EFFECTS OF ETHYLENE ON THE QUALITY OF FRUITS AND VEGETABLES

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☐ ETHYLENE, a 2-carbon volatile, is produced endogenously by perhaps all plants and their organs. At concentrations as low as 0.1 μL/L, ethylene can induce a wide array of physiological responses, including altered geotropic growth, abscission, ripening, senescence, and physiological disorders. These responses can be beneficial or detrimental, depending upon the response and one's need.

Use of Ethylene

As described by Abeles (1973), interest in ethylene dates back to at least 1864, when Girarden reported that gas from gas lamps caused injuries and defoliation of trees. In 1901, Neljubov identified ethylene as a component of the illuminating gas. Crocker and Knight reported in 1908 that ethylene and illuminating gas induced same physiological responses in flowers. In 1912, Sievers and True showed that color development of lemon was induced by the gaseous product of a kerosene heater. Gane (1934) showed that the gaseous product from the heater contained ethylene, and Denny (1924) demonstrated that coloration of lemons can be induced with ethylene.

Harvey (1925; 1928) conducted a comprehensive study on the use of ethylene to blanch celery and to ripen bananas, pineapples, dates, persimmons, tomatoes, hard pears (probably winter pears), apples, muskmelons, honeydew melons, casaba melons, mangoes, avocados, papayas, custard apples, and jujubes. Harvey indicated that loss of chlorophyll, development of ripening color, softening of tissue, removal of tannins, development of flavor, increase in sweetness, and early proteoclastic enzyme activity occurred when these fruits were exposed to ethylene.

The amount of endogenous ethylene produced by plant tissue generally increases autocatalytically at a specific stage of growth or development to initiate a physiological response. Application of exogenous or supplemental ethylene to a plant tissue prior to the autocatalytic increase will generally initiate the physiological response as well as the increase in ethylene production.

Today, supplemental ethylene is commonly used to induce ripening of avocado, bananas, mangoes, tomatoes, and honeydew melons; degreen citrus fruits (except lime) for fresh market; and induce softening of freestone peaches and pears destined for processing. Mature-green tomatoes are treated at shipping point with 100 ppm, and in some instances 1,000 ppm, ethylene for 24–48 hr at 20–25°C and 85–90% relative humidity (Gull, 1981). Although 1–10 ppm ethylene is sufficient to induce ripening, higher concentrations are used to ensure treatment of fruits located in the center of the container and pallets, and to compensate for leakage of ethylene out of the treatment rooms. Because high levels of carbon dioxide inhibit ethylene action on ripening, the recommended treatment procedure is to keep the CO_2 from accumulating beyond 4% during treatment, and to keep it below 2% after the treatment. Honeydew melons will ripen with 10 ppm ethylene, but commercially they are treated with 1,000 ppm ethylene for 18–24 hr (Redit, 1969). The fruits are generally examined after 24 hr of ethylene treatment and, if adequate ripening is not noted, may be given a repeated ethylene treatment.

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Citrus fruits that develop early in the season usually become edible when the skins are still green, so they are treated with ethylene to accelerate chlorophyll degradation and appearance of yellow and orange colors. For degreening, ethylene is metered into storage rooms at a rate to maintain the concentration at 1–5 ppm. A temperature of 28–29°C and relative humidity of 90–96% are recommended (Wardowski and McCornack, 1979). Ventilation of storage rooms with fresh air after ethylene treatment is essential because the rate of degreening is reduced if the concentration reaches 0.1% and will stop at 1.0% or above. Ethylene increases decay of citrus; therefore, concentrations above 5 ppm are avoided, and the exposure time is kept to a minimum.

Bananas are treated with ethylene at the wholesale market or distribution center rather than at the shipping point. This practice is necessary because the transit period from the shipping point to the distribution center exceeds by far the ripening time of ethylene-treated bananas. Ripening of bananas can be hastened with only 1 ppm ethylene; however, commercially, 100–1,000 ppm is used for a 12- to 24-hr period. During treatment, the recommended temperature is 18–24°C and the relative humidity 90–95%.

