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Interactions of Ethylene, Temperature, Light, and CO_2 on Leaf and Stipule Abscission and Chlorosis in *Philodendron scandens* subsp. *oxycardium*[1]

F. J. Marousky[2] and B. K. Harbaugh[3]

U. S. Department of Agriculture, Science and Education Administration, Agriculture Research, and University of Florida, Agricultural Research and Education Center, Bradenton, FL 33508

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Abstract. **Plants of *Philodendron scandens* subsp. *oxycardium* (Schott) Bunt. were exposed to ethylene-air mixtures at various temperatures and levels of light and CO_2. Plants held in ethylene (2.5 to 10 μl/liter air) abscised leaves and stipules, developed chlorotic foliage, and grew poorly. As the levels and duration of exposure to ethylene increased, the rate of leaf abscission increased. Plants exposed to 5 μl ethylene/liter air at 23.5°C for 3 days in light abscised more than 50% of their leaves, whereas plants similarly handled but held in darkness lost 20%. At a given level of ethylene, the lower the temperature the fewer the number of leaves abscised. Plants held at 27° at 10 μl/liter air had total leaf abscission. Plants held in ethylene with 5% CO_2 or with lanolin-coated leaves abscised fewer leaves than plants without added CO_2 or non-coated leaves.**

The production of tropical ornamental foliage plants in the United States has increased dramatically in the last few years. About 40% of the plants are grown in Florida, packaged and transported to northern and midwestern markets via truck. Plants may deteriorate severely during transit; abscission, chlorosis, desiccation have been reported (3, 9, 11). Deterioration symptoms typically occur when plants are packaged for lengthy periods in darkness, transit temperatures reach high levels, or are not controlled (2). Few guidelines outlining handling and transportation of tropical ornamental foliage plants are available (2).

Ethylene is implicated in this deterioration; its deleterious effects on cut flowers and ornamental plants are well documented (1, 5, 6, 12, 13). However, few studies have examined the effects of ethylene on plants during actual or simulated transit.

In early studies, Milbrath et al. (10) showed that ethylene could be used to defoliate rose plants without any adverse effects on growth. Later, Kays et al. (9) demonstrated that pepper seedlings sealed in containers emanated enough ethylene during 24 hr to cause autocatalytic defoliation. Cunningham and Staby (3) showed that ethylene injected into airtight containers holding ornamental lime plants caused serious leaf and fruit abscission. Heck and Pires (8) reported that *Philodendron cordatum (Philodendron oxycardium)* exposed to ethylene abscised more leaves, initiated fewer leaves, grew poorly and recovered more slowly than unexposed plants. Harbaugh et al. (7) showed that ornamental plant species sealed in polyethylene packages had flower and leaf abscission and greater chlorosis than unpackaged plants. Although they did not measure ethylene levels, their data suggest that ethylene build-up caused the abscission.

Plant deterioration in transit has been related directly to high temperature. Halevy and Kofranek (4) demonstrated that high temperature induced flower bud and leaflet abscission in potted roses held in simulated shipping conditions with negligible ethylene concentrations. However, other workers have found that temperature affects the activity of ethylene (1). Zimmerman et al. (14) reported that ethylene-induced leaf abscission in rose plants varied with age of the leaf, ethylene concentration, temperature, duration of exposure, and cultivar. They reported no ethylene injury when temperature was below 10°C. Milbrath and Hartman (11) showed that ethylene stimulated abscission in English holly. By controlling storage temperature and using fresh air and naphthalene acetic acid, they succeeded in preventing defoliation of packaged holly.

In this paper, we report the influence of interactions of ethylene and environmental factors (temperature, light, and CO_2) on leaf and stipule abscission and chlorosis in *Philodendron scandens* subsp. *oxycardium* under simulated transit conditions.

