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Ethylene in Relation to Postharvest Quality Deterioration in Processing Cucumbers[1]

E. F. Poenicke, S. J. Kays, D. A. Smittle, and R. E. Williamson

Departments of Horticulture and Agricultural Engineering, Coastal Plain Experiment Station, University of Georgia, Tifton, GA 31794

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Abstract. **Ethylene is produced by cucumber fruits (*Cucumis sativus* L.), at a rate which is size dependent. Small fruits (<2.6 cm diam) produced substantially more ethylene/kg fruit than did large fruits (2.6-3.8 and 3.8-5.1 cm diameter). Respiration was similarly affected. Mechanically harvested fruits produced 2 to 3 times more ethylene than did hand-harvested fruits. Texture profile analysis (TPA) of cross-sections of fruits treated 48 hr with 0, 0.1, 0.5, 1.0, 5.0 and 10.0 µl/liter ethylene indicated little change in textural parameters at concentrations below 10.0 µl/liter. Ethylene treatment, especially high concentrations, decreased fruit chlorophyll content. Greatest chlorophyll loss was at the stem-end of the fruit. Ambient concentrations of ethylene in well-ventilated trucks of cucumbers were not great enough to present a quality problem for processing cucumbers.**

Recent changes in production of cucumbers for processing from small handharvested fields to large machine-harvested acreages have changed postharvest handling techniques substantially. Harvest of large fields often results in prolonged delays between harvest and processing. In Michigan, the average delay between initial mechanical harvest and unloading at the plant was 19 hr and in one instance reached 39 hr (12). According to earlier work, prolonged holding of cucumbers decreases the quality of the pickled fruit (5). This quality reduction is typically characterized by tissue softening and off-flavor development (7).

The detrimental effect of ethylene on cucumbers was first noted when the fruits were stored with fruits of other species (e.g. *Cucumis melo* L. and *Lycopersicon esculentum* Mill.) which produce substantial amounts of ethylene (1, 15). Exposure of cucumbers to ethylene results in chlorophyll degradation and loss of firmness and its effect is a function of concn, storage temp and length of exposure (1, 6). While most studies have concentrated on external sources of ethylene, there is some indication that ethylene may also be synthesized by cucumber fruits (15). In addition, much of the research on the relationship between ethylene and detrimental physiological changes in cucumbers has been done with fresh market types which differ considerably from processing types (e.g. length/width ratio, intensity of pigmentation).

Ethylene production by many plant tissues is stimulated by injury (14); thus higher rates of ethylene might be expected with machine-harvested cucumbers since the fruits typically sustain more damage during machine-harvest than hand-harvest (12) and have higher respiration rates (9). In addition, machine harvest, in comparison with hand-harvest, alters the size distribution in individual loads of fruit and thus may alter the storability of the loads (8).

Because of the lengthy holding time and high ambient temp (30-38°C) occuring during machine-harvest and handling of pickling cucumbers in south Georgia, and since earlier work was mainly with fresh market fruit, we conducted tests to determine the relationship between ethylene evolved by cucumbers and raw product quality.

Materials and Methods

Plant material. 'Explorer' cucumbers were used for all tests except the commercial transport study in which 'Carolina' was used. Fruits were harvested, graded into commercial size classes (1 = <2.6, 2 = 2.6-3.8, 3 = 3.8-5.1, 4 = 5.1-6.4 cm diam) and used immediately. All experiments were duplicated and individual treatments had 3 or more replications with 9 or more fruits per replicate.

Chlorophyll analysis. Separate samples were taken from the stem and blossom ends of individual fruits using a number 4 (1.8 cm^2) cork bore. Four cores were taken from each of 9 fruits/replication; the pigmented surface tissue was removed from the cores, weighed and blended 3 min with 40 ml acetone. The blended tissue was filtered, and the extracted chlorophyll was brought to 100 ml with acetone. Optical density was determined at 642.5 and 660.0 nm and chlorophyll concn was calculated as outlined by Smittle and Bradley (19). Results are expressed as mg of chlorophyll/100 cm^2.

Gas chromatography. A Bendix Model 2500 gas chromatograph with flame ionization detector and 1.83 m × 6.4 mm ID glass column packed with 80-100 mesh activated alumina was utilized for ethylene detection. The operation conditions were: 75°C for injection port and column and 100°C for the detector. Nitrogen carrier gas (90 ml/min) was utilized with O_2 (60 ml/min) and H_2 (70 ml/min). Minimum detection limit by peak height was 6 nl/liter with 1 ml samples.