Application of Ethephon

In the early 1960s, various compounds were evaluated which would release ethylene after the compound was applied to the plant tissue (de Wilde, 1971). From these studies evolved the compound (2-chloroethyl)phosphonic acid, also known as ethephon, which is now widely used. Ethephon is applied on growing plants to regulate flowering, to induce abscission of leaves and fruits, and to hasten ripening processes. It is used on the following horticultural crops to regulate their harvest:

- **Apples.** Ethephon is used to hasten ripening of early-season market apples, although the use differs among the various regions of the United States. In the southern region along the Appalachian foothills, approximately 60% of the Delicious and 10% of Stayman and Rome apples are sprayed with ethephon. Delicious apples grown in the Northwest are also treated with ethephon, but the chemical is applied only to a very small percentage of the total acreage. In the Northeast, about 1% of the McIntosh apples are sprayed with ethephon, and in the Midwest the Polar Red cultivars are treated. Because ethephon hastens maturity and softening, treated fruits are not held for long-term storage.
- **Cherries.** The use of ethephon on cherries to induce abscission of fruit allows effective machine harvesting of the total load on trees. In the Midwest, approximately 90% of sweet cherries and 25% of sour cherries that are harvested mechanically are sprayed with ethephon. In the Northwest, it is used only on sour cherries.
- **Blueberries.** Ethephon hastens the ripening of blueberry fruit, but is used only on a very small percentage of the crop to aid in the last harvest of the season. It can also be used to cause abscission of the fruit of the weed black barrenberry that grows interpersed with lowbush blueberries (Ismail, 1974). The fruit of black barrenberry is similar to blueberry in appearance and time of maturity, so the barrenberry fruit can cause adulteration of the blueberry product.
- **Figs.** Ethephon hastens the ripening of figs and hence shortens the harvesting period. It is currently used on 50% of the total Calmyrna figs, which constitute slightly over half of all figs grown in California.

● **Grapes.** Approximately 20% of the grapes grown for raisins in California are sprayed with ethephon to increase sugar content and hasten maturity. With a few fresh-market grapes such as Emperor and Flame Seedless, it is used to enrich the anthocyanin content.

● **Walnuts.** Ethephon is used on walnuts when the kernel and hull are not developing simultaneously, or when wet weather is anticipated during harvest. If the temperature is very high during the growing period, the kernel develops faster than the hull, and if the harvest is delayed until the hull dehisces, the kernel will be overmature and of low quality. Application of ethephon will cause abscission of the nut and dehiscence of the hulls when the quality of the kernel is at its optimum.

● **Tomatoes.** Ethephon is used to hasten the ripening of approximately 40% of the 240,000 acres of tomatoes grown for processing in California. It is used when plants scheduled for early harvest are planted late or develop slowly because of cool wet weather, or when cool wet weather is predicted at the end of the season, which can affect tomato quality. On the coastal regions, ethephon might be used to abscise some of the leaves to allow air circulation within the plant and reduce the opportunity for rot fungus to develop and grow.

Application of ethephon to regulate ripening and hence schedule harvesting time is not without problems. Ethephon will affect or induce any physiological process under potential control of ethylene. The effect on a particular process is dependent upon a number of variables, including concentration of ethylene, temperature, and physiological state of the plants. When these conditions deviate unknowingly or without control, unwanted processes, including injuries, can be initiated.

Effect of Ethylene on Quality Attributes

Ripening is a term used to encompass many processes which may occur simultaneously or sequentially and be independent or associated. Supplemental ethylene may affect many of these processes, or may affect only some of the processes that are associated with food quality.

● **Color.** Loss of green color is initiated or accelerated when plant tissue is exposed to ethylene. Ethylene at a 5 ppm level can cause the green color of cabbage to fade significantly after 1 mo of storage, and 1 ppm can have an undesirable effect on cabbage stored for 5 mo (Hicks et al., 1982). The rate of color loss differs among commodities, as noted with various types of citrus. Kitagawa et al. (1978) found that of the seven citrus types he studied, Satsuma mandarin lost the most chlorophyll (83%) and Valencia oranges the least (35%), after a 15-hr treatment with 1,000 ppm ethylene. The destruction of chlorophyll may be due to increased chlorophyllase activity, as noted with calmondin fruit (Barmore, 1975). The chlorophyllase activity of calmondin fruit increased by 50% after a 12-hr treatment with 10 ppm ethylene, and by 137% after a 24-hr treatment. At the end of 24 hr, calmondin fruit lost 11% of the chlorophyll content, as estimated with a color difference meter.