Methods and Materials

Ethylene-air mixtures. Standard cylinders for compressed gas (0.23 × 1.3 m) were charged with air to 70 kg/cm^2 (1000 psi). The compressed air was slowly released through a standard wet test gas meter at 23°C. Air volume at atmospheric pressure was calculated using the above figures. After cylinders were evacuated, the outlet valve was closed and fitted with a rubber septum. Pure grade ethylene in gas-tight syringes was introduced into the cylinder via the septum, and the cylinder valve was then opened. The higher pressure of the atmosphere pushed the syringe barrel closed and released the ethylene into the evacuated cylinder. The cylinder was brought up to ambient air pressure with fresh air and then charged to 70 kg/cm^2 with compressed air. Since the initial cylinder gas volumes were known, a specific concentration of ethylene in microliters per liter air could be made. Cylinders were charged on a manifold system equipped with Heise-Bourdon gauges. Charged cylinders were allowed to stand overnight. Air-ethylene mixtures, when sampled and analyzed using gas chromatography, were within 2-5% of calculated levels.

Gas-distribution chambers. Gas mixtures were released from each cylinder using two-stage valves at 0.35 kg/cm^2 above atmosphere pressure. Gases were distributed via tygon tubing to glass chambers (pyrex battery jars 30 cm diameter × 30 cm height with 38 cm square tops of clear acrylic plastic). Gas flow was controlled at each chamber to provide a change of air every 40-45 min. Tops were sealed to jars with neoprene gaskets and bolted to wooden bases and were fitted with brass bulkhead fittings. Gases inside the chambers were distributed via tygon tubing (6 mm) in which capillary holes were cut and ends were sealed. Similar tubes were used for exhausting gases. A 1-m piece of tubing was connected at the outside exhaust port. This dynamic flow system allowed complete movement and exchange of air mixtures without buildup or depletion of

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[2]Research Horticulturist.

[3]Ornamental Horticulturist.

any one gas. Three chambers were used for each ethylene level, and 2 or 3 plants for each chamber. Controls were held in flowing air.

Temperature. All tests were performed in laboratory held at 23.5±1°C. When temperature was an experimental variable, chambers were placed in an incubator controlled to ±0.5° of test values. Light in the laboratory was supplied by Cool White fluorescent tubes for 12 hr daily. Illuminance, measured at chamber height was 1.5 klx. No lights were used on plants held in incubators. Relative humidity in the chambers was not controlled or measured but moisture collected on the inside of chamber walls.

Plant material. Philodendron scandens subsp. *oxycardium* plants in 7.5 cm pots were grown at the Agricultural Research and Education Center or obtained from commercial sources. At the beginning of each experiment, a group of plants were selected for uniformity in leaf number and quality. Leaf blades and stipules were counted before and after plants were exposed to ethylene. Blades are referred to as leaves. Stipules refer to the light green appendage at the base of the petioles. After ethylene treatments, plants were placed in a greenhouse (minimum 21°C) and observed for 1 to 10 days.

Results

Plants were exposed to 0, 1, 5, or 10 µl ethylene/liter of air for 2, 3, and 4 days at 23.5°C in light (Table 1). Plants exposed to 1 µl ethylene for 2 to 3 days did not abscise any leaves while plants held for 4 days abscised 4% of their leaves. Plants held at 5 µl for 3 or 4 days or plants held at 10 µl for 2 or more days abscised 50% or more of their leaves. Few additional leaves abscised after plants were removed from ethylene atmospheres. Plants held in air did not lose any leaves.

Plants were held in light at 23.5°C in either 2.5 µl ethylene/liter air for 2, 3, or 4 days or 5 µl ethylene/liter air for 2 or 3 days (Table 2). Control plants were held for 4 days in flowing air. Plants exposed to 2.5 µl ethylene/liter air for 2 or 3 days abscised few leaves whereas plants exposed for 4 days abscised about 35% of their leaves. Plants exposed to 5 µl ethylene/liter air for 2 or 3 days abscised 43 and 85% of their leaves, respectively. Few additional leaves abscised after plants were removed from chambers. Plants exposed to 2.5 µl ethylene/liter air devloped chlorotic leaves 3 to 7 days after plants were removed from chambers and placed in the greenhouse. Plants held in chambers without ethylene did not lose any leaves or become chlorotic.

Table 1. Leaves abscised in *Philodendron scandens* subsp. *oxycardium* exposed to ethylene for 2, 3, or 4 days at 23.5°C in light.[z]

Ethylene level (µl/liter)	Exposure time (days)	Leaf abscission: After exposure (no.)	After exposure (%)	1 day after exposure (no.)	1 day after exposure (%)
0	2	0[y]	0	0[y]	0
1	2	0	0	0	0
5	2	1.0	18	1.3	24
10	2	4.3	54	5.3	76
0	3	0	0	0	0
1	3	0	0	0	0
5	3	4.0	56	4.7	65
10	3	3.7	61	4.3	74
0	4	0	0	0	0
1	4	0	0	0.3	4
5	4	4.6	60	5.6	76
10	4	6.0	82	6.0	82

[z]1.5 klx light for 12 hr/day.

