Cady, S. 1995. Strawberry Package Comparison. Hillsborough County Coop. Ext. Serv. Research Rept. 8 p.
Emond, J. P., F. Mercier, S. O. Sadfa, M. Bourre, and A. Gakwaya. 1996. Study of parameters affecting cooling rate of strawberry and airflow patterns in forced-air precooling process. ASAE paper FPE-1269. Amer. Soc. Agr. Eng., St. Joseph, MI. 34 p.
Florida Department of Agriculture and Consumer Services. 1996. Florida Agricultural Statistics. Vegetable Summary 1994-1995. Fla. Agric. Statistics Serv., Fla. Dept. Agric. & Consumer Serv., Orlando.
Kader, A. A., R. F. Kasmire, F. G. Mitchell, M. S. Reid, N. F. Sommer, and J. F. Thompson. 1985. Postharvest technology of horticultural crops. California Coop. Ext. Serv. Pub. 3311.
Mitchell, F. G., R. Guillou, and R. A. Parsons. 1972. Commercial cooling of fruits and vegetables. California Agr. Expt. Sta. Man. 43.
Parsons, R. A., F. G. Mitchell, and G. Mayer. 1970. Forced-air cooling of palletized fresh fruit. ASAE Paper No. 70-875. Amer. Soc. Agr. Eng., St. Joseph, MI. 12 p.
Sargent, S. A., M. T. Talbot, and J. K. Brecht. 1988. Evaluating precooling methods for vegetable packinghouse operations. Proc. Fla. State Hort. Soc. 101:175-182.
Singh, S. P. 1991. New package system for fresh strawberries and raspberries. ASAE paper 91-6017. Amer. Soc. Agr. Eng., St. Joseph, MI. 15 p.
Talbot, M. T. and C. D. Baird. 1991. Evaluating commercial forced-air precoolers. ASAE Paper 91-6021. Amer. Soc. Agr. Eng., St. Joseph, MI. 20 p.
Talbot, M. T., S. A. Sargent, C. D. Baird, and J. K. Brecht. 1993. Design and evaluation of a standardized pepper container. ASAE Paper 93-6009. Amer. Soc. Agr. Eng., St. Joseph, MI. 23 p.

Proc. Fla. State Hort. Soc. 108:268-272. 1995.

TOMATO COLOR DEVELOPMENT FOLLOWING EXPOSURE TO ETHYLENE AT HIGH TEMPERATURES

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Abstract. **Tomato (*Lycopersicon esculentum* L. Mill.) fruit ripening is reversibly inhibited at high temperatures (30C and above). In this study, the ability of tomatoes to respond to ethylene treatment at high temperatures in terms of red color development was investigated. Mature green (MG) Agriset 761 tomato fruit were exposed to 100 ppm ethylene at 20, 25, 30, 35, or 40C and 95% relative humidity (RH) for 24, 48, or 72 hr, then transferred to air at 20C for ripening. Tomatoes exposed to ethylene at high temperatures for 24 hr showed little difference in color development compared to those exposed to ethylene at lower temperatures. Increasing the duration of ethylene/high temperature treatment to 48 and 72 hr at 35 or 40C inhibited subsequent red color development at 20C while prior exposure to 30C stimulated color development. These results suggest that tomatoes can perceive ethylene at high temperatures, but are slow to respond in terms of color development until transferred to a lower temperature.**

Tomatoes are produced in Florida over about a nine-month season from late September through June, with the areas of production moving from northern Florida in the early fall to southern Florida in the winter, and the reverse occurring in the spring. Tomato is the highest valued vegetable grown in Florida, accounting for about 30 percent of the total production value among major Florida vegetables during the 1993-1994 season (Freie and Pugh, 1995). The average value of the Florida fresh market tomato crop for the years 1989-1994 was $574.3 million (Freie and Pugh, 1995).

About 85% of the tomatoes produced in Florida are harvested when green and ripened after harvest (Fla. Tomato Comm., 1995). The harvest operation usually begins in mid-morning, and harvested tomatoes are accumulated in field bins or gondolas before transport to the packinghouse. Harvested tomatoes are usually held under shade cover until they are run over the packingline. The packinghouse operations are typically begun in the afternoon and continue until that day's harvest has been processed. The first step in the packinghouse operation is the dumping of tomatoes from the field bins or gondolas into a heated, chlorinated water receiving tank. The water in the receiving tank is maintained 5C higher than the highest fruit pulp temperatures to avoid infiltration of decay organisms into the tomatoes (Sherman et al., 1981). The tomatoes are then washed, treated with waxes or other food grade coatings, graded, sized, packed in shipping containers, and the containers stacked on pallets.