Carbon dioxide and O_2 were analyzed using a standard thermal conductivity Hamilton-Fisher Model 29 gas partitioner.

Fruit texture analysis. A texture profile analysis (TPA) similar to that described by Bourne (2) and Breene et al. (3, 4) was conducted on the fruit (size 1 and 2) from several experiments. A single 1 cm thick cross-section was taken from the center of each of 9 fruits/replication and was pressed twice for force vs. distance curves (2).

Each sample was pressed to 0.25 cm using a Instron Universal Testing Machine (Model 1132) equipped with 454 kg capacity load cell. The output from the load cell was recorded graphically. Plots of the first and second bites were obtained. Crosshead speed was 0.5 cm/min with a chart speed of 3.0 cm/min. Values for A_1 (total work), brittleness, and hardness were adjusted to a value representing 1 cm sample area. Elasticity and cohesiveness are theoretically independent of sample area. The secondary parameters (gumminess and chewiness) are derived from hardness, cohesiveness, and elasticity (3).

The relationship between fruit size and rate of endogenous ethylene synthesis was established using hand-harvested fruits graded into the various commercial sizes noted earlier. Air was passed through the individual jars containing 200-400 g of fruit at a flow rate of 20 ml/min using a gas flow system similar to that of Pratt et al. (18). Ethylene in the air stream was scrubbed prior to entry into the jars by passing the air through potassium permanganate columns similar to those described by Goeschl and Kays (10). One ml samples were periodically removed from the exhaust air and analyzed for ethylene, CO_2 and O_2. The experiments were conducted for 120 hr at 29-31°C.

[1] Received for publication.

The effect of exogenous ethylene on cucumber fruits was determined by treating samples with 0, 0.1, 0.5, 1.0, 5.0, or 10.0 µl/liter at a flow rate of 1000 ml/min/3.8 liter glass jar by use of a continuous flow system (10). Three replications of 9 fruits at each concn were treated 48 hr at 29-31°C. After the treatment, chlorophyll and TPA were determined as described.

Commercial handling procedures were monitored to determine the ethylene concn that might be attained in a trailer load of cucumbers. Samples were obtained from trailer loads of mechanically harvested processing cucumbers transported 1¼ hr to a commercial processing plant. The trailers were open-topped, had wire mesh bottoms, were typical of those used for pickling cucumbers, and they allowed substantial air flow through the load, especially during transit. A thermister probe (YSI Model 401) attached to a 3 m section of Tygon tubing (6.4 mm ID) was inserted to a 1 m depth for temp monitoring and atmosphere sampling. Temp was monitored with a YSI Model 44 TD Tele-Thermometer. Gas was periodically sampled by use of a hand vacuum pump and collected with 1 ml gas syringes which were sealed until the sample was analyzed for ethylene. Measurements were taken from the time the trailers were ½-loaded until the cucumbers were dumped into washing tanks at the processing plant 18 hr later.

We determined differences in ethylene production between hand-and-machine-harvested cucumbers by collecting fruit of sizes 2 and 4 in the field. Fruits of each size were immediately placed in 3.8 liter glass jars which were sealed with caps fitted with a serum vial stopper. Ethylene accumulation was monitored for 20 hr with the initial sample taken 20 minutes after jar closure.

Results

Small cucumbers had a higher rate of ethylene production than large fruit, which produced ethylene at a relatively constant rate throughout the 120 hr of monitoring (Fig. 1). Rate of ethylene production of size 1 fruits increased during the first 18 hr then remained relatively constant until the end of 2 days of storage, thereafter ethylene production rate increased markedly. A dramatic increase in production of ethylene by size 1 fruits after 96 hr to approximately 1500 µl/kg-day was recorded. This increase probably is accounted for by fungal growth which was visible on several fruits. Small fruits showed signs of desiccation and yellowing after 96 hr and pronounced tissue breakdown by 120 hr. CO_2 production by the smaller fruits reflects a high rate of metabolism (Fig. 2). The CO_2 production of larger fruits (size 2 and 3) remained relatively constant after initial equilibration.