The development of ripening color with ethylene treatment, as noted with banana (Liu, 1976), muskmelon (Bianco and Pratt, 1977), and citrus (Wheaton and Stewart, 1973), is due to synthesis of pigment and not to unmasking with the loss of chlorophyll. Stewart and Wheaton (1972) showed that β-citraurin, cryptoxanthin, and cis-viloxanthin increased differentially with three 1-day treatments of 10 ppm ethylene. The amount of carotenoids synthesized with ethylene differs among citrus fruits. Young and Jahn (1972) found that Hamlin oranges and Bearss lemon did not respond to ethylene as well as Lee, Nova, Robinson, and Dancy. Ethylene may also hasten the biosynthesis of anthocyanins. The anthocyanin content of olives from trees treated with 1,000 ppm ethephon was almost ten times greater than that from nontreated trees, and a 2,000-ppm treatment resulted in an almost 20-fold increase in the pigment content (Rugini et al., 1982). A cyanidin was the main component of the anthocyanins found in the olives.

● **Firmness.** Firmness of many fruits and vegetables decreases with ethylene treatment. Apricots that were treated with 100 ppm ethylene during the ripening period at 20°C after cold storage had lower penetration-force test readings than apricots ripened without ethylene (Brecht et al. 1982). Results of a sensory panel also indicated that ethylene-treated fruit were softer than the control fruit. The differences in penetration force between the treated- and the control-ripened fruit were 19 newtons (N) for Patterson cultivar and 5 N for Tilton cultivar. The difference was not as great for Tilton, probably because the control fruit softened almost to the minimum firmness level during the ripening period. Ethylene appeared not to affect the softening rate of nectarines (Brecht and Kader, 1982); however, this lack of effect also may have been due to the rapid softening of untreated fruit.

Honeydew melons and muskmelons soften rapidly with ethylene treatment. Bianco and Pratt (1977) found the penetration force of Honeydew melons to drop from 31 N to 27 and 14 N in 24 and 48 hr, respectively, with 60 ppm ethylene. Softening of cantaloupes was more rapid; their firmness dropped from 44 N to 14 and 5 N after 24 and 48 hr, respectively.

Ethylene can affect the softening process without affecting other physiological processes. In mature Anjou pears, softening is initiated simultaneously with the respiratory climacteric. In treatment of a younger but mature fruit with 2 ppm ethylene, Wang et al. (1972) reported that the softening processes were initiated before the climacteric period.

Ethylene accumulates in some holding or storage areas and causes undesired softening. Firmness of watermelon flesh decreased significantly when exposed to 5 ppm ethylene for 3 days, and this decrease was sufficient to cause the acceptability ratings to be low (Risse and Hatton, 1982). The loss of firmness is probably due to activation of cell-wall-hydrolyzing enzymes induced by ethylene. Activities of cellulase and pectinase increased along with tissue maceration when watermelons were treated with ethylene (Shimokawa, 1973). In avocado treated with ethylene, polygalacturonase activity increased simultaneously with softening of the fruit (Chaplin et al., 1983). Haas avocado stored in 100 ppm ethylene at 6°C for 12 days lost more than 75% of its firmness within 2 days after being placed at 20°C; however, the control fruit still had about 50% of its firmness on the fourth day.

The optimum temperature range for ethylene to induce physiological response is 20–25°C; however, undesired softening can be induced at lower storage temperatures. McIntosh apples (Liu, 1977) and Cox's Orange Pippin apples (Knee, 1976), which are stored at 3.3°C, have been found to soften, as determined objectively and by sensory panel, when ethylene was present at a low level of 1 ppm. Apple cultivars such as Delicious, Golden Delicious, and Idared, which are stored at 0°C, were not affected by the low levels of ethylene (Liu, 1977). Kiwifruit, which is stored at 0°C, softened when a very low level of ethylene (30 ppb) was present (Arpaia et al., 1985). With all of these fruits, it is critical to keep the storage rooms and transit space free of ethylene to maintain firmness and storage life.

