at which it burns cannot be changed. Most of the heat is released in the first 4 hours. After this the protection is very small even though hot, glowing embers remain. If temperatures remain below damaging levels for more than 4 hours, 2 lightings will be required. Once Tree Heet is lit, it cannot be extinguished. Conventional oil fired heaters can be regulated, extinguished and they will burn for 8 hours.

The cost of Tree Heet is greater than oil if more than 8 hours of heating are required per year.

Tree Heet has been used successfully as a supplement to wind machines (5) and can be used in conjunction with other heaters. It is very clean burning and no residue is left in the field to be removed after heating.

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EFFECT OF CHILLING ON ETHYLENE PRODUCTION, SENESCENCE, AND ABSCISSION IN LEAVES OF EVERGREEN AND DECIDUOUS FRUIT TREES

W. C. Cooper and P. C. Reece

Agricultural Research Service
U. S. Department of Agriculture
Orlando

Abstract

Ethylene production induced by chilling and related to the development of senescence and leaf fall were similar in the leaves of the deciduout trifoliate orange and peach. The exact timing of increased ethylene production in relation to development of senescence is not clear in these experiments, although they occurred close together. Chilling did not promote ethylene production nor senescence in the leaves of the evergreen trees. The low levels of ethylene detected in the leaves of the evergreen plants may be largely a wound effect from detaching the leaves from the stems.

Introduction

In evergreen trees we have progressive or sequential senescence in which the lower leaves senesce first, and more leaves entering senescence as new leaves develop at the apex. If senescence and growth proceed at the same pace, the plant may always bear the same number of leaves as it grows.

In deciduous trees all the leaves develop typical coloring and abscission coincident with the onset of chilling temperatures in the autumn. This synchronous senescence is so distinct in timing and control from sequential senescence in evergreen trees as to suggest some basic difference in the process.

It has long been known that ethylene causes leaf abscission (4). Recently, Cooper et al. (3) reported increased ethylene production by leaves of the deciduous trifoliate orange (*Poncirus trifoliata* Raf.) at the onset of cool nights in the late autumn. The present paper describes experiments in which ethylene production was measured in several deciduous and evergreen fruit trees subjected to various chilling temperatures in programmed climate chambers.

Methods and Materials

These studies involved the following plants: 'Maygold' peach (*Prunus perisica* L.), 'Haden' mango (*M. indica* L.), 'Keitt' mango (*F. indica* L.), 'Brogden' Mexican race avocado (*Persea americana* Mill.), 'Lula' West Indian X Guatemalan race hybrid avocado (*P. americana* Mill.), 'Brewster' lychee (*Litchi chinensis* L.), 'Rough' lemon (*Citrus limon* [L.] Burm. f.) and 'Towne' trifoliate orange (*Poncirus trifoliata* Raf.). The Maygold peach trees, grafted on Nemaguard rootstock purchased from Haley Nursery Company,* were transplanted into 5-gal cans. The Rough lemon and trifoliate oranges grew as seedlings in 1-gal cans. The lychee plants were rooted cuttings and the avocado and mango plants were grafted onto rootstocks: all except the Brogden avocado were 3-years old, grown in 5-gal cans, and purchased from the Coral Reef Nurseries.* The Brogden avocados were small plants grown in 1-gal cans.

We divided 12 plants of each variety into three lots of four each. We placed one lot in a plant growth chamber with a programmed climate of 40°F, 8-hr dark period; a 60°F, 16 hr light period; and a constant 50% relative humidity (RH). We placed a second lot in a growth chamber programmed for 50-70°F, with constant RH of 50%. The third lot was kept outdoors, where night (9 hr) temperatures average about 70°F, and day temperatures about 90°F.

To facilitate the capture and measurement of ethylene produced by leaves, we detached four leaves from each plant at each sampling; placed them in 250-ml flasks sealed with a vicine cap; and incubated them for 24 hr at 70°F. We obtained a sample of air from the flask with a hypodermic syringe and measured it for ethylene by gas chromatography. Data are the averages of the four replicate samples, each sample having been taken from a separate plant.

