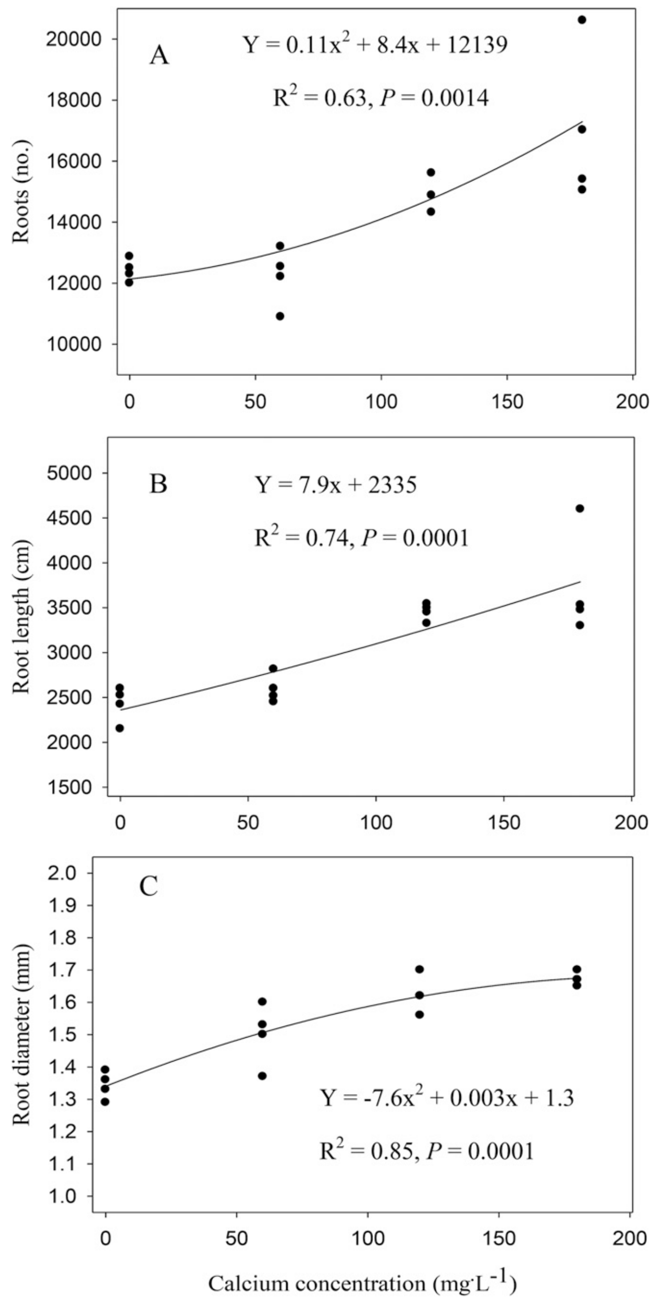

Fig. 4. Papaya total root number per tree (A), total root length per tree (B), and average root diameter per tree (C) for plants treated with four calcium concentrations (0, 60, 120, and 180 mg·L^{-1}) when calcium propionate [$Ca(C_2H_5COO)_2$] was used as a source for a foliar spray. Each treatment had four replicates; 1 mg·L^{-1} = 1 ppm, 1 cm = 0.3937 inch, 1 mm = 0.0394 inch.

Texture and flavor were measured after 3 weeks in storage. A panel of six judges was selected and trained for texture and flavor analysis. Quality ratings were made using a Hedonic scale from 0 to 5, with 0 for very poor and 5 for excellent.

For the field experiment, four blocks in each treatment were arranged in a randomized complete block design with two plants per treatment per block. Data were analyzed using regression analysis (SAS version 8.2).