● **Texture.** The detrimental effect of ethylene on textural quality can be noted immediately, as found with cucumber or asparagus, or it may occur only after cooking, as found with sweetpotatoes. Poenicke et al. (1977) found that the textural attributes of cucumber Explorer cultivar were affected differentially by ethylene concentrations: after a 48-hr treatment at 29–31°C, the values for hardness, chewiness, and workload (brittleness and hardness), as determined by Instron texture profile, increased with ethylene concentration up to 0.5 ppm and then decreased with increased concentration beyond 0.5 ppm. Gumminess, brittleness, elasticity, and cohesiveness were not affected by ethylene concentrations up to 5 ppm.

A short exposure to ethylene can cause toughening of asparagus spears. Haard et al. (1974) reported that 1 hr of 100 ppm ethylene treatment at 20°C caused an increase in rate of fiber development and dramatic changes in isoperoxidase distribution. From these and other results, they concluded that ethylene initiates a shift to peroxidase isozymes which are involved in lignification.

The cores of some sweetpotatoes become hard and inedible when cooked, and this condition occurs with certain roots stored at temperatures below 15°C. Studies have shown that this condition, termed hardcore, can be induced by ethylene.

Timbie and Haard (1977) reported that Jewel sweetpotatoes treated with 92 ppm ethylene for 3 days at 2°C had more severe hardcore upon cooking than those sweetpotatoes held in air. Tannic acid can cause firming of sweetpotatoes, and Buescher et al. (1975) reported that ethylene enhanced phenolic content and phenolic oxidizing enzyme activity. It is not clear how these changes cause modification of the intercellular cement involved in the development of hardcore.

• **Vitamins.** Ethylene affects the vitamin C content but not the β-carotene content of tomatoes. Mature-green Walter tomatoes treated with 8,000 ppm ethylene for 24 hr and then ripened had a 16% higher vitamin C content than the untreated fruit. Treated and untreated fruit had similar β-carotene (provitamin A) content. (Watada et al., 1976).

• **Chemical Composition.** Ethylene has a variable or differential effect on the chemical composition. It generally does not have an effect on soluble solids or titratable acid contents in stone fruits (Brecht et al., 1982), muskmelons (Bianco and Pratt, 1977), apples (Forsyth et al., 1969), and possibly many other commodities; exceptions, however, are possible, as noted with apples by Liu (1977). Hicks et al. (1982) analyzed individual acids in stored cabbages and noted that the typical increase in malic acid during storage was greater when the storage environment contained ethylene, whereas the typical decrease in citric acid content was not affected by the ethylene. The difference in malic acid contents between the treated and nontreated cabbages was apparent by the third month of storage with 5 ppm ethylene and the fifth month with 1 ppm ethylene. It is possible that ethylene affects biosynthesis or degradation of a specific acid or carbohydrate, but not the total content of either.

Bliss and Pratt (1979) examined the flavor volatile components of muskmelons treated with 100 ppm ethylene at 20°C. They found that ethylene hastened the production and altered the ratio of volatile esters that are produced during ripening. A change in the ratio could affect the acceptability of the melons.

• **Disorders.** Ethylene in holding areas or storage rooms can cause or accelerate disorders. Marsh grapefruit stored 8 weeks at 10°C became sticky when the atmosphere contained 2 ppm ethylene (Hatton and Cubbedge, 1973). The stickiness may have been due to ethylene reacting with the wax that was applied on the fruit. McIntosh apples may develop "core browning" during storage, and 6 ppm ethylene accelerates this disorder (Forsyth et al., 1969). Kiwifruit stored in controlled atmospheres of 1% O_2 and 3, 5, or 7% CO_2 at 0°C developed internal breakdown, and the severity of breakdown was greater when 0.5 ppm ethylene was present (Arpaia et al., 1985). In these kiwifruit, white inclusions developed in the core, possibly due to the interaction between ethylene and elevated CO_2 content in the tissue. The inclusions contained large amounts of starch granules. In lettuce, small dark lesions termed brown spots or russet spotting, which can be caused by ethylene, occur occasionally on stored heads (Rood, 1956). The spotting will develop with a level as low as 1 ppm ethylene and occurs most readily with lettuce stored at 5°C. Carrot roots sometimes become bitter during storage, and the bitterness is caused by ethylene (Ells, 1958). The compound responsible for the bitterness is isocoumarin, which can be formed when the ethylene level is only 1 ppm (Sondheimer, 1957). Carlton et al. (1961) showed that labeled ethylene was not incorporated into the bitter compound, so ethylene apparently played a catalytic role in the formation of isocoumarin. These various disorders appear to be specific to the commodity, as they have nothing in common.