Results

The leaves of trifoliate orange, starting at a zero (non-detectable) level of ethylene production, were producing 333 ppb/g fr wt/250 ml/24 hr after 3 wk at the 40-60° day, as compared to zero levels on plants held at 50-70° and 70-90° F (Tables 1 and 2). The leaves on the 40-60° plants were rapidly turning yellow; those on plants exposed to 50-70°F and outdoor conditions remained green. After 8 wk the leaves from

Table 1. Ethylene production by leaves (ppb/g fr wt/250 ml/24 hr)[a] of fruit plants grown under two programmed climates and outdoors at Orlando, Fla., for 1 week beginning May 23, 1969. Leaves on all plants were green on this date

Variety of fruit	Temperatures of programmed climates 40-60°F	50-70°F	70-90°F (outdoors)
Rough lemon	16	10	10
Towne trifoliate orange	0	0	0
Maygold peach	84	43	81
Brogden avocado	1008[b]	177	208
Lula avocado	19	22	14
Brewster lychee	10	17	8
Haden mango	6	7	5
Keitt mango	10	7	7

a/ Four leaves detached from each plant, placed in 250-ml flasks, sealed with a vicine cap, and incubated for 24 hr at 70°F. Values given are an average for four replicate samples.

b/ Mesophyll collapse of recently mature leaves.

40-60° plants had abscised; those at 50-70° were turning yellow and producing ethylene; and those on the outdoor plants remained green and produced no detectable ethylene (Table 3).

In a second series of Towne trifoliate orange plants placed in the 40-60° room, some were sprayed with 25 ppm gibberellic acid (GA_3), and others were left untreated. The rates of ethylene production and development of yellowing and leaf fall of the treated and untreated plants did not differ for the GA_3-treated and untreated plants (Table 4). In a third series of

Table 2. Ethylene production by leaves (ppb/g fr wt/250 ml/24 hr)[a] and color of leaves of leaves of fruit plants grown under two programmed climates and outdoors at Orlando, Fla., for 3 weeks beginning May 23, 1969

Variety of fruit	Temperatures of programmed climates 40-60°F	50-70°F	70-90°F (outdoors)
Rough lemon	5 green	7 green	7 green
Towne trifoliate orange	333 yellow 10% drop	0 green	0 green
Maygold peach	526 yellow 50% drop	24 green	27 green
Brogden avocado	85 green	273 green[b]	132 green
Lula avocado	7 green	16 green	12 green
Brewster lychee	6 green	11 green	7 green
Haden mango	4 green	4 green	5 green
Keitt mango	7 green	5 green	10 green

a/ Four leaves detached from each plant, placed in 250-ml flasks, sealed with a vicine cap, and incubated for 24 hr at 70°F. Values given are an average for four replicate samples.

b/ Mesophyll collapse of recently mature leaves.

*Mention of name of supplier does not imply endorsement by the U.S. Department of Agriculture.

Table 3. Ethylene production by leaves (ppb/g fr wt/250 ml/24 hr)[a] and color of leaves of fruit plants grown under two programmed climates and outdoors at Orlando, Fla., for 8 weeks beginning May 23, 1969

Variety of fruit	Temperatures of programmed climates 40-60°F	50-70°F	70-90°F (outdoors)
Rough lemon	60 green	14 green	12 green
Towne trifoliate orange	Defoliated	105 yellow	0 green
Maygold peach	"	617 yellow	17 green
Brogden avocado	39 green	32 green	23 green
Lula avocado	14 green	13 green	9 green
Brewster lychee	39 green	69 green	14 green
Haden mango	18 green	14 green	10 green
Keitt mango	10 green	29 green	11 green

a/ Four leaves detached from each plant, placed in 250-ml flasks, sealed with a vicine cap, and incubated for 24 hr at 70°F. Values given are an average for four replicate samples.

plants, treatment with 2,4-dichlorophenoxyacetic acid (2,4-D) and kinetin did not delay the yellowing of the leaves (Table 5).

The results obtained with the Maygold peach were similar to those obtained with the trifoliate orange, except that the leaves of peach trees grown outdoors produced small amounts of ethylene. Increased ethylene production, yellow color, and abscission of both trifoliate orange and Maygold peach developed slower at 50-70° than trees of the same varieties grown at 40-60°F.

Ethylene levels in leaves of the Lula avocado and Haden and Keitt mangos were generally less than 30 ppb in all three climates. There was no leaf-yellowing or abscission at any temperature. However, the buds swelled on the terminal flush of growth of the 40-60°F mango plants. Two weeks after the plants were moved to the warm

Table 4. Effect of GA_3 on color of leaves and ethylene production (ppb/g fr wt/250 ml/24 hr)[a] by leaves of Towne trifoliate orange seedlings grown under a 40-60°F programmed climate beginning June 16, 1969

Duration of treatment (weeks)	Treatment	Top leaves	Bottom leaves
2	Untreated	7 green	15 marginal yellow
2	25 ppm GA_3[b]	5 green	6 yellow spots
6	Untreated	100 green	7400 yellow[c]
6	25 ppm GA_3	507 green	7500 yellow[c]

a/ Four leaves detached from each plant, placed in 250-ml flasks, sealed with a vicine cap, and incubated for 24 hr at 70°F. Values given are an average for four replicate samples.

b/ Applied on June 16 and June 29.

c/ 25% leaf fall of yellow bottom leaves.