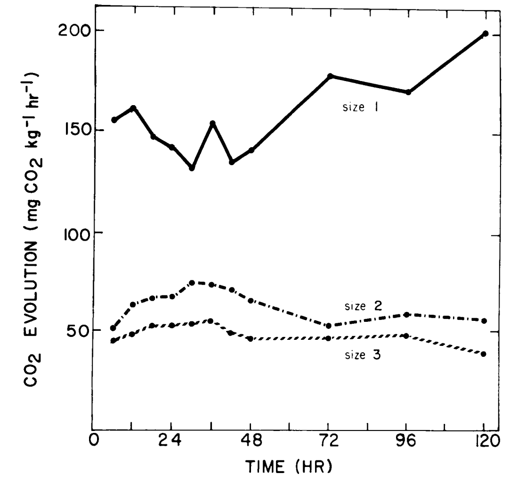

Fig. 2. Carbon dioxide production rates of 3 commercial sizes (1 = <2.6, 2 = 2.6-3.8, 3 = 8-5.1 cm diam) of 'Explorer' cucumber fruits during 120 hr post-harvest holding at 29-31°C.

Treatment of fruits of size 1 with various concn of ethylene resulted in a chlorophyll loss (Fig. 3), which was also noted by others (1, 6). Chlorophyll loss was greater at the more highly pigmented stem-end of the fruit. There was little effect at the blossom-end, except at 10 µl/liter of ethylene. Chlorophyll concn declined at both ends of cucumbers during the initial 48 hr after harvest.

Added ethylene had only a minor effect on texture unless a concn of 10 µl/liter was used (Table 1). At this concn, tissue softened after 48 hr exposure to ethylene. Fruit hardness was the most sensitive of the textural characteristics tested and decreased substantially in size 1 fruits treated with 5.0 or 10.0 µl/liter. Treatment with ethylene at concn between 0.1 – 1.0 µl/liter resulted in significantly harder fruit than in the control. A similar effect was absent in size 2 fruits.

Ethylene concn measured in a loaded truck of cucumbers increased until transit to the processing plant (Fig. 4). Air movement through the load during transit decreased the ethylene concn to a low level. The concn in the load gradually increased while the truck was parked at the plant, but decreased again during a short transfer to the unloading bins. The air temp decreased as the day progressed. However, virtually no change was detected in the product temperature during the entire 18 hr (Fig. 4). Mechanically-harvested fruits (sizes 2 and

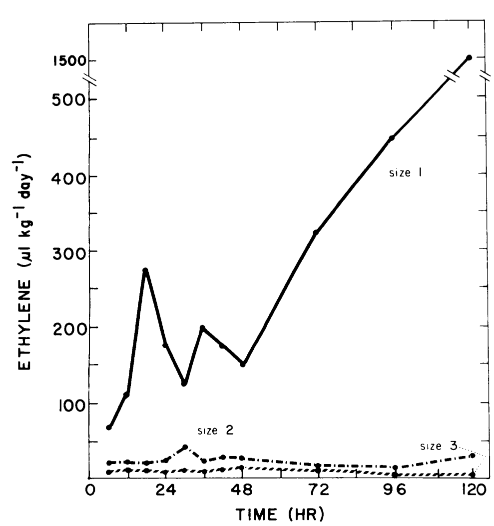

Fig. 1. Ethylene production rates of 3 commercial sizes of 'Explorer' cucumber fruits during 120 hr post-harvest holding at 29 to 31°C.

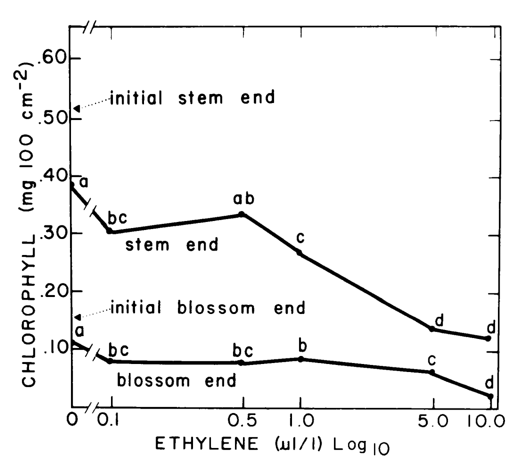

Fig. 3. Effect of exogenous application of ethylene (48 hr) at 29-31°C on the chlorophyll content of the blossom and stem ends of size 1 'Explorer' cucumber fruits. Mean separation by Duncan's multiple range test, 1% level.