Mature green tomatoes are commonly treated with supplementary ethylene at about 20 to 21C and 85 to 95 percent RH in ripening rooms to provide for faster and more uniform ripening (Hardenburg et al., 1986). Tomatoes are typically held in the ripening rooms for 1 to 3 days, with daily inspections to determine when almost all the fruit have begun to develop red color. Although the ripening rooms used to treat MG tomatoes with ethylene are maintained at 20 to 21C, the pulp temperature of fruit placed in these rooms may be well over 30C (Brecht and Sargent, unpublished). Tomato ripening rooms are generally not designed for efficient cooling of the tomatoes (Sherman and Talbot, 1986). Thus, it is likely that tomatoes may remain above 30C for a substantial time while being treated with ethylene in ripening rooms. After removal from ripening rooms, tomatoes are usually shipped to market in refrigerated trucks at about 12 to 15C.

Tomato color development during ripening and postharvest storage is influenced by many factors. Under normal dis-

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tribution and storage circumstances, however, color development depends for the most part on temperature, initial maturity and storage duration (Tijskens and Evelo, 1994). Tomato fruit ripening, as indicated by red color (lycopene) development, is reversibly inhibited at temperatures above 30C (Atta-Aly, 1992; Cheng et al., 1988). For example, 'Sunny' tomato fruit at the breaker stage were held at 30, 35, or 40C and then transferred to a ripening room at 20C. After transfer, increasing delays in red color development were observed that corresponded to the temperature and time of exposure to high temperatures (Atta-Aly and Brecht, 1995). When Cheng et al. (1988) treated MG tomato fruit with ethylene, stored them at 37C for 3 or 7 days, then ripened them at 21C, red color development was delayed by the high temperature treatment, but developed rapidly when the tomatoes were transferred to 21C. The delay in color development at high temperatures is thought to be caused by inhibition of lycopene biosynthesis or that of its precursors phytofluene and phytoene (Yakir et al., 1984). Incubation of 'Rutgers' tomato fruit at 34C or above also resulted in a marked decrease in ripening-associated ethylene production (Biggs et al., 1988).

Florida often experiences temperatures greater than 30C during parts of the tomato harvest season, especially early and late in the season. When harvested fruit are left in the field or outside the packinghouse, they may warm substantially. Temperatures up to 49C have been measured in tomato fruit that were exposed to sunlight for 1 hr (Bartz, 1995). High temperature exposure also occurs when tomato fruit are attached to the plant. Midsummer, field-grown tomatoes in warm growing regions are often subjected to high temperatures during portions of the day, resulting in inhibition of lycopene development, but lower temperatures at night permit lycopene formation during part of the 24 hours on most days (MacGillivray, 1934). In Japan, undesirable color changes from green to yellow (abnormal coloring) on the surface of 'Momotaro' tomato fruit were observed after harvest due to high temperatures (Maezawa et al., 1993). Yakir et al. (1984) also reported that processing tomatoes left to ripen at high temperatures had undesirable quality as indicated by poor color development.

High temperature exposure of fruits and vegetables can also have beneficial effects. Postharvest heat treatments have been developed or proposed for insect disinfestation or disease control of several fruits, including mangoes, papayas and tomatoes (Couey, 1989). For example, holding inoculated MG and pink tomatoes for 3 days at 38C completely inhibited decay caused by *Botrytis cinerea*, one of the main postharvest pathogens of tomatoes in Israel (Fallik et al., 1993). Heat treatments have also been reported to protect against physiological disorders such as chilling injury and to be useful for regulation of ripening (Klein and Lurie, 1992; Paull, 1990). Mature green tomatoes held for 3 days at 36, 38 or 40C, then exposed to 2C for 3 weeks did not develop chilling injury, but ripened more slowly than freshly picked fruit (Lurie and Klein, 1991, 1992).