Table 5. Effect of 2,4-D and kinetin on color of leaves and ethylene production (ppb/g fr wt/250 ml/24 hr)[a] by leaves of Towne trifoliate orange seedlings under a 40-60°F programmed climate beginning June 29, 1969

Date of sampling	Treatment	Top leaves	Bottom leaves
July 30	Untreated	40 green	1219 yellow
"	50 ppm 2,4-D[b]	40 green	1440 yellow[c]
"	50 ppm kinetin	37 green	761 yellow[c]

a/ Four leaves detached from each plant, placed in 250-ml flasks, sealed with a vicine cap, and incubated for 24 hr at 70°F. Values given are an average for four replicate samples.

b/ Applied June 29, July 6, July 13, and July 20.

c/ Yellow bottom leaves loose and a few had fallen.

outdoor temperatures, the swollen buds developed inflorescences, a response not made by any other plants.

The leaves of the Brogden avocado generally produced more ethylene than leaves of the Lula variety. Increased ethylene production was detected twice by leaves of the Brogden avocado, but this was associated with a wound effect from mesophyll collapse, which occurred on some plants in both the 40-60° and 50-70°F regimes (Tables 1, 2, and 3).

Ethylene production in the leaves of the Brewster lychee was generally low and did not show any increases induced by low temperatures (Tables 1, 2, and 3).

Discussion

The autumnal yellowing and subsequent fall of leaves of deciduous trees occur during short days and cool nights. With both the trifoliate orange and peach, yellowing and abscission of leaves do not occur when plants are exposed to short days and warm nights (8, 9). Hence, the yellowing and abscission of leaves from plants of these two species in the present experiments, when exposed to 40-60°F for short daylengths, appear to be caused by the chilling temperatures, rather than by the short days. The results showing slower development of yellowing and abscission of leaves at 50-70° for short days, as compared with 40-60°F for short days, are additional evidence that the yellowing and abscission of leaves is a chilling effect, rather than a short-day effect.

A correspondence between degradation of chloroplasts in senescent yellow leaves and a large loss of ribonucleic acid (RNA) has been observed for tissues from a wide range of species (1, 7, 10). Where chloroplastic RNA is intact at presenescence, senescence can be retarded by application of kinetin (5), GA_3 (2), and 2,4-D(6). Hence, the failure of these growth regulators to retard yellowing of the leaves of trifoliate orange plants exposed to 40-60°F appears to constitute a reasonable indication of cellular senescence.

Prior to senescence, when the leaves of the trifoliate orange were still green, there was no detectable ethylene production. Coincident with the cold-induced color break of the leaves, however, a peak of ethylene production occurred. It was surprisingly similar to the increased ethylene coincident with a color break induced by chilling in 'Robinson' (*Citrus reticulata* Blanco X *C. paradisi* Macf. X *C. reticulata*) tangerines and 'Pineapple' (*Citrus sinensis* [L.] Osb.) oranges. The ethyelne peak in trifoliate leaves was not the result of a wound, since the excised green leaves of plants under all three temperature regimes did not show a detectable amount of the gas in samples taken 1 wk after treatment (Table 1).

The timing of the ethylene peak in relation to the development of senescence symptoms was not precisely determined. The older leaves at the base of the plants turned yellow first, and the younger leaves at the top, last. Generally, during the first month, a range from yellow to green on the same plant existed, and only later did all of the leaves turn yellow. However, when we carefully separated the yellow from the green leaves (Table 4), the green leaves at the top of the plants treated with GA_3 showed an ethylene peak before turning yellow.

Abscission generally occurred after the leaf turned completely yellow, although some partially yellow leaves abscised. Also, some yellow leaves remained on the plant long enough to become necrotic before abscising.

Ethylene peaks related to the development of senescence in the peach appeared to be similar to that in the trifoliate orange. However, the exact timing of the increased ethylene production in relation to the development of senescence was not determined.

With the Rough lemon, Lula avocado, Haden and Keitt mangos, and Brewster lychee, none showed an ethylene peak related to temperature. The relatively small amounts of ethylene detected may have been bursts of ethylene caused by wounding in excising the leaves. The observed peaks of ethylene produced by the Brogden avocado were related to injury from the mesophyll collapse disorder.

Results obtained with the senescent-resistant evergreen subtropical plants suggest that chilling promoted neither ethylene production nor senescence in their tissues. The low levels of ethylene found, caused possibly by wounding, had no effect on promoting senescence in the nonsensitive tissue.

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