Proc. Fla. State Hort. Soc. 117:48-51. 2004.

THE INFLUENCE OF CALCIUM THIOSULFATE ON YIELD AND POSTHARVEST QUALITY OF 'SWEET CHARLIE' STRAWBERRY

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Additional index words. Fragaria × *ananassa*, fruit yield, strawberry post harvest

Abstract. **Strawberries (*Fragaria* × *ananassa* Duch.) are a high-value crop with a short postharvest life. Florida is a producer of fresh winter strawberries in the United States with 2,874 hectares of production. Supplemental calcium (Ca) is applied to various fruit crops to maintain or increase commodity quality. Many Florida strawberry growers apply supplemental Ca to their crop despite lack of conclusive evidence of an increase in berry quality or yield. Supplemental Ca applied to 'Sweet Charlie' as calcium thiosulfate during production may help increase its shelf life. The objectives of this study were to determine the effects of Ca supplied as calcium thiosulfate on yield, growth, and postharvest quality when applied supplemental to a grower's standard fertilization regime and as the sole source of calcium through fertigation. 'Sweet Charlie' strawberry plants were grown at the University of Florida, on Seffner fine sand at the Gulf Coast Research Education Center (GCREC) in Dover, Florida. Experimental design was a randomized complete block design with four replications. Treatments consisted of the Florida strawberry grower's standard fertilization [Ca $(NO_3)_2$] with and without calcium thiosulfate supplement, and no Ca $(NO_3)_2$ with and without calcium thiosulfate supplement. Yield data were collected twice weekly throughout the growing season. Fruit were graded for quality based upon size, disease incidence, frost/water damage, and misshapen form. Calcium content was determined for fruit during January, February, and March. Postharvest quality evaluations of pH, total titratable acidity, soluble solids content, and firmness were determined in March. For all measured variables, no significant interaction occurred between fertilizer and calcium thiosulfate**

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supplementation. Total culls for November was significantly reduced by calcium thiosulfate supplementation. All other variables were not significantly affected by calcium thiosulfate application or fertilization regime.

Florida is a producer of fresh winter strawberries with 2,874 hectares of production with a total value of US $136 million for the 2003 season (FASS, 2003). A typical Florida strawberry grower uses calcium nitrate [Ca $(NO_3)_2$] as their primary nitrogen source, which also provides calcium throughout the season. Florida has Karst typography, limestone bedrock, which can be a soluble calcium source. Therefore, soluble calcium is present in Florida well water. Many Florida strawberry growers apply additional calcium to their crop despite the lack of conclusive evidence of an increase in fruit quality or yield. The rationale for application of supplemental calcium comes from calcium's involvement in cell wall integrity and reduction of fruit quality when inadequately available at critical times.

Calcium has been extensively reviewed as both an essential element and with regard to its role in maintaining postharvest quality of fruit and vegetable crops. Calcium is well known for its role in membrane stability (Kirkby and Pilbeam, 1984). Calcium contributes to the linkages between pectic substances within the cell wall (Demarty et al., 1984). Postharvest improvement implications are that calcium maintained in relatively high concentrations in fruit tissue results in a slower rate of ripening, and reduced respiration, ethylene production and softening of fruit flesh (Ferguson, 1984). Calcium is mainly absorbed in the plant by young root tips and translocation is via the transpirational stream (Mengel and Kirkby, 1987). Applying preharvest calcium as a supplement to the root zone as part of a regular fertigation event may improve postharvest calcium content and quality of strawberry.