[y]Ethylene main effects significant at the 1% level; ethylene × time interaction significant at the 5% level.

Plants were held in the laboratory in 0, 1 or 5 µl ethylene/liter air for 3 days in light at 23.5°C (Table 3). A control group of plants was held in the greenhouse (minimum night temperature 21°) for 3 days. After exposure to ethylene, all plants were placed in a greenhouse for 3 weeks. Before and 3 weeks after exposure, stem length and plant dry weights were measured. Plants were severed at soil surface and leaves and stems were dried to constant weight at 70°.

Growth of plants held in the laboratory or in the greenhouse was similar (Table 3). Plants held in 1 µl ethylene/liter air abscised few leaves but did develop chlorotic foliage. A significant amount of chlorosis occurred in the greenhouse-grown plants only after exposure to ethylene. Plants held in 5 µl ethylene/liter air had severe leaf abscission, developed chlorotic foliage and grew poorly.

Plants were held in air or 5 µl ethylene/liter air in light or darkness for 3 days at 23.5°C (Table 4). Plants held in ethylene in light abscised more leaves and stipules than plants held in ethylene in darkness. Plants held in light or darkness in air did not abscise any leaves.

Plants were held in chambers in air or 5 µl ethylene/liter air at 16 or 23.5°C for 3 days in darkness (Table 5). Plants held in ethylene at 23.5° abscised 28% of their leaves. Plants held at 16 or 23.5° in air did not abscise any leaves. A few leaves abscised from plants held at 16° in ethylene but the difference was not significant compared to plants held in air. A few stipules abscised from these plants, but more abscission occurred in plants held at 23.5° in ethylene.

Plants were held in chambers in air or 10 µl ethylene/liter air at 16 or 27°C for 2 or 3 days in darkness (Table 6). Plants held in 10 µl ethylene/liter air for 3 days at 16 and 27° abscised 70% and 100% of their leaves, respectively. Plants held in 10 µl ethylene/liter air at 27° for 2 days abscised 57% of their leaves whereas plants held at 10 µl at 16° did not abscise any leaves. Plants held at 10 µl ethylene for 3 days at 27° abscised more stipules than plants held at 10 µl ethylene for 2 days. Plants held at 16° and 27° in air for 3 days and at 16° in ethylene for 2 and 3 days had little stipule abscission.

Plants were held in chambers in one of the following gas mixtures: 1) air, no ethylene or CO_2 added, 2) no ethylene, 5% CO_2 added, 3) 5 µl ethylene/liter air, no CO_2 added, and 4) 5 µl ethylene/liter air + 5% CO_2 added. Ambient CO_2 in air was 300-375 ppm (Table 7). Plants were held in these gas mixtures for 2 days at 23.5°C in light. Plants held in air or air containing 5% CO_2 did not abscise any leaves or stipules (Table 7). Plants held in 5 µl ethylene abscised more leaves than plants held in 5 µl ethylene + 5% CO_2. Leaves on plants held in ethylene with or without 5% CO_2 became chlorotic whereas leaves on plants exposed to air or 5% CO_2 retained

Table 2. Leaves abscised in *Philodendron scandens* subsp. *oxycardium* exposed to 2.5 or 5 µl ethylene per liter of air for 2, 3, or 4 days at 23.5°C in light.[z]

Ethylene level (µl/liter)	Exposure time (days)	Leaf abscission: After exposure (no.)	After exposure (%)	1 day after exposure (no.)	1 day after exposure (%)
0	4	0c[y]	0	0c	0
2.5	2	0.2c	1	0.2c	1
2.5	3	0c	0	0.3c	5
2.5	4	2.5b	35	3.3b	47
5.0	2	4.7b	43	6.7a	61
5.0	3	8.0a	85	8.3a	89

[z]1.5 klx light for 12 hr/day.

