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Ethylene Production in Netted Muskmelon Subjected to Postharvest Heating and Refrigerated Storage

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Abstract. Postharvest ethylene production and ACC levels were determined in netted muskmelon fruits (*Cucumis melo* L. var. *reticulatus* 'Magnum 45') exposed to temperature extremes by heating for 3 hr at 45C and/or storage at 4C. The possibility of using seal-packaging to protect the fruit against temperature-induced changes in ethylene production was examined by wrapping melons before treatment with a high-density polyethylene (HDPE) shrink-film. Ethylene production measured in fruit immediately after heating or removal from refrigeration was only 30% of the level determined before treatment, and continued to decline during refrigerated storage. However, the concentration of ACC in these same tissues remained constant or even increased slightly during storage. Wrapping fruit in HDPE film had no effect on the tissue concentrations of ACC or capacity for ethylene synthesis. In contrast to initial measurements, heated or refrigerated fruit held at room temperature (25C) for 24 hr produced ethylene at rates that equalled or exceeded the levels for freshly harvested fruit. These results strongly suggest that temperature-imposed restrictions on ethylene synthesis by netted muskmelon fruit are reversible and occur at the step responsible for converting ACC to ethylene via EFE rather than in the synthesis of ACC. Chemical names used: 1-aminocyclopropane-1-carboxylic acid (ACC).

During commercial harvest and storage operations, netted muskmelon fruit can be subjected to a 50C difference in temperature within 12 hr. For example, the internal temperature of muskmelon fruit can reach 42 to 47C when exposed to direct sunlight (Kasmire et al., 1961; Lipton et al., 1987). Solar heating of netted muskmelon fruit can accelerate softening and cause a loss of quality (Kasmire, et al., 1961). Immediately after harvest, netted muskmelon are routinely hy-

drocooled to near 10C and placed into storage at 4C (Hardenburg et al., 1986). Water heated to 57C has been used in conjunction with fungicides to control postharvest diseases in netted muskmelons (Carter, 1981). Postharvest exposure to high or low temperatures above freezing has been identified as the cause of injury and product losses in diverse fruits and vegetables (Ryan and Lipton, 1979; Weichmann, 1987).

Ripening in climacteric fruit, including netted muskmelon, is characterized by an increase in ethylene production coincident with an accelerated rate of senescence (McGlasson, 1985). This change is clearly demonstrated in netted muskmelon, where the postharvest life, even at 4C, is <14 days (Ryan and Lipton, 1979). Physical injury or wounding is capable of stimulating the synthesis of both ethylene and ACC, the im-

mediate precursor to ethylene, in preclimacteric as well as fully ripe muskmelon fruit (Dunlap and Andersen, 1985; Yang and Hoffman, 1984). Injury caused by exposure of fruit to extreme temperatures during postharvest handling may be reflected as a change in the ethylene biosynthetic mechanism. For example, ACC is reported to accumulate during refrigerated storage of 'Honey Dew' muskmelon (Lipton et al., 1987). Under certain conditions, increases in ethylene production can accelerate ripening and shorten the postharvest life of horticultural crops (Kader, 1985).

Although the mechanism of temperature injury remains unclear, the response in tomato and papaya has been attributed to a loss of membrane function and increased cellular leakage (Chan, 1986; Saltveit and Cabrera, 1987). Heating to 45C or storage of netted muskmelon fruit at 4C elevates solute leakage, indicating injury to the tissue (Lester et al., 1988). Protection from temperature injury has been achieved in other fruits and vegetables by individual seal-packaging in high-density polyethylene (HDPE) films (Ben-Yehosua, 1985). The individual seal-packaging effectively delays senescence and extends the shelf-life of citrus and bell pepper, presumably by decreasing the loss of tissue moisture. The storage life of refrigerated netted muskmelon fruit is extended by 30 days with HDPE shrink-film wrap (Lester and Bruton, 1986). Consequently, studies were conducted to determine the effect of temperature extremes present during commercial handling on the ethylene biosynthetic mechanism in netted muskmelon fruit and the protection against injury provided with film wrap packaging.

Full-slip, 'Magnum 45' netted muskmelon were harvested just after sunrise from a commercial field near Weslaco, Texas. All of the melons were dipped in Imazalil and one-half of the sample population wrapped in HDPE shrink-film wrap described by Lester et al. (1988). Each treatment was conducted with at least three melons. Wrapped and non-wrapped fruit were heated at 45C and 100% RH for 3 hr by incubation in a controlled-environment chamber. Internal fruit temperatures were monitored in the direction of the seed cavity with a thermocouple installed in a 76-mm hypodermic needle. After heat treatment, the fruit were packed in commercial fiberbox containers and refrigerated at 4 ± 1C and 90 ± 5% RH for 0, 6, 12, or 18 days. A subsample of untreated fruit was held at room temperature (25 C).

