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Effect of Foliar Applications of Ascorbic Acid plus Ferrous Sulfate on Leaf Greenness of 'Arkin' Carambola (*Averrhoa carambola* L.) Trees

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The effects of foliar- or soil-applied iron on leaf greenness of 12-year-old 'Arkin' carambola trees were tested in a 1.4-ha orchard on calcareous soil at the Tropical Research and Education Center in Homestead, FL. Trees received a foliar application of ascorbic acid plus ferrous sulfate (foliar acid plus iron), soil application of EDDHA-Fe, or no iron as a control in two separate experiments. An organosilicone adjuvant (Freeway®) was added to the acid plus iron solution. In Experiment 1, trees were treated with foliar acid plus iron from 6 June to 21 July (four applications) and a chelated iron drench was applied to the soil on 12 June and 8 Aug. 2006, with control trees receiving no iron. In Experiment 2, trees were treated with foliar acid plus iron from 18 Oct. 2006 to 16 Apr. 2007 (seven applications) and the chelated iron soil drench was applied on 31 Oct. 2006 and 17 Apr. 2007. In Experiment 1, treatments were arranged in a completely randomized design with six single-tree replications per treatment, and in Experiment 2, treatments were arranged in a randomized complete-block design with three single-row replications, consisting of 35 trees per row, per treatment. Leaf greenness was assessed on three recently mature (young) and three older leaves per tree from two trees per replication with a transmittance-based chlorophyll content meter (SPAD meter) just prior to each foliar acid plus iron application. In Experiment 1, young and mature leaves of trees treated with foliar acid plus iron had significantly higher SPAD values than leaves of trees in all other treatments. In Experiment 2, there were no consistently significant SPAD value differences among treatments. However, the older leaves treated with foliar acid plus iron tended to have higher SPAD values than the EDDHA-Fe treated and control trees, although differences were not consistently statistically significant due to the large variability within treatments. Several days after the first, second, and third foliar acid plus iron applications, flowers abscised and the oldest mature leaves (closest to the base of stem) became chlorotic and abscised and immature fruit turned yellow and abscised. However, young leaves generally remained green and intact. In addition to within-treatment variability, the lack of significant differences in SPAD values among treatments may have been due to reduced tree growth and nutrient uptake during fall and winter when temperatures were relatively low, since carambola trees become quiescent below 20 °C. Further investigation is warranted to determine the efficacy of foliar acid plus iron applications as a replacement for chelated soil drenches.

Florida currently has about 80.9 ha acres of commercial carambola (*Averrhoa carambola*) production worth an estimated $9.5 million to Florida's economy (Degner et al., 2002). Nearly half the acreage is located in southern Miami–Dade County, where fruit trees are planted in an oolitic limestone based soil with a high pH (Noble et al., 1996). In these soils, most of the iron, an essential element for plant growth and development, is unavailable for plant uptake because it is tightly bound to soil particles or precipitated as water-insoluble iron oxide (Mengel and Kirkby, 1982).

Research results for correcting and preventing iron deficiency in carambola trees are not consistent. Seedlings of 'Golden Star' (self-pollinated), 'Golden Star' x 'Fwang Tung' and 'Dah Pon' (open-pollinated with 'M-18960') growing in the limestone soils of Miami–Dade County were observed to show fewer foliar symptoms of iron deficiency (interveinal chlorosis) than 'Dah Pon' x 'Fwang Tung' (Knight, 1982). In contrast, seedlings of 'Golden Star', 'M-18960', and 'Maha' grown in solution culture with bicarbonate showed no difference among cultivars in the degree of leaf iron chlorosis over an 83-d period (Marler, 1993). Various open-pollinated rootstocks are used for carambola production in southern Florida, resulting in orchards with trees showing moderate to severe iron deficiency symptoms.

Typically, nutrients such as magnesium, manganese, and zinc are applied foliarly to carambola trees to prevent or correct deficiencies. However, foliar applications of various chelated and non-chelated forms of iron with or without adjuvants have not been successful in preventing or correcting iron deficiency in southern Miami–Dade County (Green et al., 1999). Iron chelated with EDDHA [(technical sodium ferric ethylenediamine di-(o-hydroxyphenylacetate)] or EDDHSA [(technical sodium ferric ethylenediamine-*N,N´*-bis(2-hydroxy-5-sulfonylphenyl) acetic acid)] applied as soil drenches are effective in correcting and preventing iron deficiency in carambola trees (Y. Li, unpublished data). However, these materials are very expensive and can represent up to 80% of the total fertilizer cost for an orchard (E. Evans, personal communication).