[y]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 3. Leaf abscission, chlorosis and growth of *Philodendron scandens* subsp. *oxycardium* exposed to ethylene for 3 days at 23.5°C in light.[z]

Ethylene level (μl/liter)	Leaf abscission (no.)		Chlorotic leaves 2 days after exposure (no.)	Growth 3 wks after exposure	
	After exposure (no.)	2 days after exposure (no.)		Increase in stem length (cm)	Dry weight (g)
0 (greenhouse, control)	0a[y]	0a	0.3a	20.9a	4.0a
0 (laboratory control)	0a	0a	0.2a	20.8a	4.6a
1	0.1a	0.8a	6.6c	17.0a	3.3ab
5	6.5b	9.4b	2.2b	7.2b	1.8b

[z]1.5 klx light for 12 hr/day.

[y]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 4. Leaves and stipules abscised in *Philodendron scandens* subsp. *oxycardium* exposed to ethylene in light and darkness for 3 days at 23.5°C.

Light[z]	Ethylene level (μl/liter)	Leaf abscission						Stipule abscission (no.)		
		After exposure		1 day after exposure		3 days after exposure		After exposure	1 day after exposure	3 days after exposure
		(no.)	(%)	(no.)	(%)	(no.)	(%)			
Darkness	0	0[y]	0	0[y]	0	0[y]	0	0[x]	0[x]	0[x]
Light	0	0	0	0	0	0	0	0.2	0.2	0.2
Darkness	5	0.3	5	1.0	19	1.3	21	1.2	1.2	1.7
Light	5	2.7	41	3.3	57	4.0	70	1.8	2.2	2.3

[z]1.5 klx light for 12 hr/day.

[y]Ethylene main effects significant at the 1% level; ethylene x light interaction significant at the 5% level.

[x]Ethylene main effects significant at the 1% level; ethylene x light interaction not significant.

Table 5. Leaves and stipules abscised in *Philodendron scandens* subsp. *oxycardium* exposed to ethylene for 3 days at 16 and 23.5°C in darkness.

Ethylene level (μl/liter)	Temp (°C)	Leaf abscission				Stipule abscission (no.)	
		After exposure		1 day after exposure		After exposure	1 day after exposure
		(no.)	(%)	(no.)	(%)		
0	16	0[y]	0	0[x]	0	0[y]	0.2[x]
5	16	0	0	0.7	9	0	1.0
0	23.5	0	0	0	0	0	0.3
5	23.5	0.7	10	1.7	28	1.8	1.8

[y]Ethylene and temperature main effects significant at the 1% level; ethylene x temperature interaction significant at the 1% level.

[x]Ethylene main effects significant at 5% level; temperature main effects and ethylene x temperature interaction not significant.

Table 6. Leaves and stipules abscised in *Philodendron scandens* subsp. *oxycardium* exposed to ethylene for 2 and 3 days at 16 and 27°C in darkness.

Ethylene level (μl/liter)	Exposure time (days)	Temp (°C)	Leaf abscission				Stipule abscission (no.)	
			After exposure		1 day after exposure		After exposure	1 day after exposure
			(no.)	(%)	(no.)	(%)		
0	3	16	0a[z]	0	0a	0	0a	0.5a
10	2	16	0a	0	0a	0	0.3a	0.5a
10	3	16	1.7b	23	3.8b	70	0.2a	0.7a
0	3	27	0a	0	0a	0	0a	0.2a
10	2	27	4.0c	48	4.8c	57	2.3b	2.3b
10	3	27	8.3d	100	8.3d	100	3.0c	3.0c

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 7. Leaves and stipules abscised and chlorotic leaves in *Philodendron scandens* subsp. *oxycardium* exposed to ethylene and 5% carbon dioxide for 2 days at 23.5°C in light.[z]

Ethylene level (μl/liter)	Added carbon dioxide (%)	Initial leaves (no.)	Leaf abscission (no.)		Stipule abscission (no.)		Chlorotic leaves 7 days after exposure (no.)
			After exposure	3 days after exposure	After exposure	3 days after exposure	
0	0	4.8	0[y]	0[y]	0[y]	0[y]	0[x]
0	5	4.7	0	0	0	0	0
5	0	4.5	0.5	2.2	2.5	2.7	2.0
5	5	4.7	0	0.2	1.2	1.7	2.7

[z]1.5 klx light for 12 hr/day.