Using cork borers, tissue cylinders 8 mm in diameter were taken along the equatorial plane of each fruit and cut to uniform length of 30 mm. One tissue cylinder was placed

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Table 1. Ethylene production from 'Magnum 45' melons after postharvest exposure to low or high temperature.

Temperature treatment		Ethylene production	
Duration	Temp. (°C)	nl·g ⁻¹ ·hr ⁻¹	Control (%)
Cold Storage			
No storage	---	43 ± 6.3 ^a	100
6 days	25	47 ± 8.4	109
6 days	4	8 ± 3.1	23
6 days plus 24 hr at	25	35 ± 2.5	81
Heat-treated			
No heating	---	37 ± 7.6	100
3 hr	45	12 ± 5.4	32
3 hr plus 24 hr at	25	127 ± 27.0	302

^aMean ± SE for nine replications.

Fig. 1. Ethylene production (top) and ACC content (bottom) of 'Magnum 45' melon tissue samples from film-wrapped and non-wrapped fruit heated for 3 hr at 45C and/or stored at 4C. Control fruit was not wrapped or heated before storage. Vertical bars represent SE.

in each 12 × 75-mm glass tube and held at room temperature (25C) for 1 hr. After 1 hr, the glass tubes were capped with rubber serum stoppers and the gasses accumulated for 0.5 to 1.0 hr before sampling. A 1-ml sample of headspace gas was analyzed for ethylene using a gas chromatography equipped with flame ionization detector and alumina column. Tissue samples were homogenized in 80% ethanol and ACC determined according to Lizada and Yang (1979), with precautions taken to avoid interference within the assay extract (Neider et al., 1986). Three tissue cylinders were taken for ethylene and ACC analysis from three melons in each treatment (n = 9).

The high initial rates of ethylene produced by freshly harvested (control) fruit indicated

the presence of ongoing climacteric metabolism (Fig. 1). Heating the fruit for 3 hr at 45C immediately decreased the rate of ethylene production by ≈ 70%. Regardless of the prestorage treatment, ethylene production rates declined during the first 6 days of cold storage and remained low throughout the 18 days of storage. No differences in ethylene production were detected between wrapped and non-wrapped fruit (Fig. 1). Tissue levels of ACC were initially lower in heat-treated and/or wrapped fruit than in the controls (Fig. 1). However, ACC increased in all fruits during the first 6 to 12 days of refrigeration, with the highest concentrations accumulating in untreated control fruit. The levels of ACC remained the same or declined only slightly over the balance of the storage period.

Ethylene production by freshly harvested netted muskmelon fruit remained unchanged after holding at room temperature (25C) for 6 days (Table 1). During the same period, ethylene production by refrigerated fruit decreased to 23% of the original rate. Although severely inhibited by refrigeration, 81% of the original capacity for ethylene production was restored after subsequently holding the fruit at room temperature for 24 hr. Heating freshly harvested fruit to 45C for 3 hr reduced the capacity for ethylene production by nearly 70% (Table 1). However, when the heated fruit was held for 24 hr at room temperature (25 C), ethylene production exceeded the original level by 300%.

Freshly harvested netted muskmelon fruit continued to produce high levels of ethylene, associated with the climacteric, when held at room temperature. Consequently, the observed inhibition of ethylene production was a direct response to heat (45C) or refrigeration (4C) and not the progression of a naturally occurring decline. The accumulation of ACC in chilled fruit is partially responsible for the observed increases in ethylene production (Lipton and Wang, 1987; Lipton et al., 1987; Wang and Adams, 1982). The relatively constant levels of ACC found in refrigerated melons throughout storage fail to support the concept of ACC synthesis limiting ethylene production. ACC levels and ethylene production both decreased in heated fruit, implying a direct relationship. How-

ever, similar reductions in ACC content occurred in non-heated, wrapped fruit without any comparable loss of ethylene production (Fig. 1). These results support the conclusion that ACC is not regulating the decline in ethylene production characteristic of heated or refrigerated melons.