Results from preharvest applications of calcium to improve strawberry fruit yield and quality have been inconclusive. Eaves and Leefe (1962) found that a 0.4% foliar spray of calcium as calcium chloride increased firmness in strawberry fruit. This finding was supported by Canadian investigators Cheour et al. (1990; 1991), who found that calcium chloride delayed the ripening of strawberry fruit and mold development, but also increased firmness of fruit at harvest and during storage. However, Polish researchers Wojcik and Lewandowski (2003) found no significant effect of supplemental foliar calcium on observed yield or numbers of misshapen fruit, but did report favorable effects on fruit quality. In contrast, research conducted in Ohio, found that foliar applications of calcium chloride had no consistent effects on calcium content of fruit, yield, fruit firmness, soluble solids content, fruit acidity, and external color of fruit in field and greenhouse experiments (Erincik et al., 1998). Studies done in Arkansas further support the conclusion that foliar and soil application of supplemental calcium does not significantly increase postharvest quality or mineral distribution of calcium within strawberry fruit (Makus and Morris, 1989; 1998). It is hypothesized that supplemental calcium applied to the root system through the drip irrigation as calcium thiosulfate will increase calcium in fruit tissue and improve fruit quality. The objectives of this study were to determine the effects of Ca supplied as calcium thiosulfate on yield, growth, and postharvest quality when applied supplemental to a grower's standard fertilization regime and as sole source of calcium through fertigation.

Materials and Methods

Experimental design was a randomized complete block with two factors replicated four times. Each experimental unit measured 12.2 m (40 ft) long by 1.2 m (4 ft) wide. Fertilizer treatments were the grower's standard fertilization source of Ca $(NO_3)_2$ (5-0-7-3Ca -0S, Chemical Dynamics Plant City, Fla.) or a no calcium fertilization source (6-0-6-0Ca-0S, Dyna-Flo, Chemical Dynamics Plant City, Fla.) with or without calcium thiosulfate supplement (0-0-0-6Ca-10S, ThioCal, Best Sulfur Products, Fresno, Calif.) of 46.7 L ha^{-1} per week (5 gal $acre^{-1}$ per week). Fertilization regime for N-P-K and irrigation were managed in accordance to IFAS recommendations for strawberry in the Florida Vegetable Production Guide (Simonne et al., 2003).

Soil was fumigated to industry standards with 381.7 kg ha^{-1} of a 67:33 methyl bromide-chloropicrin mixture. Plants were grown in double row culture with beds set 1.2 meters (4 ft) on center. Transplants were 'Sweet Charlie' obtained from a Nova Scotia nursery and planted 3 Oct. 2003. 'Sweet Charlie' strawberry was chosen because it produces soft fruit with short shelf life and is grey mold (*Botrytis cinerea*) susceptible in the field. Overhead irrigation was applied for 10 d to reduce heat stress during crop establishment. Runner removal was performed "as needed" during the season. All other crop maintenance was conducted according to IFAS recommendations (Simonne et al., 2003).

Yield data were collected from a 12-plant harvest plot. Fruit were harvested when they were at least 80% ripe. Quantification of harvest was measured by total yield (flats per hectare), total number of fruits from each treatment, and quality (marketable or cull). Marketable fruit were >10 g and free of visible defects. Culls were determined upon visual inspection and separated based upon pathological infection, size, misshapedness, or water damage.

Ten marketable size and 80% ripe fruit were randomly collected from each experimental unit's postharvest plot on 5 Jan., 28 Feb., and 15 Mar. 2004. Calyces were collected and replications combined to create a tissue sample as done by Albregts and Howard (1978). All samples were dried at 70 °C in a forced-air dryer. Once dried, fruit samples were ground with a coffee grinder and calyx samples were ground using a Foss Tecator Cyclotec Sample Mill (Sweden). The samples were sent to Micro Macro International in Athens, Ga. for calcium content determination.

Fruit selected for destructive mechanical resistance measurement were as uniform in color and size as possible, being at least 10 g in weight. On 11 Mar. 2004, fruit were harvested from each experimental unit and placed into 0.9 kg hinged clamshell containers, then transported to the Postharvest Horticulture Laboratory, University of Florida, Gainesville for measurements. Each sample consisted of 10 fruit selected from the collected population representing each experimental unit. Samples were stored in a 1 °C cooler for a maximum time interval of 2 h until the destructive test was performed. Preparation consisted of slicing each fruit into a 11 mm equatorial section at room temperature (approx. 22 °C). Each slice was orientated posterior end up for mechanical resistance measurement. The destructive mechanical resistance measurements were taken using a penetrometer (Instron Universal Testing Instrument, Model 4411) with a 5 kg load cell with a 4 mm convex probe to an end point of 7 mm with a cross head speed of 50 mm·min^{-1}. Two measurements were taken within the cortex tissue of each

Table 1. Monthly totals of flats per hectare of 'Sweet Charlie' strawberry grown at Dover-GCREC 2003-04 season.