Table 1. Texture changes in 'Explorer' cucumbers (size 1) as a result of exposure for 48 hr to various concn of ethylene.

Ethylene concn (µl/liter)	Hardness (kg)	Gumminess (kg)	Chewiness (kg mm)	Brittleness (kg)	Elasticity (mm)	Cohesiveness (cm^2)	A_1 (cm^2)
0	12.5c[z]	.9a	5.5c	9.4a	6.1a	.1a	11.9b
0.1	13.9b	1.2a	7.0b	9.9a	5.9a	.1a	10.3c
0.5	14.7a	1.1a	7.2a	9.3a	6.5a	.1a	12.2a
1.0	13.9b	1.1a	6.9a	9.5a	6.3a	.1a	10.0c
5.0	11.7d	.9a	6.0a	8.9a	6.4a	.1a	8.2d
10.0	9.1e	.6b	3.5d	8.1a	5.5b	.1a	6.4e

[z]Mean separation in columns by Duncan's multiple range test, 1% level.

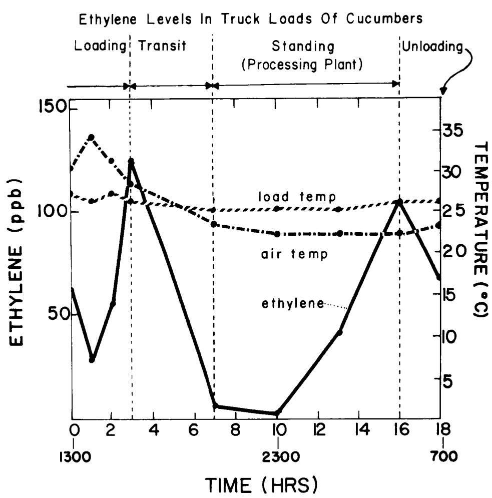

Fig. 4. Ethylene concn, product temp and air temp in a commercial truck load of mechanically harvested 'Carolina' cucumbers between harvest and unloading at the processing plant.

4) from the same load produced more ethylene in sealed containers during the 20 hr after harvest than did hand-harvested fruits (Fig. 5).

Discussion

Fruit of various species of Cucurbitaceae [e.g. *Ecballium elaterium*, A. Rich., *Citrullus lunatus* (Thumb.) Mansf., *Cucumis*

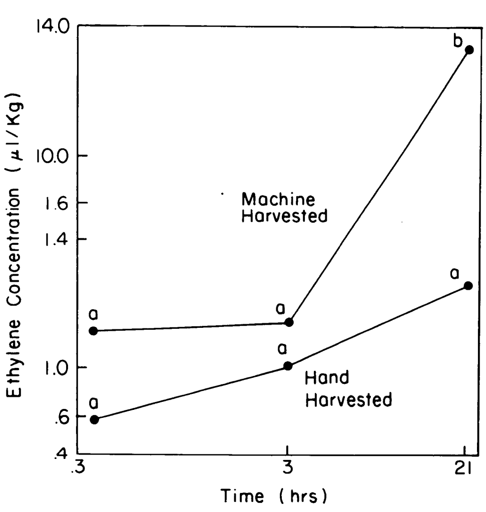

Fig. 5. Ethylene concn in sealed 3.8 liter jars holding mechanically or hand-harvested cucumbers (sizes 2 and 4) during 20 hr at room temp. Mean separation for each curve by Duncan's multiple range test, 1% level.

melo L., etc. (11, 13, 16, 17)] produce ethylene; generally the highest rates of production are associated with their ripening response. Our results indicate that ethylene is produced by cucumber fruits, and that the rate of production is size-dependent. Large and relatively mature fruits produce lower amounts of ethylene per unit fresh wt than young fruits. Young fruits produce ethylene at 2 to 3 times the rate of larger fruits during the first 48 hr of storage. This high rate of ethylene evolution corresponds to a proportionally high rate of respiration by the young fruit. The rates of respiration and ethylene evolution of fruit of sizes 2 and 3 indicate that the responses and consequently the requirements of these fruits differ substantially from those of size 1 fruits, especially after 48 hr. The elevated level of ethylene synthesis of the smallest fruits after 48 hr probably represents the onset of a relatively advanced stage of senescence. In addition, damage sustained during mechanical harvest, and the resultant increase in ethylene production (Fig. 5), could accentuate handling problems. Differences in ethylene production between fruits in this static experiment and those used to determine rates of evolution, are probably due primarily to the difference in method, although cultivar and temperature may have been contributing factors.