Research has shown that reducing the internal pH of iron-

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Table 1. Foliar ascorbic acid plus iron and chelated-iron soil application treatments applied to 'Arkin' carambola trees.

Treatment	Materials applied[z]	Method of application	Dates treatments applied
Experiment 1			
Acid-iron foliar spray	Ascorbic acid (6.2 $kg\cdot ha^{-1}$) + ferrous sulfate (1.8 $kg\cdot ha^{-1}$) + Freeway® (1.4 $L\cdot ha^{-1}$)	Foliar	6 June 2006 2 June 2006 7 July 2006 21 July 2006
Chelated iron soil drench	EDDHA-iron soil drench (30.4 $kg\cdot ha^{-1}$)	Individual tree soil drench	12 June 2006 8 Aug. 2006
No iron control	None	None	NA[y]
Experiment 2			
Foliar acid plus iron	Ascorbic acid (6.2 $kg\cdot ha^{-1}$) + ferrous sulfate (1.8 $kg\cdot ha^{-1}$) + Freeway® (1.4 $L\cdot ha^{-1}$)	Foliar	19 Oct. 2006 20 Nov. 2006 20 Dec. 2006 18 Jan. 2007 22 Feb. 2007 21 Mar. 2007 16 Apr. 2007
Chelated iron soil drench	EDDHA-iron soil drench (30.4 $kg\cdot ha^{-1}$)	Fertigation	31 Oct. 2006 17 Apr. 2007
No iron control	None	None	NA[y]

[z]The acid-iron foliar spray had a solution pH of about 3 prior to each application.
[y]NA = not applicable.

chlorotic leaves with foliar applications of dilute acids, such as sulfuric, citric, or ascorbic acid, resulted in a decrease in the leaf apoplastic pH and "re-greening" of leaves of some fruit species including orange (Pestana et al., 2001), kiwifruit (Tagliavini et al., 1995), and peach (Tagliavini et al., 2000) growing in calcareous soil. Preliminary research with foliar applications of ascorbic, sulfuric, or citric acid plus ferrous sulfate on carambola trees resulted in greener leaves (as measured with a SPAD meter) than trees not receiving iron or trees treated only with foliar acid applications. Leaves of carambola trees treated with acids plus iron were as green as those of trees receiving periodic EDDHA soil applications (B. Schaffer, unpublished data). Thus, the potential exists for the use of foliar applied weak acids as low-cost alternatives to expensive chelated iron for preventing iron deficiency in carambola trees growing in the calcareous soil of south Miami–Dade County.

Materials and Methods

Twelve-year-old 'Arkin' carambola trees in a 1.4-ha grove located at the Tropical Research and Education Center were used to compare foliar ascorbic acid plus ferrous sulfate (foliar acid plus iron), periodic soil applications of EDDHA-chelated iron (EDDHA-iron) and no-iron application (no-iron) during two periods: 6 June to 21 July 2006 (Expt. 1) and 19 Oct. 2006 to 19 Apr. 2007 (Expt. 2) (Table 1). The foliar acid plus iron mixture was made by mixing the ascorbic acid with water 12 h prior to all applications. This was done to allow the pH of the acid and well-water to stabilize. Just prior to each foliar application the iron sulfate was added to the mixture along with an organosilicone adjuvant (Freeway®, Loveland Products, Inc., Greeley, CO). The resulting pH of the acid-iron- Freeway® mixture ranged from 3.0 to 3.5.

Treatments in Expt. 1 were laid out in a completely randomized design with six single-tree per replications per treatment and Expt. 2 was laid out in a randomized complete-block design with three single-row replications, consisting of 35 trees per row, per treatment. The leaf chlorophyll index, which is a measure of leaf "greenness," was measured prior to each foliar acid plus iron application from five mature (hardened off) and five young (recently fully expanded) leaves from all trees in each treatment in (Expt. 1) or six randomly selected (but repeatedly measured) trees in each treatment (Expt. 2) with a transmittance-based chlorophyll content (SPAD) meter (Minolta, Inc., Tokyo). Soil and Plant Analyzer Development (SPAD) measurements were made 1 to 3 d prior to each foliar acid plus iron application. There is a high correlation between SPAD readings and carambola leaf chlorophyll content ($r^2 = 0.92$) (B. Schaffer, unpublished data).