Considering the potential positive and negative effects of high temperature exposure on tomato fruit, we wondered how lack of efficient cooling prior to being placed in ripening rooms might be affecting the response of MG tomatoes to ethylene treatment. The ripening response of tomatoes in terms of color development following exposure of MG fruit to ethylene at high temperatures has not previously been investigated. Therefore, the objective of this study was to investigate the influence of high temperatures on the effectiveness of exogenous ethylene in promoting MG tomato fruit ripening as measured by color development.

Materials and Methods

Mature green, large size 'Agriset 761' and 'Sunny' tomato fruit were obtained from a commercial packinghouse in the Ruskin area on the day of harvest, or picked from plots at the IFAS NFREC, Quincy, transported to Gainesville, and stored overnight at 8C. The tomatoes were re-graded, and fruit that were wounded or showing red color development were discarded. Three buckets, each containing 30 fruit, were placed at each of the following five temperatures: 20, 25, 30, 35 or 40C at 95% RH and treated with 100 ppm ethylene. Ethylene was applied by mixing air and ethylene at constant pressure in a flow through system via a gas mixing board utilizing needle valve flowmeters. High RH was maintained by bubbling the gas mixtures through water before entering the storage chambers. After 24, 48 or 72 hr, the fruit were moved to air at 20C and 95% RH for ripening.

While at the ripening temperature (i.e. 20C), the color of three, 10-fruit replicates of tomato fruit per time-temperature combination was measured daily for up to 11 days using a Hunterlab Color Quest colorimeter (Hunter Assoc., Reston, Virginia) fitted with a 2.5-cm viewing port and aided by a Zenith 286 computer. Light reflected by the specimen is picked up by a three-element optical sensor in the colorimeter, the output from which is converted into color specifications which are presented in alphanumeric form as three parameters: L*, a measure of lightness on a scale of 0 (black) to 100 (white); a*, which denotes greenness when negative and redness when positive; and b*, denoting blueness when negative and yellowness when positive (Hobson et al., 1983). The hue was calculated from a* and b* values as follows: hue = $\tan^{-1} b^*/a^*$, representing the shade of color. Chroma was calculated as follows: chroma = $(a^{*2}+b^{*2})^{1/2}$, representing the purity of color of a specific hue. The surface color of the tomatoes was measured at random spots near the blossom end of each fruit (Hobson et al., 1983). The results of these experiments were analyzed as a completely randomized design using Analysis of Variance (ANOVA) and Least Significant Difference (LSD) values calculated at the 5% level using the Statistical Analysis System (SAS, 1986). The results presented here are for 'Agriset' fruit; results obtained with 'Sunny' fruit were similar.

Results

L Value.* The L* value of the fruit following treatment with 100 ppm ethylene generally decreased with time of air exposure at 20C. There were no significant differences in L* values for fruit previously exposed to ethylene at the five temperatures for 24 hr or 48 hr (Fig. 1A and B). However, fruit treated with ethylene for 72 hr at 40C had significantly ($P<0.05$) higher L* values than fruit treated at 20, 25, 30, or 35C (Fig. 1C).

a Value.* The a* value of the fruit generally increased with ripening time at 20C in all treatments. There were no a* value differences among fruit treated with ethylene at 20, 25, 30, 35, or 40C for 24 hr (Fig. 2A). However, there were significant ($P<0.05$) differences in the a* values of fruit treated with ethylene at 20, 25, 30, 35 or 40C for 48 or 72 hr (Fig. 2B and C). Fruit previously exposed to ethylene at 30C for 48 or 72 hr