[y]Ethylene and CO_2 main effects significant at 5% level; ethylene x CO_2 interaction significant at the 5% level.

[x]Ethylene main effects significant at 1% level, CO_2 main effects and ethylene x CO_2 interaction not significant.

Table 8. Leaves and stipules abscised in *Philodendron scandens* subsp. *oxycardium* coated with lanolin and exposed to ethylene for 3 days at 23.5°C in light.[z]

Lanolin coating	Ethylene level (μl/liter)	Leaf abscission (no.)		Stipule abscission (no.)	
		After exposure	2 days after exposure	After exposure	2 days after exposure
No	0	0[y]	0[y]	0[x]	0[x]
Yes	0	0	0	0	0
No	5	3.8	4.2	2.1	2.3
Yes	5	1.5	3.2	2.0	2.3

[z]1.5 klx light for 12 hr/day.

[y]Ethylene and coating main effects significant at the 1% level; ethylene x coating interaction significant at the 1% level.

[x]Ethylene main effects significant at the 1% level, coating main effects and ethylene x coating interaction not significant.

their green color. Plants held in ethylene without CO_2 abscised more stipules than plants held in ethylene with CO_2.

Leaves on one group of plants were coated with lanolin, and those on another group of plants were left untreated. Both groups were placed in the chambers and exposed to air or 5 μl ethylene/liter air for 3 days at 23.5°C in light. Lanolin coating had no effect on leaf or stipule abscission when plants were held in air (Table 8). Greater leaf abscission occurred in plants exposed to ethylene that were not coated with lanolin than in those that were coated. Similar numbers of stipules abscised on plants with coated and uncoated leaves when exposed to ethylene.

Discussion

The observations in the experiments show that exogenous ethylene is damaging to plants of *Philodendron scandens* subsp. *oxycardium*. Typical observed symptoms of ethylene toxicity included leaf and stipule abscission and leaf chlorosis. Their incidence varied with the level and length of exposure to ethylene (Tables 1, 2, 5 and 6), temperature (Tables 5 and 6) and levels of light and CO_2 (Table 4 and 7).

Plants exposed to 5 μl ethylene/liter air at 16°C had little leaf abscission or injury whereas plants exposed to the same concentrations of ethylene at 23.5° or higher were severely injured. At 16°, plants are apparently above chilling level but below optimum temperature for the physiological activity of ethylene (1). Our observations are similar to those of Milbrath and Hartman (11) and Zimmerman et al. (14) who found that ethylene caused little or no leaf abscission at low temperatures. Control plants exposed to air for 3 days at 27° in darkness had no visible signs of injury (Table 6), suggesting that physiological damage in *Philodendron scandens* subsp. *oxycardium* is not due directly to elevated temperatures during shipping but rather to the greater physiological activity of ethylene at these elevated temperatures.

Our results also showed that high concentrations of CO_2 (5%) inhibited the action of ethylene. Similar inhibition of ethylene activity by CO_2 has been demonstrated with cut flowers, fruits, and vegetables (1, 5, 6). Although we cannot fully explain how CO_2 inhibits ethylene activity, stomatal closure may be a factor. At high levels of CO_2 stomata are almost closed; thus decreasing the absorption of exogenous ethylene. In our experiments, plants exposed to ethylene in light had greater leaf abscission than plants exposed in the dark (Table 4). Typically, stomata are closed in the dark. Leaves coated with lanolin, which blocks stomata, abscised fewer leaves than uncoated leaves when exposed to equal concentrations of ethylene (Table 8).

In commercial practice, plants can arrive at their destination with no visible symptoms of deterioration and yet develop chlorosis or abscise leaves within a few days. Our results suggest that an ethylene exposure can predispose a plant to deterioration (Tables 3 and 7).

Our data have implications for handling plants by growers and shippers. Our observations suggest that plants should arrive at their destination with maximum quality if plants are packaged for as little time as possible and exogenous ethylene is prevented from entering the package or transit environment. Our data also suggest that maintaining low temperature (but above the chilling level) would minimize the physiological activity of exogenous ethylene.