Throughout the experiments, trees in each treatment were observed for signs of phytotoxicity and any obvious differences in tree phenology. Separate statistical analyses of SPAD data were done for mature and young leaves because mature leaves consistently had higher SPAD values than young leaves. Data were analyzed by ANOVA and Duncan–Waller multiple range test using SAS statistical software (SAS Institute, Cary, NC).

Table 2. Effect of 3 and 4 foliar applications of ascorbic acid-iron and 2 soil drenches of EDDHA-Fe on SPAD values of 'Arkin' carambola leaves (Expt. 1).

	SPAD			
	After 3 foliar applications		After 4 foliar applications	
Treatment	Young leaves	Mature leaves	Young leaves	Mature leaves
Foliar acid plus iron	15.9 a[z]	39.1 a	18.3 a	38.1 a
Chelated iron soil drench	11.6 b	34.8 b	5.3 b	25.0 b
No iron control	5.8 c	14.8 c	4.3 b	11.1 c

[z]Different letters indicate significant differences among treatments according to a Duncan–Waller multiple range test ($P \leq 0.05$).

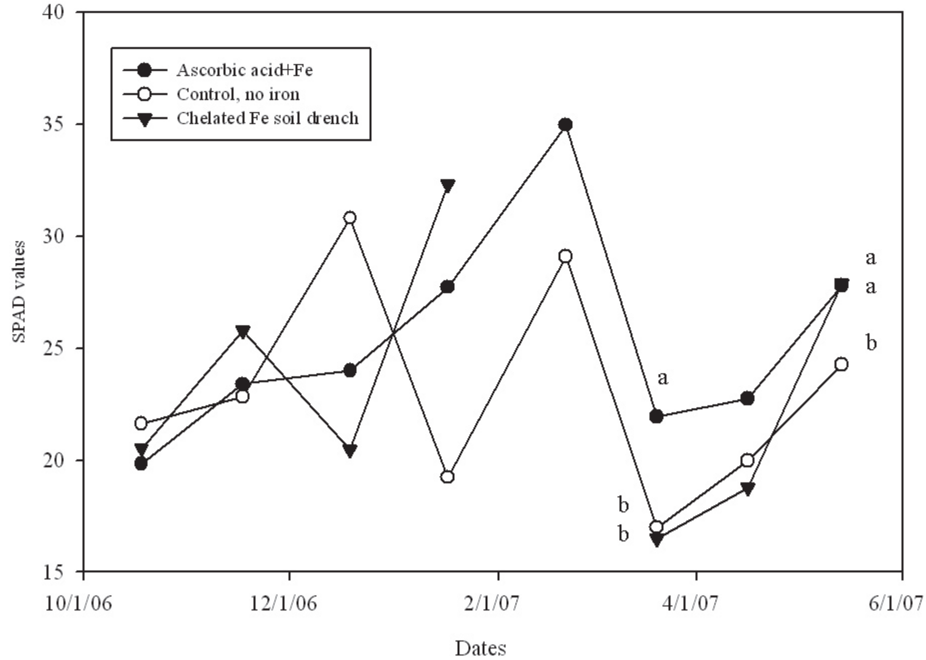

Fig. 1. SPAD values recorded monthly (from 19 Oct. 2006 to 14 May 2007) for young (recently matured) leaves of 'Arkin' carambola trees. Different letters indicate significant differences among treatments according to a Duncan-Waller multiple range test ($P < 0.05$). On 21 Feb. 2007, there were no young leaves in the chelated Fe soil drench treatment and only one value was recorded for the control, no iron treatment.