Results and discussion

NET HOUSE TRIAL. Foliar applications of different Ca sources had variable effects on the nutrient content of papaya plants (Table 1), but there were no interactions ($P \geq 0.05$) between Ca source and concentrations for any of the leaf macronutrients measured. A significant quadratic response to Ca concentrations was observed for leaf nutrients for all sources of Ca (Table 1, Fig. 1). Although there were no differences among the three fertilizer sources for leaf Ca concentration [$P \geq 0.05$ (Table 1)], leaf Ca gradually increased and reached a maximum at 180 mg·L^{-1} (Fig. 1A). In a study with parsley, Ca concentration in the leaves increased when sprayed with $Ca(NO_3)_2$ when compared with a control (Chondraki et al., 2012).

Leaf Mg concentration increased gradually until 100 mg·L^{-1} and then decreased (Fig. 1B). Results of research by Guimarães et al. (2012) showed that an increase in $CaCl_2$ and $CaSO_4$ concentration in the nutrient solution caused a decrease in Mg concentration and an increase in Ca concentration in cowpea (*Vigna unguiculata*) leaves. This was attributed to an antagonistic effect of Ca on Mg (Mills and Benton-Jones, 1996). N concentration was highest when the foliar source was $Ca(NO_3)_2$ [$P \leq 0.05$ (Table 1)], and leaf N concentration gradually increased and reached the maximum at 180 mg·L^{-1} (Fig. 1C). In apple (*Malus ×domestica*), the N concentration of leaves increased with four foliar applications of $CaCl_2$ (Kadir, 2005), and with plum (*Prunus domestica*), $Ca(NO_3)_2$ foliar sprays produced plants with high leaf N (Abdel-Hafeez et al., 2010). For leaf P concentration, there were significant differences between $Ca(NO_3)_2$ and $CaCl_2$ fertilizers [$P \leq 0.05$ (Table 1)]. The maximum P concentration in leaves was between 120 and 180 mg·L^{-1} Ca (Fig. 1D). Al-Hamzawi (2010) indicated a synergistic effect of Ca and P, and Kadir (2005) showed that foliar Ca sprays increased P in apple leaves. The greatest leaf K concentration also was measured in papayas sprayed with $Ca(NO_3)_2$ [$P \leq 0.05$ (Table 1)]. Leaf K concentration increased with 60 mg·L^{-1} Ca and then decreased to a minimum at 180 mg·L^{-1} (Fig. 1E). The higher concentration of K in papaya leaves when treated with foliar $Ca(NO_3)_2$ may be linked to a synergistic influence of K and N (Premaratne and Oertli, 1994), whereas a decrease in leaf K at the 180 mg·L^{-1} Ca concentration may be related to antagonism between Ca and K (Zharare et al., 2009).