Treatment	Total (flats/ha)	November (flats/ha)	December (flats/ha)	January (flats/ha)	February (flats/ha)	March (flats/ha)
Fertilizer						
Calcium nitrate	4,174	529	201	64	2,013	1,365
No calcium	4,814	583	214	149	2,287	1,579
Significance[z]	NS	NS	NS	NS	NS	NS
Supplement						
ThioCal	4,686	564	199	88	2,265	1,568
No ThioCal	4,302	549	216	125	2,035	1,375
Significance[z]	NS	NS	NS	NS	NS	NS
CV	97	28	39	71	29	18

[z]Significance: NS = no significance, * = $p < 0.05$.

fruit slice. Measurements in which the tissue pushed out the side of the epidermis during deformation were removed from the data set. Maximum load measurement (bioyield point) was used to determine texture of each sample.

Postharvest quality assessments of pH, titratable acidity, and soluble solids were conducted upon frozen fruit. Fruit were collected randomly from each experimental unit on 5 Mar. and 20 Mar. 2004. Samples were thawed at room temperature (approx. 22 °C) before homogenization in a Waring blender, centrifuged (2576 g_n for 40 min) and filtered with cheesecloth. The filtered supernatant was used for all postharvest quality assessments. The pH was directly measured from the sample of supernatant using a Corning 140 pH meter, standardized with pH 4.0 and 7.0 buffer solutions. A sub-sample of 6 g of supernatant plus 50 mL of diH_2O was used for titratable acidity measurements on a Fisher Electrode meter (model 380), Burette/Dispenser (model 395), Titrate Demand (model 381) using 0.1 N NaOH. All measurements were adjusted to reflect percent citric acid. Soluble solids content was measured using an ABBE Mark II Digital Refractometer as °Brix. A sub-sample of two drops was used on the prism to determine soluble solids content.

All statistical analysis was performed using a general linear model in SAS (Version 9.0) with Tukey's Studentized Range Test for mean separation.

Results and Discussion

For every variable measured, no significant interaction between fertilizer and calcium thiosulfate supplementation was evident (data not presented). Therefore, data will be discussed based upon the significance of the treatments. Total yield and monthly totals for yield were not significantly different among treatments (Table 1). These results are similar to previous results measuring yield as affected by additional calcium (Erincik et al., 1998; Wojcik and Lewandowski, 2003). Total culls were not significantly reduced by calcium thiosulfate treatments (Table 2). Monthly totals for culls were significantly affected by calcium thiosulfate for only November (Table 2). All other monthly and total cull values were not significantly affected by treatments (Table 2). It is not clear why a reduction of culls for calcium thiosulfate application occurred for this month alone. There was no increase in yield corresponding to the reduction in culls for this month. Previous studies focused upon certain aspects of culled fruit either grey mold infection or malformation. No other study with supplemental calcium on strawberry evaluated total culls. Previous studies found reduction in fruit with grey mold during storage or at harvest (Cheour et al., 1990, 1991; Wojcik and Lewandowski, 2003). Therefore, it can only be hypothesized that as the season progressed to higher output, any benefit to reduce total culls by a calcium thiosulfate application was negated by the environment.

The total number of culls affected by visible grey mold development was not significantly affected by calcium thiosulfate application for the season or monthly totals. Visible grey mold development, however, was significantly reduced by $Ca(NO_3)_2$ treatment for the month of March (Table 3). These results confirm results from studies conducted in Arkansas, Canada, and Poland that found similar results for reduction of grey mold formation during storage and at harvest (Cheour et al.,

Table 2. Monthly totals for number of culls per hectare of 'Sweet Charlie' strawberry grown at Dover-GCREC 2003-04 season.