The effect of ethylene on chlorophyll degradation of processing cucumbers is similar to that previously noted for fresh-market cucumbers (1). Chlorophyll loss occurs at lower concn of ethylene (0.1 µl/liter) than those which cause undesirable changes in fruit texture. Loss of chlorophyll is less critical in processing than in fresh market cucumbers since they are typically not selected for intense pigmentation and because artificial coloring is often added during processing. Factors related to texture generally were not adversely affected by ethylene until the ambient concn reached 10.0 µl/liter. Hardness and A_1 (total work) were somewhat more sensitive.

Ethylene evolution from the fruits does not endanger the quality of pickling cucumbers when shipped in well-ventilated vehicles. However, over long hauling distances and/or in enclosed trucks, accumulation of ethylene evolved by the fruit may be potentially hazardous. Cucumbers of the smaller sizes are occasionally shipped to Georgia from Mexico or from one area of the U.S. to another by truck. Since small fruits produce substantially more ethylene per unit of fruit weight and pack more closely, refrigeration and/or removal of ethylene may be beneficial in maintaining acceptable product quality.

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Photoperiod and Temperature Effects on Root Cold Acclimation[1]

James R. Johnson[2] and John R. Havis
Department of Plant and Soil Sciences, University of Massachusetts, Amherst, MA 01003

Additional index words. root cold hardiness, *Picea glauca, Potentilla fruiticosa*

Abstract. **Hardiness of intact roots of *Potentilla fruiticosa* L. cv. Katharine Dykes and *Picea glauca* Voss were determined during the autumn. Both extended photoperiod and warm temperature interfered with root acclimation to cold. Seasonally short days and near freezing temperature were necessary for maximum rates of cold acclimation of roots.**

Studies on the cold acclimation of plant roots are few, but it is generally accepted that plant stems withstand a lower temp than roots (1, 6, 7, 13). With increased production of container-grown nursery crops, however, root cold hardiness may be more important for winter survival than stem hardiness.

Temp just above freezing are necessary to induce maximum rates of cold acclimation of roots (6, 14). Minimum air temp and hardiness may be related during the period of greatest cold hardiness (6). Reduced moisture content of roots appears to be related to hardiness (11, 12), although moisture differences between stems and roots do not account for their difference in hardiness (7, 10). Root hardiness does not appear to be correlated with levels of soil N (10), plant N (8, 11), plant P (8), or endogenous sugars (11). Roots farther from the stem and younger are less hardy than those closer to the stem and older (6, 9). Mityga and Lanphear (6) concluded that the youngest roots of *Taxus* did not have the capacity to harden, and this was confirmed in *Pyrancantha* (14). We have found no reports on the effect of photoperiod on cold acclimation of roots.

The objective of this study was to determine the importance of day length and temp on the cold acclimation of roots of *Picea* and *Potentilla.*

Materials and Methods

Three-year seedlings of *Picea* and rooted cuttings of *Potentilla* were transplanted into 15 cm pots containing 1 peat:1 sand (v/v). During the mixing process 2.46 kg of 9-month Osmocote (18N-1.3P-5K), 2.95 kg superphosphate, 2.95 kg lime, and 56 g fritted trace elements were added per m^3 of medium. The potted plants were placed in a container area under normal seasonal growing conditions on May 7, 1975.

Root hardiness determinations were made on plants maintained under the 4 environmental conditions shown in Table 1. Temp of the air at the foliage level and media in the center of the containers, at each of the treatment locations, were measured by thermisters through a specially constructed switching box, and recorded on Rustrak recorders. Minimum air and media temp for the 4 conditions are shown in Fig. 1 and 2. The outdoor air temp was below freezing 10 times and the

Table 1. Cold acclimation treatments.

Treatment	Min air temp (°C)	Photoperiod	Initiation
Outdoor	−3.9	Natural	May 7
ND Poly house[z]	2	Natural	Sept. 12
LD Poly house[y]	2	14.5 hr	Aug. 3
Greenhouse	15	Natural	Sept. 4

[z]ND Poly house = naturally shortening daylength in a clear polyethylene house.

[y]LD Poly house = natural light extended to 14.5 hr with incandescent 1.2 klx at plant height in a clear polyethylene house.

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[2]Present address: Sullivan County Extension Service, Claremont, NH 03743.