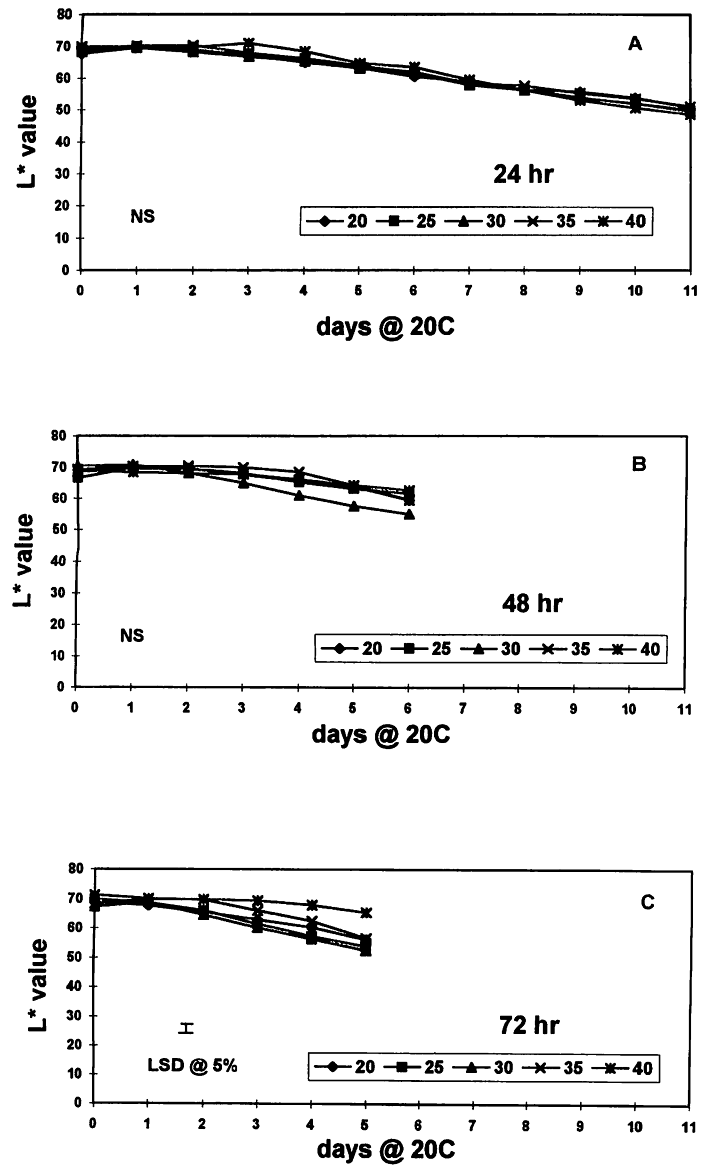

Figure 1. The L* value of tomatoes during ripening in air at 20C following treatment with 100 ppm ethylene at 20, 25, 30, 35 or 40C for 24 (A), 48 (B) or 72 hr (C).