Cucumber, a chilling-sensitive fruit, loses the capacity to convert ACC to ethylene after low-temperature storage for 6 days (Wang and Adams, 1982). The inability of cucumber fruits to produce ethylene results from permanent damage to the ethylene-producing system. Similar damage is implied during the heat inactivation of EFE in cucumber, papaya, and apple fruit tissue (Apelbaum et al., 1981; Chan and Tam, 1982; Yu et al., 1980). Our results show that high- and low-temperature inactivation of ethylene production in netted muskmelon is reversible and occurs at the level of EFE. At certain temperatures, chilling-induced ethylene production in cucumber and 'Honey Dew' muskmelon and papaya resembles the characteristic ethylene response to physical injury (Chan et al., 1985; Lipton and Wang, 1987; Wang and Adams, 1980; Yang and Pratt, 1978). Netted muskmelon are less sensitive to chilling injury as indicated by successful storage at temperatures as low as 0C (Ryan and Lipton, 1979). Therefore, the low-temperature-induced ethylene response pattern may be somewhat different in netted muskmelon than in 'Honey Dew'. The elevated level of ethylene production in response to heat implies the presence of physical injury to the fruit tissue. The same response might have developed in refrigerated fruit if held at room temperature for a longer period of time.

Netted muskmelons are relatively resistant to immediate injury resulting from exposure to heat or refrigeration. Neither the sugar content (Lingle et al., 1987) nor the appearance (personal observation) of the fruit was adversely affected by the temperature treatments. In spite of the increased solute leakage symptomatic of decreased membrane function in non-wrapped fruit (Lester et al., 1988), wrapping fruit with HDPE film provided no obvious protection against temperature-induced changes in the ethylene production patterns during our experiments. This result surprised us in view of the relationship between membrane integrity and solute leakage that is considered a prerequisite to proper functioning of EFE (Yang and Hoffman, 1984).

Our study has demonstrated the capacity of refrigerated storage to temporarily disrupt ethylene production by, presumably, inhibiting EFE. Heat has a similar effect but seems to elicit a wound response characterized by an increase in ethylene production. Although wrapping fruit with HDPE film delays physical deterioration during prolonged storage (Lester and Bruton, 1986), no effect was detected with regard to temperature-induced changes in ethylene synthesis. These results suggest that the expression of physiological damage initiated during postharvest exposure to high or low temperatures and asso-

ciated with elevated ethylene production is delayed during refrigerated storage. However, the return of fruit to room temperature quickly re-establishes ethylene production and, presumably, the natural progression of senescence underlying the decline in melon shelf-life.

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Conditioning of Florida Grapefruit to Reduce Peel Stress during Low-temperature Storage

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Abstract. 'Thompson' pink grapefruit (*Citrus paradisi* Macf.), waxed or film-wrapped, treated with thiabendazole (TBZ) or untreated, were used to determine the effect of high-temperature conditioning at 31C for 3 days on fruit during subsequent storage for 4 weeks at 1 or 10C. Chilling injury (CI) developed in all conditioned fruit stored at 1C, but was drastically reduced in film-wrapped compared to waxed fruit. Thiabendazole slightly reduced CI, and fruit held at 10C had fewer CI symptoms than those held at 1C for 4 weeks. Conditioning Florida grapefruit at 31C for 3 days did not allow subsequent storage at 1C without rind discoloration. Chemical name used: 2-(4'-thiazolyl)-benzimidazole (thiabendazol, TBZ).

Grapefruit harvested after 1 Jan. in Florida are generally more susceptible to attack by the Caribbean fruit fly (*Anastrepha suspensa* Loew.) than early season fruit. All fruit, except those harvested from certified, fly-free zones, must be subjected to an approved quarantine treatment before entry into Japan. The only approved quarantine treatments for grapefruit imported by Japan from Florida are cold treatment and methyl bromide fumigation (U.S. Department of Agriculture, 1976). The cold treatment has proved quite effective for grapefruit, but it must be carefully and precisely conducted by commercial packers or export shippers (Ismail et al., 1986). The approved time/temperature regimes for cold treatment are 0.6C for 11 days,

1.1C for 12 days, 1.6C for 14 days, or 2.2C for 17 days (U.S. Department of Agriculture, 1976). To reduce or eliminate chilling injury (CI), grapefruit must be conditioned for 7 days at 16C (90% ± 5% RH) before the fruit are exposed to the cold treatment (Chalutz et al., 1985; Hatton and Cubbedge, 1981, 1982, 1983). In some commercial lots, however, receivers have observed CI on grapefruit following cold treatment and subsequent commercial storage and/or transport.

Hopkins and Loucks (1948) reported that "curing" (conditioning) of citrus fruits at 30C for up to 72 hr provided protection against penicillium rots. Later, Ismail and Brown (1975) and Brown et al. (1978) demonstrated that lignin formation at wounded sites on the peel of oranges held at 30C for 48 hr provided a barrier that retarded the penetration to injured tissue by the mycelium of *Penicillium digitatum*.

Thiabendazole was found to reduce CI as well as decay in grapefruit (Schiffmann-Nadel et al., 1972; Wardowski et al., 1975), and plastic film wrapping reduced CI in

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