• **Abscission.** Ethylene induces abscission; however, very little attention is given to this phenomenon with stored vegetables. Pendergrass et al. (1976) demonstrated that 10 ppm ethylene increased the number of abscising cabbage leaves during 5 weeks of storage at 1°C. Ethylene (100 ppm also) caused leaf abscission of Chinese cabbage stored for 2 weeks at 10°C (Wang, 1985). These studies indicate that storage rooms should be free of ethylene to avoid accelerated defoliation.

• **Chilling Injury.** Many fruits and vegetables are susceptible to chilling injury when placed at temperatures between 0 and 10°C. Commodities differ in chilling sensitivity, and the degree of sensitivity can be influenced by many factors, including ethylene. Honeydew melons have been found to be less sensitive to chilling when treated with ethylene before placement at the chilling temperatures (Lipton and Mackley, 1984). These melons, when treated with 1,000 ppm ethylene for 18 hr at 20°C, can be held for almost 3 weeks at 3.6°C without developing serious chilling injury, and the melons still have the capacity to ripen.

Chilling sensitivity of tomatoes and lemons is not affected by ethylene treatment. Ripening characteristics were similar for chilling-sensitive mature-green tomatoes that were held for 15 days at 5°C with or without 50 ppm ethylene (Manzano-Mendez et al., 1984). Bearss lemons degreened at 15.5°C with and without 1 ppm ethylene were equally sensitive to chilling when stored for 21 days at 1°C (McDonald et al., 1985).

Chilling sensitivity of avocado and grapefruit increases with ethylene treatment. Chaplin et al. (1983) indicated that the chilling injury of Haas avocado held for 4 weeks at 1.5°C was more severe when 10 ppm ethylene was present than without ethylene. These avocados were more sensitive to chilling injury at 5°C than at 1.5°C. At 5°C, ethylene had no effect, perhaps because of the rapid breakdown. The Fuerte avocado, which will ripen normally at temperatures between 9 and 24°C, developed chilling injury at 12°C when 100 ppm ethylene was present (Lee and Young, 1984). At 6°C, the ethylene-treated and nontreated Fuerte avocado failed to ripen, because of chilling injury.

The effect of ethylene on sensitivity of grapefruit to chilling injury depends on the condition of the fruit before placement at the chilling temperature (Hatton and Cubbedge, 1981). Grapefruit are typically degreened at 25–29°C, conditioned at 16°C, then stored at 1°C. If 5 ppm ethylene is added to hasten degreening at 25–29°C, the treatment has no effect on chilling sensitivity when the grapefruit are held at 1°C. However, if the conditioning at 16°C is omitted, the grapefruit are injured by chilling at 1°C, and the severity of injury appears to be greater with longer ethylene treatment during the degreening process.

Questions on Mechanism

The above studies show that ethylene has differential effects on the various quality attributes of stored fruits and vegetables. Some of the effects are desirable and others are not. The mechanism by which ethylene triggers or regulates these attributes is not known. Ethylene becomes more effective in triggering these processes as plant tissue becomes progressively sensitive to the gas. The factors involved in sensitivity are not clear. If ethylene initiates its effects by binding reversibly to metal-containing receptor sites (Burg and Burg, 1967), then possibly sensitivity is dependent on development or exposure of receptor sites. However, it is unknown whether ethylene binding is a requisite for the action of ethylene.

Additional questions are raised as to whether the attributes induced by ethylene are caused by induction of genes, amplifications of specific genes, repression of genes, or modification of existing proteins. These questions need to be answered and clarified to utilize ethylene effectively in regulating food quality.

References

Abeles, F.B. 1973. "Ethylene in Plant Biology." Academic Press, New York.