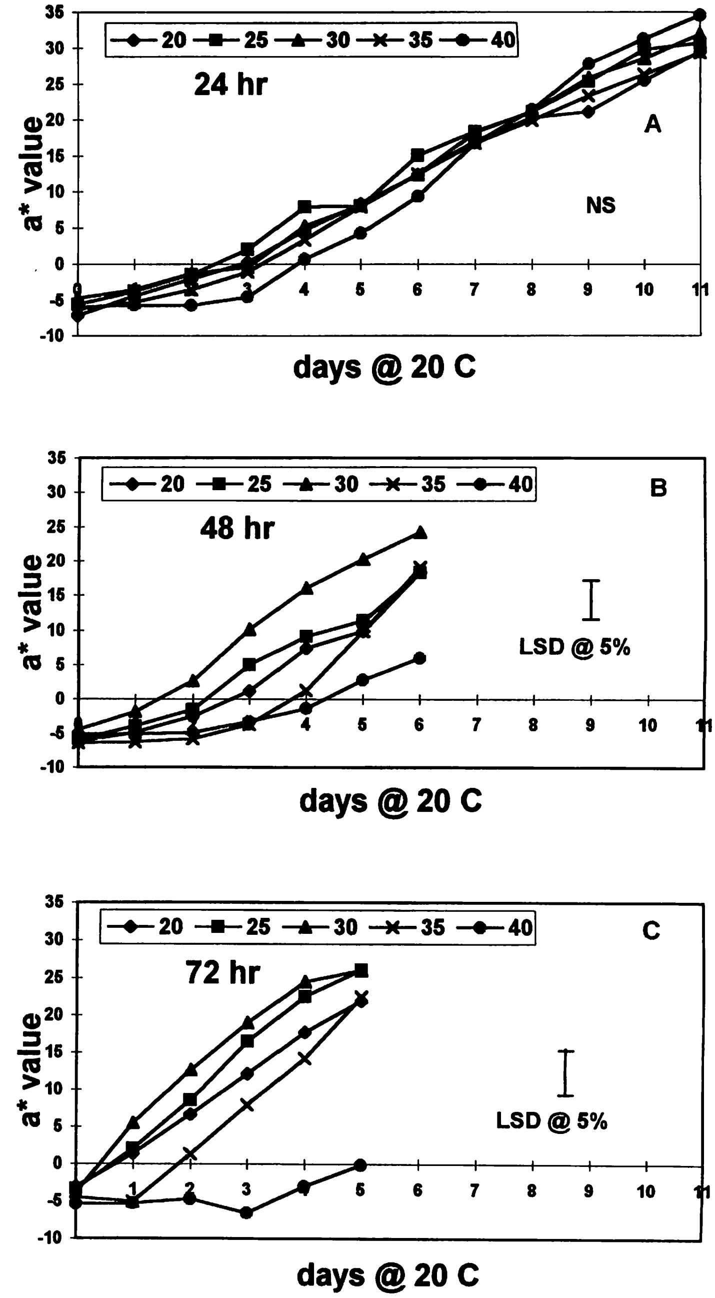

Figure 2. The a* value of tomatoes during ripening in air at 20C following treatment with 100 ppm ethylene at 20, 25, 30, 35 or 40C for 24 (A), 48 (B) or 72 hr (C).

had the highest a* values, while fruit exposed to ethylene at 40C for 48 or 72 hr had the lowest a* values. Fruit exposed to ethylene at 20, 25, and 35C for 48 or 72 hr had intermediate a* values.

Hue. The hue of the fruit decreased with ripening time at 20C in all treatments. There were no hue differences observed for fruit treated with ethylene for 24 hr at the various temperatures (Fig. 3A). The hue declined slowly in fruit treated with ethylene for 48 hr and 72 hr at 35 and 40C (Fig. 3B and C). Fruit previously treated with ethylene at 20, 25 and 30C for 48 or 72 hr showed similar and more rapid declines in hue with ripening time for the duration of the experiment.

Chroma. The chroma of the fruit increased with ripening time at 20C for all treatments. There were no chroma differences for fruit treated with ethylene for 24 hr or 48 hr (Fig. 4A and B). However, fruit treated with ethylene for 72 hr did show chroma change differences, with fruit previously exposed to 40C changing chroma more slowly and maintaining the lowest chroma values compared to fruit from the other temperatures (Fig. 4C).

Discussion

Tomatoes exposed to ethylene at high temperatures (≥30C) for 24 hr showed no significant differences in subsequent red color development after removal to 20C in air when compared to fruit treated with ethylene at lower temperatures (20 or 25C). It is possible that exposing the tomatoes to high temperatures for only 24 hr did not impair the ability of the fruit to perceive and respond to ethylene as far as induction of color change is concerned. It is not known how long it took for the tomatoes to reach the treatment temperatures in these experiments. Fruit previously exposed to