Treatment	Total (no./ha)	November (no./ha)	December (no./ha)	January (no./ha)	February (no./ha)	March (no./ha)
Fertilizer						
Calcium nitrate	325,030	13,177	23,609	23,060	163,613	101,572
No calcium	345,345	9,883	27,452	30,746	168,555	108,709
Significance[y]	NS	NS	NS	NS	NS	NS
Supplement						
ThioCal	348,090	6,588 b	26,903	26,354	176,241	112,004
No ThioCal	322,285	16,471 a	24,158	27,452	155,927	98,278
Significance[yz]	NS	*	NS	NS	NS	NS
CV	98	73	56	60	12	41

[y]Significance: NS = no significance, * = $p < 0.05$.
[z]Mean separation by Tukey's Studentized Range Test.

Table 3. Monthly totals for number of culls with visible Botrytis symptoms per hectare of 'Sweet Charlie' strawberry grown at Dover-GCREC 2003-04 season.[x]

Treatment	Total (no./ha)	November (no./ha)	December (no./ha)	January (no./ha)	February (no./ha)	March (no./ha)
Fertilizer						
Calcium nitrate	1,200	274	0	0	384	543 b
No calcium	1,630	0	0	0	378	1251 a
Significance[yz]	NS	NS	NS	NS	NS	*
Supplement						
ThioCal	1,650	274	0	0	433	944
No ThioCal	1,180	0	0	0	329	851
Significance[y]	NS	NS	NS	NS	NS	NS
CV	152	400	0	0	53	43

[x]Data presented as untransformed means.
[y]Significance: NS = no significance, * = $p < 0.05$.
[z]Mean separation by Tukey's Studentized Range Test.

1990; Makus and Morris, 1989; Wojcik and Lewandowski, 2003). Postharvest quality was not significantly affected by calcium thiosulfate (Table 4). These results are consistent with previous studies with soil and/or foliar applied calcium treatments (Erincik et al., 1998; Markus and Morris, 1989). Calcium concentration within fruit was not significantly affected by calcium thiosulfate applications (Table 5). These results are consistent with the Arkansas studies findings of no significant distribution or increase of calcium in fruit with supplemental calcium (Markus and Morris, 1989; 1998). Soil samples taken in late February; showed no significant difference in calcium content among treatments (data not presented).

The benefit of applying supplemental calcium as calcium thiosulfate is minimal at best. Further investigation could be suggested in the area of monthly culls in comparison to monthly yield, but additional rates and sources may be needed to expand the possible benefit that could be gained from an early season reduction in culls.

Table 4. Postharvest quality of 'Sweet Charlie' strawberry grown at Dover-GCREC 2003-04 season.

Treatment	Total titratable acidity (% citric acid)	Soluble solids content (°Brix)	pH	Firmness (N)
Fertilizer				
Calcium nitrate	6.14	5.6	3.63	0.51
No calcium	6.05	5.4	3.62	0.53
Significance[z]	NS	NS	NS	NS
Supplement				
ThioCal	6.25	5.6	3.62	0.53
No ThioCal	5.93	5.3	3.63	0.51
Significance[z]	NS	NS	NS	NS
CV	7	14	1	24

[z]Significance: NS = no significance, * = $p < 0.05$.

Table 5. Calcium concentration within fruit of 'Sweet Charlie' strawberry grown at Dover-GCREC 2003-04 season.

Treatment	5 Jan. (mg/kg)	28 Feb. (mg/kg)	15 Mar. (mg/kg)
Fertilizer			
Calcium nitrate	2,145	2,682	2,370
No calcium	2,095	2,683	2,395
Significance[z]	NS	NS	NS
Supplement			
ThioCal	2,106	2,574	2,479
No ThioCal	2,135	2,591	2,286
Significance[z]	NS	NS	NS
CV	7	9	7

[z]Significance: NS = no significance, * = $p < 0.05$.

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