Arpaia, M.L., Mitchell, F.G., Kader, A.A., and Mayer, G. 1985. Effects of 2% O_2 and varying concentrations of CO_2 with or without C_2H_4 on the storage performance of kiwifruit. J. Am. Soc. Hort. Sci. 110: 200.

Barmore, C.R. 1975. Effect of ethylene on chlorophyllase activity and chlorophyll content in calmondin rind tissue. HortScience 10: 595.

Bianco, V.V. and Pratt, H.K. 1977. Compositional changes in muskmelons during development and in response to ethylene treatment. J. Am. Soc. Hort. Sci. 102: 127.

Bliss, M.L. and Pratt, H.K. 1979. Effect of ethylene, maturity, and attachment to the parent plant on production of volatile compounds by muskmelons. J. Am. Soc. Hort. Sci. 104: 273.

Brecht, J.K. and Kader, A.A. 1982. Ripening and reduced ethylene production of nectarine fruits following exposure to ethylene. HortScience 17: 224.

Brecht, J.K., Kader, A.A., Heintz, C.M., and Norona, R.C. 1982. Controlled atmosphere and ethylene effects on quality of California canning apricots and Clingstone peaches. J. Food Sci. 47: 432.

Buescher, R.W., Sistrunk, W.A., and Brady, P.L. 1975. Effects of ethylene on metabolic and quality attributes in sweet potato roots. J. Food Sci. 40: 1018.

Burg, S.P. and Burg, E.A. 1967. Molecular requirements for the biological activity of ethylene. Plant Physiol. 42: 144.

Carlton, B.C., Peterson, C.E., and Tolbert, N.E. 1961. Effect of ethylene and oxygen on production of a bitter compound by carrot roots. Plant Physiol. 36: 550.

Chaplin, G.R., Wills, R.B.H., and Graham, D. 1983. Induction of chilling injury in stored avocados with exogenous ethylene. HortScience 18: 952.

Denny, F.E. 1924. Hastening the coloration of lemons. J. Agric. Res. 27: 757.

de Wilde, R.C. 1971. Practical applications of (2-chloroethyl)phosphonic acid in agricultural production. HortScience 6: 364.

Ells, J.E. 1958. The influence of various factors on the induction of bitterness in stored carrots by ethylene and its detection by fluorescence. M.S. thesis, Michigan State Univ., East Lansing.

Forsyth, F.R., Eaves, C.A., and Lightfoot, H.J. 1969. Storage quality of McIntosh apples as affected by removal of ethylene from the storage atmosphere. Can. J. Plant Sci. 49: 567.

Gane, R. 1934. Production of ethylene by some ripening fruits. Nature 134: 1008.

Gull, D.D. 1981. Ripening tomatoes with ethylene. Vegetable Crops Fact Sheet VC 29. Florida Coop. Ext. Serv., Gainesville.

Haard, N.F., Sharma, S.C., Wolfe, R., and Frenkel, C. 1974. Ethylene induced isoperoxidase changes during fiber formation in postharvest asparagus. J. Food Sci. 39: 452.

Harvey, R.B. 1925. A new method of blanching celery. Minn. Horticulturist 53: 41.

Harvey, R.B. 1928. Artificial ripening of fruits and vegetables. Bull. 247. Minnesota Agric. Exp. Sta., St. Paul.

Hatton, T.T. and Cubbedge, R.H. 1973. Influence of ethylene on stored late-season 'Marsh' grapefruit. HortScience 8: 101.

Hatton, T.T. and Cubbedge, R.H. 1981. Effects of ethylene on chilling injury and subsequent decay of conditioned early 'Marsh' grapefruit during low-temperature storage. HortScience 16: 783.

Hicks, J.R., Ludford, P.M., and Masters, J.F. 1982. Effects of atmosphere and ethylene on cabbage metabolism during storage. In "Controlled Atmosphere for Storage and Transport of Perishable Agricultural Commodities," ed. D.G. Richardson and M. Meheriuk, p. 309. Timber Press, Beaverton, OR.

Ismail, A.A. 1974. Selective thinning of black barrenberry fruit in lowbush blueberry fields with ethephon. HortScience 9: 346.

Kitagawa, H., Kawada, K., and Tarutani, T. 1978. Effectiveness of ethylene degreening of certain citrus cultivars. J. Am. Soc. Hort. Sci. 103: 113.