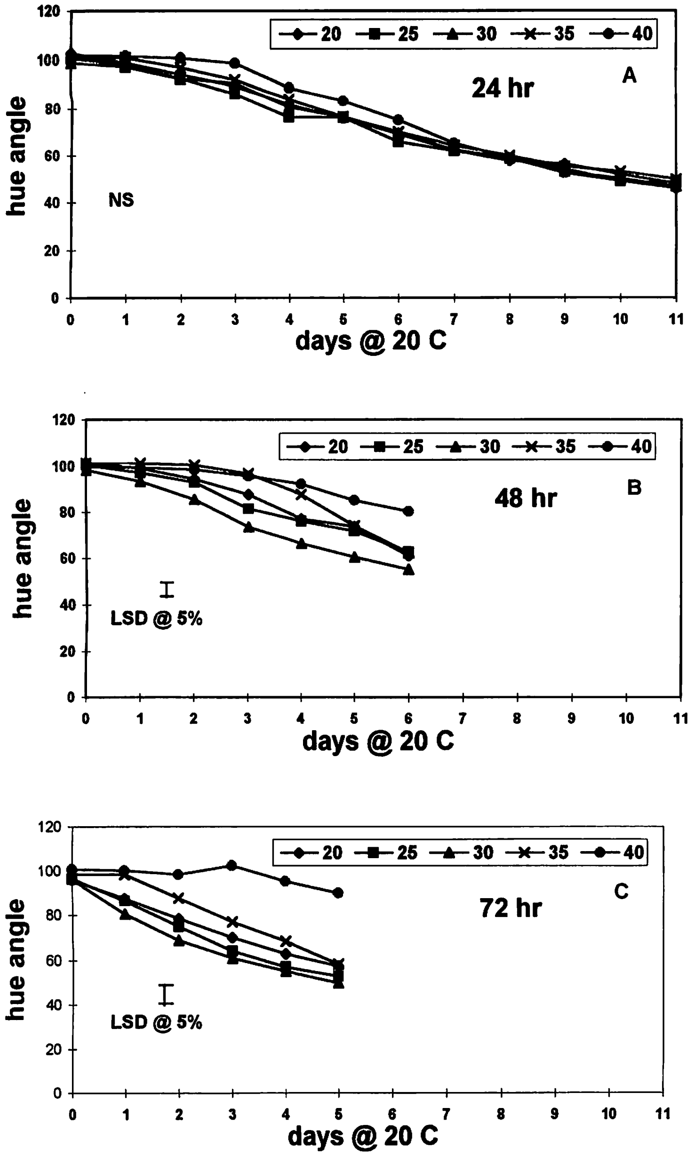

Figure 3. Hue angle values of tomatoes during ripening in air at 20C following treatment with 100 ppm ethylene at 20, 25, 30, 35 or 40C for 24 (A), 48 (B) or 72 hr (C).

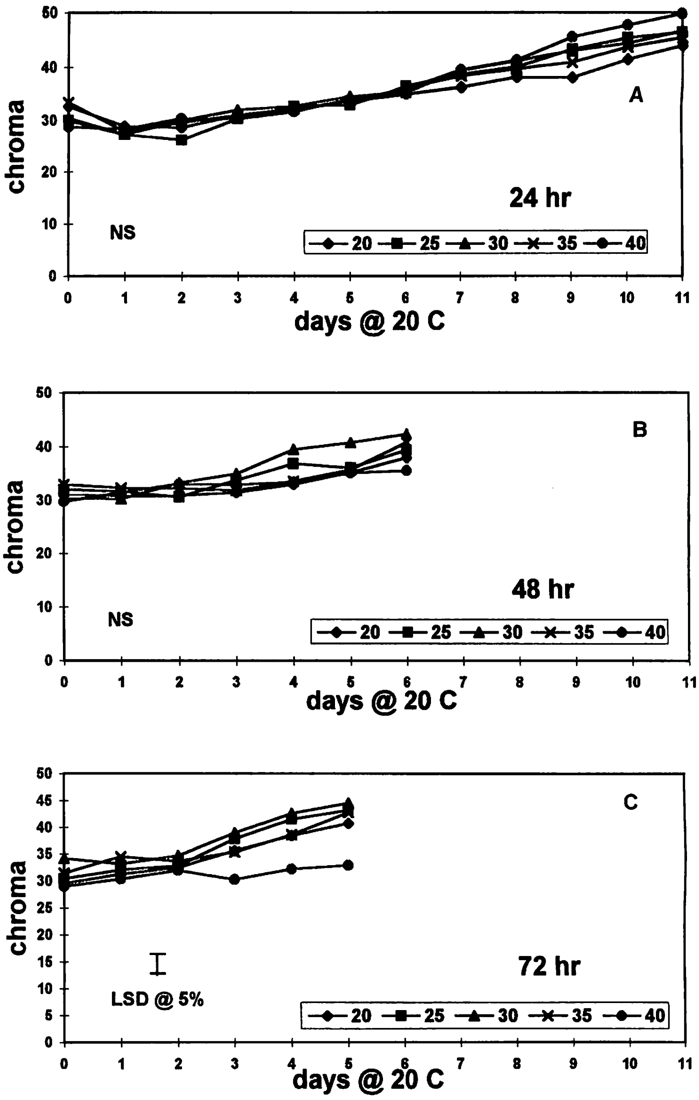

Figure 4. Chroma values of tomatoes during ripening in air at 20C following treatment with 100 ppm ethylene at 20, 25, 30, 35 or 40C for 24 (A), 48 (B) or 72 hr (C).

ethylene at 30C for 48 or 72 hr ripened faster after removal to 20C than fruit exposed to ethylene at 20, 25 or 35C, while fruit subjected to 40C remained green (Fig 2). Fruit exposed to ethylene at 35C for 48 or 72 hr ripened slowly for the first 4 days or 1 day, respectively, after transfer to 20C, but thereafter ripened at the same rate as fruit exposed to ethylene at 20 or 25C for the same period.