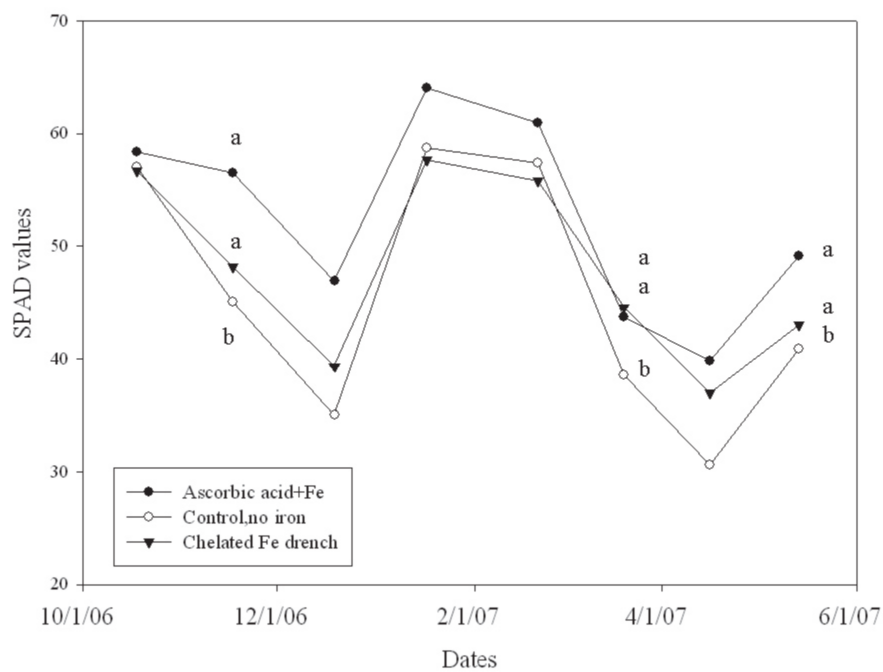

Fig. 2. SPAD values recorded monthly (from 19 Oct. 2006 to 21 Feb. 2007) for mature leaves of 'Arkin' carambola trees. Different letters indicate significant differences among treatments according to a Duncan-Waller multiple range test ($P < 0.05$ on 11 Nov. 2006 and 16 Apr. 2007; and $P \leq 0.10$ on 14 May 2007).

Results and Discussion

In Expt. 1, SPAD values were significantly higher for young and mature leaves treated with foliar acid plus iron than for leaves of all other treatments after three and four applications (Table 2). After the first and second foliar acid plus iron treatment, some abscission of the oldest mature leaves (most basipetal leaves) was observed. However, mature and young leaves appeared undamaged.

In Expt. 2, there were no significant differences in SPAD values among treatments for mature or young leaves prior to the foliar application of acid plus iron in October (Figs. 1 and 2). Significant differences in SPAD values for young leaves were observed on only two dates (20 Mar. and 14 May 2007) (Fig. 1). Significant differences in SPAD values for mature leaves were observed on three dates (17 Nov. 2006; 16 Apr. and 14 May 2007) (Fig. 2). On most measurement dates, mature leaves treated with foliar acid plus iron tended to have higher SPAD values than the other treatments, although differences were often not statistically significant due to the large variability within treatments. The general lack of differences in SPAD values for young leaves from Nov. 2006 Nov. to Mar. 2007 among treatments may have been due to the EDDHA-iron soil drench applied to all trees in the orchard (2 July 2006) prior to the initiation of treatments.

The oldest mature leaves, new flowers, and young fruit of trees treated with foliar acid plus iron abscised over a 7- to 10-d period after the first, second, and third foliar applications. Typically, carambola trees defoliate during the winter months in southern Florida and the rate of defoliation depends upon the duration and depth of cool non-freezing temperatures below about 18 °C (J.H. Crane, personal observation). However, no additional defoliation was observed after any subsequent foliar acid plus iron applications. No differences in time to flowering during the spring (April–May), flowering phenology, or emergence of new shoots and leaves among treatments were observed.

SPAD values of mature leaves were consistently greater than those of young leaves in both experiments (Table 2, Figs. 1 and 2). The significant difference in treatment effects between Expts. 1 and 2 may be due to cooler environmental conditions during the fall–winter–early spring (Expt. 2) as compared to the hot and humid conditions during the summer (Expt. 1). Previous research has demonstrated carambola leaf water potential and gas exchange decrease significantly during the cooler temperatures of fall, winter, and early spring compared to late spring and summer conditions (George et al., 2000, 2002).

These results along with preliminary positive results found during Summer 2006 and Spring 2007 of applying various weak acids plus iron and adjuvant foliarly to 'Arkin' carambola trees growing in oolitic limestone soil (B. Schaffer, unpublished data) suggest further investigation utilizing weak acids plus iron is warranted.

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