Differences in bruising and respiration rate could be helpful in managing packing operation temperature and attaining maximum postharvest life for these new cherry cultivars. A critical review of the actual harvesting, hauling, cooling, and packing operations should be done to identify when and how fruit damage occurs. After doing so, steps can be taken to reduce or eliminate these problems.

Literature Cited

- Ceponis, M.J., R.A. Cappellini, and G.W. Lightner. 1987. Disorders in sweet cherry and strawberry shipments to the New York market, 1972–1984. *Plant Dis.* 71:472–475.
- Crisosto, C.H., D. Garner, J. Doyle, and K. Day. 1992. Evaluation of the maturity index for cherry varieties. *Perishables Handling Postharvest Nwsl.*, Coop. Ext., Univ. of California, Davis. 73:4–7.
- Gerhardt, F., H. English, and E. Smith. 1942. Respiration, internal atmosphere, and moisture studies of sweet cherries during storage. *Proc. Amer. Soc. Hort. Sci.* 41:119–123.
- Kupferman, E. and R. Ebel. 1989. Cherry warehouse survey report. *Wash. State Univ. Postharvest Pomol. Nwsl.* 7(1):4–8.
- Lidster, P.D. and M.A. Tung. 1980. Effects of fruit temperature at time of impact damage and subsequent storage temperature and duration on the development of surface disorders in sweet cherries. *Can. J. Plant Sci.* 60:555–559.
- Micke, W.C., F.G. Mitchell, and E.C. Maxie. 1965. Handling sweet cherries for fresh shipment. *Calif. Agr.* 19(4):12–13.
- Mitchell, F.G. 1987. Influence of cooling and temperature maintenance on the quality of California grown stone fruit. *Rev. Intl. Froid* 10:77–81.
- Nanos, G. and G.M. Mitchell. 1991. High-temperature conditioning to delay internal breakdown development in peaches and nectarines. *Hort-Science* 26:882–885.
- Neter, J., W. Wasserman, and M.H. Kutner. 1983. Applied linear regression models. Richard D. Irwin, Homewood, Ill.
- Ogawa, J.M., E. Bose, B.T. Manji, and W.R. Schraeder. 1972. Bruising of sweet cherries resulting in internal browning and increased susceptibility to fungi. *Phytopathology* 72:579–580.
- Overholser, E.L. 1932. The cold storage behavior of cherries. *Proc. Amer. Soc. Hort. Sci.* 22:54–58.
- Patten, K.D. and M.E. Patterson. 1985. Fruit temperature effects on mechanical damage of sweet cherries. *J. Amer. Soc. Hort. Sci.* 110:215–219.
- Ramsey, P.H. 1978. Power differences between pair-wise multiple comparisons. *J. Amer. Stat. Assn.* 73:363.
- Ryugo, K. 1988. Fruit culture, its science and art. Wiley, New York.
- SAS Institute, Inc. 1988. SAS/STAT user's guide. Release 6.03 ed. SAS Inst., Cary, N.C.
- Sommer, N.F., F.G. Mitchell, R. Guillou, and D.A. Luvisi. 1960. Fresh fruit temperatures and transit injury. *Proc. Amer. Soc. Hort. Sci.* 76:156–162.

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Ethylene Production and Fruit-softening Rates in Several Apple Fruit Ripening Variants

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Abstract. Ethylene production and fruit softening during postharvest storage of several apple (*Malus domestica* Borkh.) ripening variants were compared with two standard cultivars. PA14-238 and D101-110 produced only low levels of ethylene ($<10 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{hour}^{-1}$) at harvest and throughout most of 86 days of storage at 4°C, whereas 'Red Chief Delicious' and 'Golden Delicious' fruit produced $>100 \mu\text{L}$ ethylene/kg per hour during the same time period. PA14-238 and D101-110 flesh disks converted aminocyclopropane-1-carboxylic acid (ACC) but not methionine (MET) to ethylene. 'Red Chief Delicious' readily converted both MET and ACC to ethylene at the end of cold storage. PA14-238 fruit were the firmest and did not soften during postharvest storage; however, D101-110 softened appreciably. NJ55 did not produce ethylene at harvest, but produced a significant amount of ethylene ($90 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{hour}^{-1}$) during storage. Despite its high capacity to produce ethylene, NJ55 remained nearly as firm as PA14-238 at the end of cold storage.