Tomatoes exposed to ethylene at 35 or 40C for 48 or 72 hr showed a delay or inhibition of red color development at 20C. The inhibition of red color development in tomatoes while at high temperatures has previously been reported (Cheng et al., 1988; Yakir et al., 1984; Maezawa et al., 1993). However, in those previous studies the fruit were not treated with ethylene while at the high temperatures. The delay in red color development at high temperatures may be caused by inhibition of lycopene biosynthesis. With the exception of *beta*-carotene and possibly prolycopene, lycopene synthesis was drastically inhibited at 32C in every tomato strain which produced this pigment (Tomes, 1963). Jeffery et al. (1984) determined that formation of lycopene by tomatoes requires ethylene. Thus, the lack of red color development during ethylene treatment at high temperatures in these experiments suggests an inability of the fruit either to perceive or respond to ethylene. However, ethylene treatment at 30C stimulated subsequent red color development by the tomatoes in air at 20C. This would imply that the signal (i.e. ethylene) was perceived at 30C, but that some step(s) in signal transduction must have been blocked, preventing color development while the fruit were at that temperature.

The progressive inhibition of red color development at 20C following longer exposure times at 40C suggests the occurrence of progressive injury. Color development at 20C was also inhibited following ethylene treatment at 35C but the lag time before onset of red color development decreased as the time at 35C was increased from 48 to 72 hr. This suggests that ethylene perception was not completely blocked at 35C. Biggs et al. (1988) reported that ethylene production by tomatoes was progressively inhibited at temperatures above 30C, being inhibited by about 75% at 34C compared to control fruit at 22C and completely inhibited at 37C. However, they also observed a rapid recovery of ethylene production upon transfer of tomato fruit to 25C following exposure to 35C - within 12 hr for breaker to turning stage tomatoes held for 48 hr at 35C, and within 24 hr for MG fruit exposed to 35C for 7 days. Therefore, the lag time in red color development observed in this study was probably not due to a lag in resumption of ethylene production following exposure to 35C, but rather due to lack of ethylene perception while the fruit were at that temperature and possibly a requirement for repair of pigment synthesis mechanisms. Inhibition of ethylene production while the tomatoes were at high temperatures should not have been a factor in our experiments since the fruit were exposed continuously to 100 ppm ethylene while at the high temperatures. It is not possible to know if the tomatoes exposed to ethylene at 40C for 48 to 72 hr would have eventually developed red color equivalent to fruit from the lower temperature treatments, however this appeared to be unlikely in light of evidence of physical injury in the form of water soaked lesions and decay that appeared 5 or 6 days after transfer from 40C for 48 or 72 hr, respectively.

Conclusions

This is the first study of the ripening behavior of MG tomatoes treated with ethylene at high temperatures. The results reported here show that there is little difference in color development of tomatoes exposed to ethylene at high temperatures for 24 hr compared to tomatoes treated with ethylene at lower temperatures. Tomatoes treated with ethylene at 35C and above for longer periods (48 or 72 hr) exhibited delayed color development upon transfer to 20C while tomatoes treated with ethylene at 30C had stimulated color development. This suggests that tomatoes can perceive ethylene at high temperatures but can not respond until transferred to a lower temperature (in this case, 20C) and that 30C appears to be the optimum temperature for ethylene perception under the conditions of this experiment. It is likely that the processes of ethylene synthesis, perception, and signal transduction in tomato fruit are altered at high temperatures but are subsequently restored upon transfer of fruit to air at 20C.

The practical significance of this information is that it appears unlikely that color development is being negatively affected when warm tomatoes are placed in ripening rooms at 20 to 21C for ethylene treatment. Even though the ripening rooms are not designed for efficient cooling, it seems unlikely that, under normal conditions, the tomatoes would remain at 35C or above for 48 hr or more, as shown here to be necessary for inhibition of red color development to occur. However, it remains to be seen how other aspects of tomato physiology, especially susceptibility to decay, might be affected by warm temperatures during ethylene treatment.

Literature Cited

Atta -Aly, M. A. 1992. Effect of high temperature on ethylene biosynthesis by tomato fruit. Postharvest Biol. Technol. 2:19-24.