Papaya plant growth was unaffected by the source of Ca fertilizer

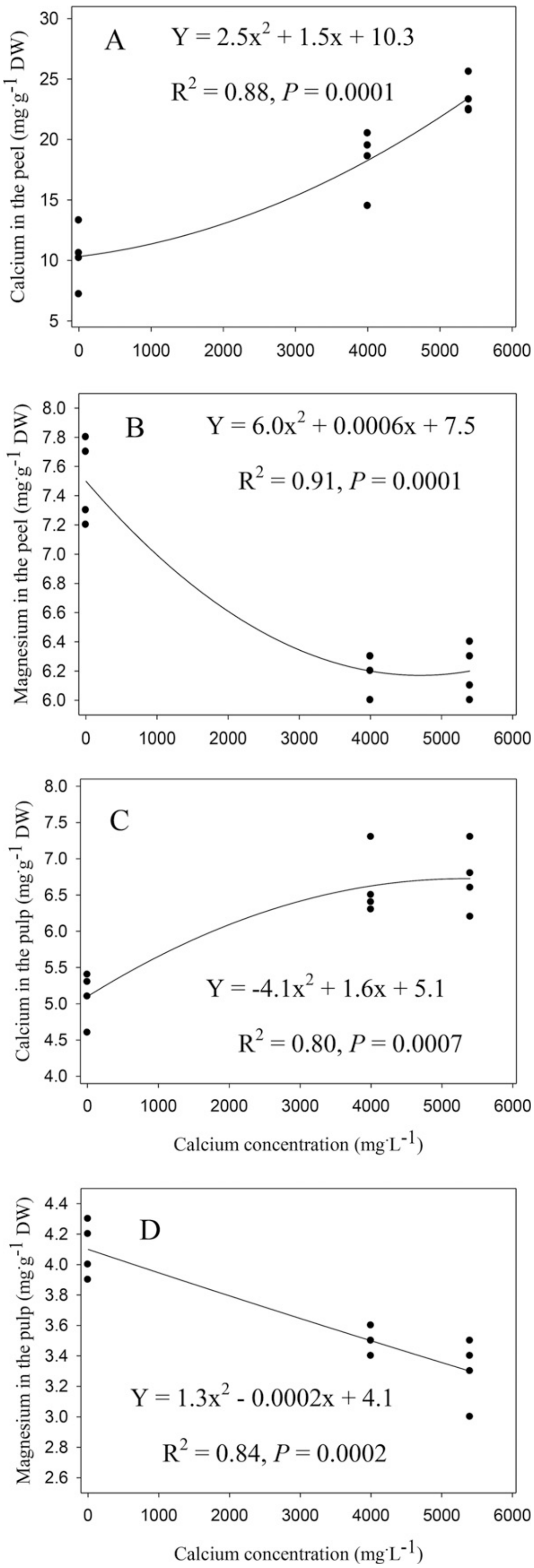

Fig. 5. Relationship between foliar- and fruit-applied calcium (Ca) concentrations (0, 4000, and 5400 mg·L^{-1}) and Ca content in papaya fruit peel (A), Ca content in the pulp (B), magnesium (Mg) content in the peel (C), and Mg content in the pulp (D) after 3 weeks storage at 12 °C (53.6 °F). Each treatment had four replicates; 1 mg·L^{-1} = 1 ppm, 1 mg·g^{-1} = 1000 ppm.

(Table 2), and there were no significant interactions ($P \geq 0.05$) between the foliar-applied Ca formulations and Ca concentrations for stem height and diameter. However, there were significant quadratic responses for stem height and diameter with Ca concentration. Foliar Ca applications also were shown to increase plant height of tomato (Rab and Haq, 2012).

For root growth variables, the interaction between Ca source and concentration was significant ($P \leq 0.05$). Regression analysis established functional relationships between Ca concentration and total root number, length, and average root diameter (Figs. 2–4). There was a significant quadratic response between Ca concentration and root number for $CaCl_2$ (Fig. 2A). Root number for plants treated with $CaCl_2$ increased slowly until 60 mg·L^{-1} and thereafter increased, attaining the greatest number with Ca at 180 mg·L^{-1}. Plants treated with $Ca(NO_3)_2$ also exhibited a quadratic response for root number (Fig. 3A), but the increase was dramatically higher at a Ca level of 180 mg·L^{-1}. Root number gradually increased for plants treated with $Ca(C_2H_5COO)_2$, again reaching a maximum at 180 mg·L^{-1} Ca concentration (Fig. 4A).

Plants treated with $CaCl_2$ showed a quadratic response for total root length, with maximum growth at higher Ca levels [120 to180 mg·L^{-1} (Fig. 2B)]. When $Ca(NO_3)_2$ or Ca $(C_2H_5COO)_2$ were used as the sources, a linear response was observed between root length and Ca level (Figs. 3B and 4B, respectively). Papaya average root diameter increased slowly until 120 mg·L^{-1} Ca was applied using $CaCl_2$, and then increased dramatically at 180 mg·L^{-1} (Fig. 2C). When $Ca(NO_3)_2$ was used as the source, root diameter also exhibited a quadratic response to Ca concentration, but the increment was gradual (Fig. 3C). The quadratic response was more pronounced for $Ca(C_2H_5COO)_2$, with the greatest root diameter in papayas treated with 120 to 180 mg·L^{-1} Ca (Fig. 4C).