Knee, M. 1976. Influence of ethylene on the ripening of stored apples. J. Sci. Food Agric. 27: 383.

Lee, S.K. and Young, R.E. 1984. Temperature sensitivity of avocado fruit in relation to ethylene treatment. J. Am. Soc. Hort. Sci. 109: 689.

Lipton, W.J. and Mackley, B.E. 1984. Ethylene and low-temperature treatments of honeydew melons to facilitate long-distance shipment. Agric. Res. Service ARS-10, U.S. Dept. of Agriculture, Fresno, CA.

Liu, F.W. 1976. Banana response to low concentrations of ethylene. J. Am. Soc. Hort. Sci. 101: 222.

Liu, F.W. 1977. Varietal and maturity differences of apples in response to ethylene in controlled atmosphere storage. J. Am. Soc. Hort. Sci. 102: 93.

Manzano-Mendez, J., Hicks, J.R., and Masters, J.F. 1984. Influence of storage temperature and ethylene on firmness, acids, and sugars of chilling-sensitive and chilling-tolerant tomato. J. Am. Soc. Hort. Sci. 109: 273.

McDonald, R.E., Hatton, T.T., and Cubbege, R.H. 1985. Chilling injury and decay of lemons as affected by ethylene, low temperature, and optimal storage. HortScience 20: 92.

Pendergrass, A., Isenberg, F.M.R., Howell, L.L., and Carroll, J.E. 1976. Ethylene-induced changes in appearance and hormone content of Florida grown cabbage. Can. J. Plant Sci. 56: 319.

Poenicke, E.F., Kays, S.J., Smittle, D.A., and Williamson, R.E. 1977. Ethylene in relation to postharvest quality deterioration in processing cucumbers. J. Am. Soc. Hort. Sci. 102: 303.

Redit, W.H. 1969. Protection of rail shipments of fruits and vegetables. Agric. Handbook 195, U.S. Dept. of Agriculture, Beltsville, MD.

Risse, L.A. and Hatton, T.T. 1982. Sensitivity of watermelons to ethylene during storage. HortScience 17: 946.

Rood, P. 1956. Relation of ethylene and postharvest temperature to brown spot of lettuce. Proc. Am. Soc. Hort. Sci. 68: 256.

Rugini, E., Bongi, G., and Fontanazza, G. 1982. Effects of ethephon on olive ripening. J. Am. Soc. Hort. Sci. 107: 835.

Shimokawa, K. 1973. Maceration of watermelon by ethylene evolved by the 'Prince' melon. Bull. Fac. Agric., Miyazaki Univ. 20: 365.

Sondheimer, E. 1957. The isolation and identification of 3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin in carrots. J. Am. Chem. Soc. 79: 5036.

Stewart, I. and Wheaton, T.A. 1972. Carotenoids in citrus: Their accumulation induced by ethylene. J. Agric. Food Chem. 20: 448.

Timbie, M. and Haard, N.F. 1977. Involvement of ethylene in the hardcore syndrome of sweet potato roots. J. Food Sci. 42: 491.

Wang, C.Y. 1985. Private communication. U.S. Dept. of Agriculture, Beltsville, MD.

Wang, C. Y., Mellenthin, W.M., and Hansen, E. 1972. Maturation of 'Anjou' pears in relation to chemical composition and reaction to ethylene. J. Am. Soc. Hort. Sci. 97: 9.

Wardowski, W.F. and McCornack, A.A. 1979. Recommendations for degreening Florida fresh citrus fruits. Cir. 389. Florida Coop. Ext. Serv., Gainesville.

Watada, A.E., Aulenbach, B.B., and Worthington, J.T. 1976. Vitamins A and C in ripe tomatoes as affected by stage of ripeness at harvest and by supplementary ethylene. J. Food Sci. 41: 856.

Wheaton, T.A. and Stewart, I. 1973. Optimum temperature and ethylene concentrations for postharvest development of carotenoid pigments in citrus. J. Am. Soc. Hort. Sci. 98: 337.

Young, R. and Jahn, O. 1972. Ethylene-induced carotenoid accumulation in citrus fruit rinds. J. Am. Soc. Hort. Sci. 97: 258.

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