Atta-Aly, M. A. and J. K. Brecht. 1995. Effect of postharvest high temperature on tomato fruit ripening and quality, p. 250-256. In: A. Ait-Oubahou and M. El-Otmani (eds.) Postharvest Physiology, Pathology and Technologies for Horticultural Commodities: Recent Advances. Inst. Agron. Vet. Hassan II, Morocco.

Bartz, J. A. 1995. Control of postharvest bacterial diseases of vegetables. Citrus and Vegetable Magazine. October, 1995. 45-47.

Biggs, M. S., W. R. Woodson, and A. K. Handa. 1988. Biochemical basis of high-temperature inhibition of ethylene biosynthesis in ripening tomato fruits. Physiol. Plant. 72:572 -578.

Cheng, T.-S., J. D. Floros, R. L. Shewfelt, and C. J. Chang. 1988. The effect of high temperature stress on ripening of tomatoes (*Lycopersicon esculentum*). J. Plant Physiol. 132:459-464.

Couey, H. M. 1989. Heat treatment for control of postharvest diseases and insect pests of fruits. HortScience 24:198-202.

Fallik, E., J. Klein, S. Grinberg, E. Lomaniec, S. Lurie, and A. Lalazar. 1993. Effect of postharvest heat treatment of tomatoes on fruit ripening and decay caused by *Botrytis cinerea.* Plant Disease. 77:985-988.

Florida Tomato Committee. 1995. Annual Report. 1994-1995. Florida Tomato Committee, Orlando, FL.

Freie, R. L. and N. L. Pugh. 1995. Florida Agricultural Statistics. Vegetable Summary 1993-1994 season. Florida Agr. Stat. Serv. Orlando.

Hardenburg, R. E., A. E. Watada, and C. Y. Wang. 1986. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. USDA Handbook Number 66.

Hobson, G. E., P. Adams, and T. J. Dixon. 1983. Assessing the color of tomato fruit during ripening. J. Sci. Food Agr. 34:286-292.

Jeffery, D., C. Smith, P. W. Goodenough, I. Prosser, and D. Grierson. 1984. Ethylene-independent and ethylene-dependent biochemical changes in ripening tomatoes. Plant Physiol. 74:32-38.

Klein, J. D. and S. Lurie. 1992. Heat treatment for improved postharvest quality of horticultural crops. Hort. Technol. 2:316-320.

Lurie, S. and J. D. Klein. 1991. Acquisition of low-temperature tolerance in tomatoes by exposure to high-temperature stress. J. Amer. Soc. Hort. Sci. 116:1007-1112.

Lurie, S. and J. D. Klein. 1992. Ripening characteristics of tomatoes stored at 12°C and 2°C following a prestorage heat treatment. Sci. Hort. 51:55-64.

MacGillivray, J. H. 1934. The variation in temperature of tomatoes and their color development. Proc. Amer. Soc. Hort. Sci. 32:529-531.

Maezawa, S., H. Yamada, and K. Akimoto. 1993. Postharvest yellowing of tomato 'Momotaro' as a function of maturity and ripening temperature. J. Japan. Soc. Hort. Sci. 62:647-653.

Paull, R. E. 1990. Postharvest heat treatments and fruit ripening. Postharvest News and Info. 1:355-363.

SAS Institute 1986. SAS/STAT User's Guide. SAS Inst., Cary, NC.

Sherman, M. and M. T. Talbot. 1986. Simple modifications that improve air distribution within tomato ripening rooms. Fla. Coop. Ext. Serv. Veg. Crops Fact Sheet VC-35.

Sherman, M., R. K. Showalter, J. R. Bartz, and G. W. Simone. 1981. Tomato packinghouse dump tank sanitation. Fla. Coop. Ext. Serv. Veg. Crops Fact Sheet VC-31.

Tijskens, L. M. M. and R. G. Evelo. 1994. Modelling color of tomatoes during postharvest storage. Postharvest Biol. and Technol. 4:85-98.

Tomes, M. L. 1963. Temperature inhibition of carotene synthesis in tomato. Bot. Gaz. 124:180-184.

Yakir, D., A. Sadovski, H. R. Rabinowitch, and J. Rudich. 1984. Effect of high temperature on quality of processing tomatoes of various genotypes ripened off vine. Sci. Hort. 23:323-330.