Whether applied to the foliage (this study) or the root zone (Madani et al., 2013), Ca promotes the development of longer, thicker roots in papaya seedlings. Foliar-applied Ca at 180 mg·L^{-1} produced the greatest number of roots, regardless of source. In a previous study,

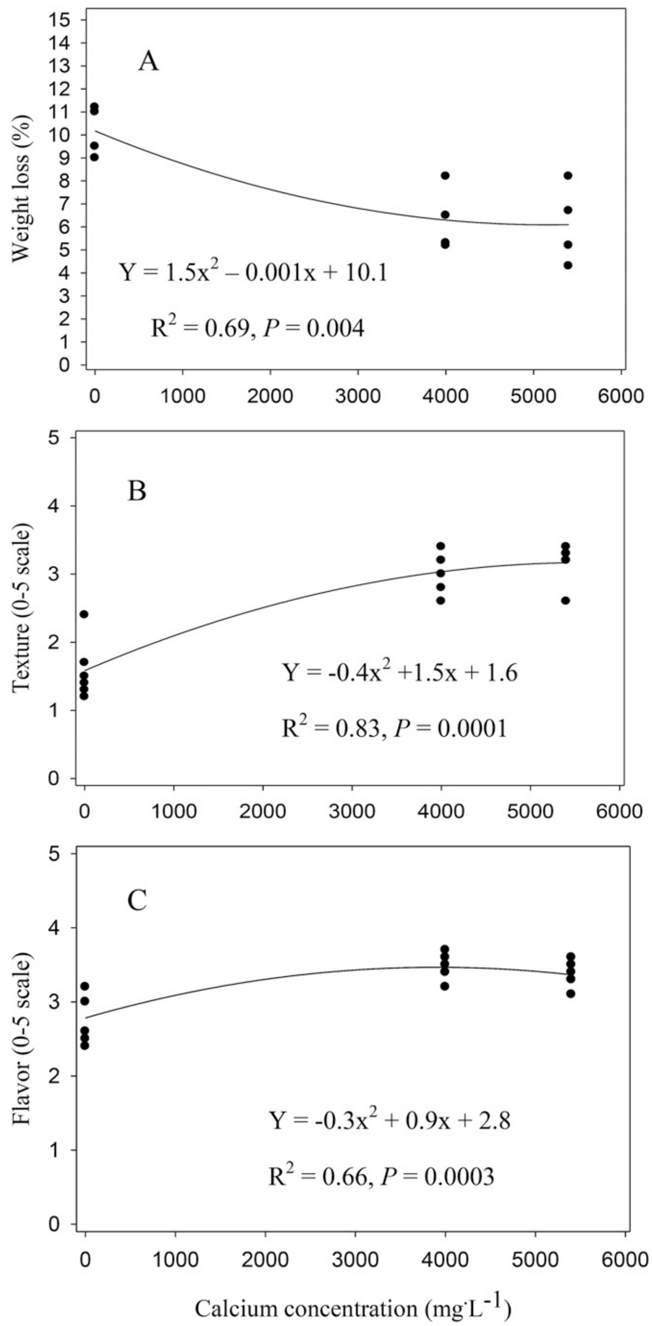

Fig. 6. Relationship between foliar- and fruit-applied calcium concentrations (0, 4000, and 5400 mg·L^{-1}) and papaya fruit weight loss (A), texture (B), and flavor (C) after 3 weeks storage at 12 °C (53.6 °F). Fruit texture and flavor were rated using a Hedonic scale where 0 was very poor and 5 was excellent. Four replicates per treatment were used; 1 mg·L^{-1} = 1 ppm.

total root length was maximal when 180 mg·L^{-1} Ca was applied to the soil (Madani et al., 2013). Together, these studies support the role of Ca for healthy papaya root growth, and demonstrate that Ca can be delivered via the foliage or the root zone to achieve root growth. However, total elimination of Ca in the root zone will decrease root growth and gradually cause root death (Mengel et al., 2001). The effect of foliar Ca on root growth may be indirectly associated with photosynthesis and hormonal stimuli. Ca plays a critical role in water oxidation, which is part of the mechanism of photosynthesis (Homann, 2002). Subsequently, increasing assimilates produced via photosynthesis may transfer to the root zone. Also, Ca has a synergistic effect with auxins that have a positive role in root growth (Saure, 2005).