Ethylene production is closely associated with fruit ripening. Apple harvest date is often determined by the ethylene climacteric exhibited by the fruit (Chu, 1988), and ethylene production generally coordinates and maintains fruit ripening processes. While increased soluble solids concentration, reduced acidity, volatiles production, and the stimulation of

anthocyanin synthesis in the peel contribute to fruit quality, excessive softening and attendant physiological disorders reduce fruit storage life. Environmental conditions have been manipulated to increase fruit storage life. Using low temperature, hypobaric pressure, and low O_2 tensions may maintain fruit firmness by inhibiting ethylene production or physiological function. Chemical treatments such as applying butanedioic acid mono(2,2-dimethylhydrazide) (daminozide) preharvest to reduce internal ethylene concentration (Looney, 1968) or calcium postharvest to inhibit cell wall hydrolysis (Glenn and Poovaiah, 1990) has also been successful. Another method, which can be used in conjunction with those described above, identifies geno-

types with inherent long-term storage capability and uses them in a breeding program to develop new commercially acceptable varieties. In this paper we examine several apple selections that can be stored for up to 1 year at 1°C without loss in fruit physical quality or texture to determine if the long storage life of these genotypes results from their inability to produce ethylene.

Ethylene production and fruit firmness were compared using three numbered selections (NJ55, D101-110, and PA14-238), and two commercial cultivars ('Red Chief Delicious' and 'Golden Delicious') as standards. NJ55, a cross between an NJ-numbered selection and 'Golden Delicious', was chosen for this study because it maintains its texture in common storage (1°C) for several months. D101-110 and PA14-238, selections from the Purdue Univ., Rutgers Univ., Illinois cooperative scab resistance breeding programs (Crosby et al., 1992), were chosen because they produced low levels of ethylene when they initially ripened. In addition, PA14-238 maintains its crisp texture in common storage (1°C) for more than 1 year. D101-110 and PA14-238 share *Malus floribunda* 821 early in their pedigrees.

'Red Chief Delicious' and 'Golden Delicious' fruit were harvested at commercial maturity. Fruit from the numbered selections were harvested based on sensory evaluations. All fruit were stored at 4°C. Ethylene production was determined by incubating individual fruit ($n=4$) in 1.85-liter jars at 25°C for 1 h after the stored fruit reached 25°C. Three 1-ml gas samples from the headspace were analyzed for ethylene by gas chromatography using a flame ionization detector and a stainless steel Porapak Q column (1.83 m long $\times$ 3.18 mm wide) at 100°C. Fruit firmness ($n=3$) was measured using a fruit pressure tester with an 11-mm probe (McCormick Fruit Technology, Yakima, Wash.) after removing a small section of the peel from three locations around the circumference of the fruit. Feeding experiments with ethylene precursors using flesh disks were similar to those of Lieberman et al. (1966). Whole-fruit ethylene production was deter-

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Table 1. Effect of methionine (MET) and 1-aminocyclopropane 1-carboxylic acid (ACC) on ethylene synthesis in 'Red Chief Delicious', D101-110, and PA14-238 apples.

Selection	Temp regime ^a	Ethylene ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$)			
		Whole fruit	Flesh disks		
Red Chief Delicious	A	63.6 ab ^b	52.4 a	75.9 b	83.0 b
	B	56.6 ab	40.7 a	64.4 b	77.7 b
Significance		NS	NS	NS	NS
D101-110	A	4.9 a	5.8 a	6.8 a	74.0 b
	B	9.4 a	5.7 a	6.5 a	75.9 b
Significance		NS	NS	NS	NS
PA14-238	A	8.5 a	9.7 a	9.1 a	65.0 b
	B	57.6 a	54.0 a	53.6 a	72.6 b
Significance		*	*	*	*

^aEthylene was measured at 25°C after fruit were removed from 4°C storage for A) 3 h or B) 96 h.^bMean separation within rows by Duncan's multiple range test ($n = 5$).*, NS Significant or nonsignificant, respectively, within columns by protected LSD_{0.05}.

Fig. 1. Effect of postharvest storage at 4°C on fruit firmness (closed symbols) and ethylene production at 25°C (open symbols) in five apple genotypes: (A) 'Red Chief Delicious', (B) 'Golden Delicious', (C) NJ55, (D) PA14-238, and (E) D101-110. Lines derived from appropriate regression analyses.

mined initially. The fruit was subsequently sliced crosswise into circular slabs ≈ 1 cm thick, and disks (cylinders) of tissue were removed using an 8-mm-diameter cork borer. Four disks (≈ 3 g) were weighed and placed in a 25-ml Erlenmeyer flask with 5 ml of test solution. The disks were cut and weighed rapidly, and the flask was sealed with a serum

stopper and shaken at 150 to 200 rpm for 1 h at 25°C. Two 1-ml gas samples from the flask headspace were analyzed for ethylene. All test solutions contained 0.4 M sucrose, 0.1 M NaHCO_3 buffer (pH 8) and, in some cases, either 1 mM L-methionine (MET) or 100 μM aminocyclopropane-1-carboxylic acid (ACC) ($n = 5$).

Fruit firmness varied significantly among cultivars (Fig. 1). 'Golden Delicious' (Fig. 1B) was the softest. 'Red Chief Delicious' (Fig. 1A) and D101-110 (Fig. 1E) were intermediate in firmness during the early postharvest storage period, but continued to soften during cold storage. D101-110 softened the most between 60 and 86 days. NJ55 (Fig. 1C) and PA14-238 (Fig. 1D) fruit were the firmest and changed only slightly over the 36- to 86-day storage interval tested.