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Effects of Stage of Maturity, Storage, and Cultivar on Some Quality Attributes of Tomatoes[1]

Ali M. H. Al-Shaibani and J. K. Greig[2]
Department of Horticulture, Kansas State University, Manhattan, KS 66506

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Abstract. **Fruits of tomato (*Lycopersicon esculentum* Mill cvs. Jet Star and Floramerica) were harvested at various maturity stages and ripened at 20°C and 80% relative humidity. Differences in pH between field-ripened and storage-ripened fruits of either cultivar were not significant. Ascorbic acid of 'Jet Star' fruits increased slightly during ripening both on and off the plant; 'Floramerica' fruits showed no changes in ascorbic acid content during ripening. Field-ripened fruits had significantly higher ascorbic acid than storage-ripened fruits. The β-carotene content significantly increased with ripening for both cultivars, with no significant differences between field- and storage-ripened fruits. Fruits of 'Jet Star' contained more β-carotene than 'Floramerica' fruits. Total sugars increased during ripening up to the firm ripe stage. Total sugar content of field-ripened fruits was significantly higher than storage-ripened fruits in 'Jet Star' but not in 'Floramerica'. Fruits harvested in the breaker stage retained the highest total sugar content during storage.**

The quality of fresh tomatoes available in markets has been a concern of retailers and consumers. McCollum and Skok (15) reported that tomatoes harvested in the mature green stage and ripened in storage would have poorer quality than fruits ripened on the plant. Recently, Kader et al. (7) reported that tomatoes picked at earlier stages of ripeness and ripened at 20°C were evaluated as being less sweet, more sour, less "tomato-like" and having more "off-flavor" than those picked at the table-ripe stage. Many studies have shown that factors such as cultivar (10), harvest date (9), and stage of ripeness (5) influence pH values in tomato fruits, but that sunlight exposure and post-harvest storage temperature did not. However, Lambeth et al. (9) and Lower and Thompson (10) reported that field-ripened fruits had a higher pH than chamber-ripened fruits. Hanna (5) found a difference in pH between cultivars. The pH is highest just after fruit set, decreases as the fruit grows, is lowest at the breaker stage, and increases slightly as the fruit ripens.

Wokes and Organ (21) showed that tomatoes harvested green and ripened at room temperature in sunlight and field-ripened fruits contained similar ascorbic acid contents but the content was appreciably lower in fruits ripened in the dark at room temperature. An apparent increase in ascorbic acid associated with tomato fruits maturing was shown (4, 12). However, Maclinn et al. (11) reported that stage of ripeness had no effect on ascorbic acid content. Bisogni et al. (2) and Kays (8) reported a remarkably uniform loss of ascorbic acid from tomatoes ripening in storage.

McCollum (14) reported that β-carotene content of tomato fruits ripened at a constant temperature (23.9°C) under sufficient light had higher carotene contents than those ripened in the dark at the same temperature. Watada et al. (19) indicated that differences in Vitamin A activity were wider among cultivars than among ripeness stages. Meredith and Purcell (16) reported that β-carotene content of green 'Homestead' tomatoes increased through all stages of maturity to the light red, then decreased. Watada et al. (19) reported that tomatoes ripened on the plant had significantly higher average β-carotene content than those ripened after harvesting.

Numerous studies dealing with soluble solids (60% sugar) have been reported. Winsor et al. (20) stated that total sugars in the expressed juices increased significantly from the mature green to the red ripe stage, but decreases once the fruit has begun to color.

The objectives of this study were to compare pH, ascorbic acid, β-carotene, and total sugar of storage-ripened with field-ripened tomatoes, and to determine compositional attributes of 2 cultivars primarily grown for local marketing.

Materials and Methods

'Jet Star Hybrid' and 'Floramerica Hybrid' tomato plants were grown at Ashland Horticultural Farm, Kansas State University, during the summer of 1977 using conventional cultural practices. Both cultivars were harvested at:

1. *Mature green,* a completely green skin that will turn red either on or off the vine.
2. *Breaker,* primarily green with a tinge of yellow or pink, usually at the blossom-end.
3. *Pink,* 50% or more pink or red skin.
4. *Firm ripe,* fully red but firm.
5. *Overripe,* fully red, but soft.

Fifteen fruits of each cultivar at each stage were selected for chemical analyses. Then 3 replicates of 5 fruits each were picked at random from the 15 fruits. Fruits of each sample were quartered so a portion from each could be used in chemical analyses.

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[2]Graduate student in Food Science and research horticulturist, respectively.