FIELD TRIAL. $Ca(NO_3)_2$ has the potential to increase plant growth and divert Ca away from the xylem. For this reason, we selected $CaCl_2$ as the foliar source in a field experiment. We analyzed the Ca and Mg concentrations in the fruit, because Ca has an important role in postharvest quality of fruit and Mg has an antagonism with Ca. Papaya fruit peel and pulp had quadratic increases in Ca when treated with up to 5400 mg·L^{-1} foliar- and fruit-applied Ca (Fig. 5A and C, respectively). Preharvest spraying of Ca to the fruit and leaves of strawberry (*Fragaria ×ananassa*) also increased fruit Ca concentration (Singh et al., 2007). Interestingly, Qiu et al. (1995) found that six $CaCl_2$ sprays to the fruit alone did not increase Ca in Hawaii-grown 'Kapoho Solo' papaya flesh. This is contrary to our results in which fruit and leaves of Malaysian 'Eksotika II' papayas were treated with Ca. In papaya, a thick, waxy cuticle and the lack of lenticels create a barrier to Ca absorption through the fruit. Environmental factors, the presence of stomata or cracks, and genetic differences among cultivars also can affect Ca absorption in fruit (Saure, 2005). Therefore, foliar treatments may be a more effective mode for Ca absorption than fruit sprays. Papaya fruit peel and pulp exhibited a quadratic decrease in Mg concentrations up to 5400 mg·L^{-1} Ca concentration (Fig. 5B and D, respectively). Declines in Mg in fruit peel and pulp tissue treated with $CaCl_2$ is consistent with a report of antagonism between Ca and Mg in tomato (Navarro et al., 2000).

Papaya fruit had a quadratic decrease in weight loss in response to increasing Ca concentrations at 4000 to 5400 mg·L^{-1} Ca (Fig. 6A). Ca may increase cell wall resistance to water permeability and decrease water vapor diffusion through a firm matrix, thereby decreasing weight loss (Han et al., 2004). Preharvest treatments of Ca also decreased weight loss in blueberry [*Vaccinium corymbosum* (Angeletti et al., 2010)].

Postharvest apparent disease incidence declined sharply in response to $CaCl_2$ treatment. Control fruit (0 mg·L^{-1}) had 100% disease incidence after storage compared with 8.8% and 0% for the papayas treated with foliar

Ca at 4000 and 5400 mg·L^{-1}, respectively (data not shown). This effect of $CaCl_2$ demonstrates that Ca sprays to the leaves and fruit can be a practical and effective approach for postharvest disease management of papaya fruit. Ca may mitigate fungal disease incidence via two ways; directly by inhibition of fungal germination and fungal cell wall degrading enzymes (Wisniewski et al., 1995), and indirectly through its effects on cell wall integrity (Biggs, 1999). Preharvest applications of $CaCl_2$ also significantly decreased postharvest decay in grape [*Vitis vinifera* (Nigro et al., 2006)].

Papaya fruit texture and flavor improved with preharvest Ca applications and followed a quadratic response with increasing Ca concentration (Fig. 6B and C). Texture and flavor increased sharply for papayas treated with Ca at 4000 or 5400 mg·L^{-1}. Ca has been shown to maintain texture of carrots (*Daucus carota*) via a stabilization of cell walls and membranes (Izumi and Watada, 1994). Foliar sprays of $CaCl_2$ on mango (*Mangifera indica*) increased marketability (decreased fungal spots, softness), appearance, texture, and flavor (Singh et al., 1993).

Conclusions

Preharvest foliar applications of Ca on young papaya plants and on established fruiting plants had a positive impact on growth, root development, leaf mineral concentration, and fruit quality. In a net house study, the results were similar for the three sources of Ca on plant growth. However, $Ca(C_2H_5COO)_2$ is more costly than $Ca(NO_3)_2$ and $CaCl_2$. Increasing concentrations of $CaCl_2$ could increase Ca in papaya fruit peel and pulp, improve texture and flavor, and decrease fruit weight loss and disease incidence. Further study of foliar fertilization with $CaCl_2$ is needed to optimize concentration and timing.

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