At harvest, 'Red Chief Delicious' and 'Golden Delicious' were producing significant amounts of ethylene, whereas NJ55, PA14-238, and D101-110 were preclimacteric. Ethylene production continued to increase in 'Red Chief Delicious' during storage at a maximum rate of $128 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ after 42 days, and in 'Golden Delicious' at a maximum rate of $190 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ after 29 days. NJ55 began producing significantly more ethylene after 7 days of cold storage, compared to ethylene production at harvest, and continued to synthesize ethylene at $\approx 90 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ throughout the rest of cold storage. In contrast, ethylene production in PA14-238 and D101-110 never exceeded $10 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$, even after 2 months in storage. However, when PA14-238 was kept at 25°C for 96 h after storage at 4°C, large amounts of ethylene were produced (Table 1). When fruit were stored continuously at 1, 7, or 13°C (Fig. 2), ethylene production was directly related to storage temperature and time, and increased most rapidly at 13°C. In contrast, D101-110 produced little ethylene, even after 96 h at 25°C (Table 1).

To determine the step in the ethylene production pathway in which ethylene synthesis was being blocked, PA14-238, D101-110, and 'Red Chief Delicious' flesh disks were incubated with MET and ACC. Fruit were stored at 25°C for either 3 or 96 h. The storage temperature regime did not significantly alter ethylene evolution in 'Red Chief Delicious' or D101-110 (Table 1). 'Red Chief Delicious' converted both MET and ACC to ethylene. Although D101-110 and PA14-238 readily converted ACC to ethylene, their ethylene production did not increase when incubated with exogenous MET. PA14-238 flesh disks kept at 25°C for 96 h produced significantly more ethylene than after 3 h at this temperature.

Considerable variation existed in the relation between fruit ethylene production and softening in the selections we examined. D101-110 produced little ethylene at harvest, during cold storage, and after an extended period at high temperatures. Nevertheless, this selection softened during cold storage and was about as firm as 'Red Chief Delicious' and 'Golden Delicious' after 2 months. Fruit softening in this genotype was generally unrelated to ethylene production, although after cold storage for 62 to 86 days, a low but significant amount of ethylene was produced and the fruit softened considerably (Fig. 1E).

NJ55 is a long-storing genotype; however, it produces a considerable amount of ethylene. We have not yet determined whether NJ55 produces ethylene only after harvest, or if ethylene production is simply delayed as long

Fig. 2. Effect of storage temperature on ethylene production at 25°C in the apple genotype PA14-238 at 1°C (●), 7°C (▲), and 13°C (■). Bars represent SE.

as the fruit remains attached. Lau et al. (1986) have shown that the latter is the case for 'Golden Delicious', a parent of NJ55. However, Greene and Autio (1990) report that 'Gala' does not produce ethylene until it is removed from the tree. NJ55 is either incapable of synthesizing the enzymes responsible for softening or it is insensitive to ethylene's inducing effect.

PA14-238 is another selection that remained firm after an extended storage period. It was not able to produce ethylene until almost 3 months of cold storage, although ethylene production (and fruit softening, data not shown) can be induced by keeping the fruit at room temperature for longer periods than was required for 'Red Chief Delicious' or 'Golden Delicious'. This selection also differs from 'Golden Delicious' (Knee et al., 1983) and 'Granny Smith' (Jobling et al., 1990) in that these cultivars can be induced to produce ethylene by low-temperature storage. A family of ACC synthase genes under differential regulation exists in apples (Kim et al., 1992)

and other fruit (Imaseki et al., 1990). PA14-238 may contain an ACC synthase that is poorly expressed at low temperatures but functions normally at higher temperatures.

The ability of D101-110 and PA14-238 to convert ACC to ethylene is consistent with the earlier expression of the gene for ACC oxidase compared to ACC synthase in ripening fruit (Knee, 1984; Lau et al., 1986). The inability of PA14-238 to convert exogenous MET to ethylene at a time when it is producing large amounts of ethylene after prolonged room temperature induction is surprising, although not unprecedented. Lieberman et al. (1966) found that flesh disks were unable to metabolize exogenous MET to ethylene until the fruit had been in cold storage for several months. We have found similar results with 'Rome Beauty' (unpublished). By identifying cDNA probes for ACC synthase(s) from apple fruit (Kim et al., 1992), it should be possible to determine whether PA14-238 and D101-110 contain altered forms of the gene for this enzyme.

Literature Cited

- Chu, C.L. 1988. Internal ethylene concentration of 'McIntosh', 'Northern Spy', 'Empire', 'Mutsu', and 'Idared' apples during the harvest season. *J. Amer. Soc. Hort. Sci.* 113:226-229.
- Crosby, J.A., J. Janick, P.C. Pecknold, S.S. Korban, P.A. O'Connor, S.M. Ries, J.C. Goffreda, and A. Voordeckers. 1992. Breeding apples for scab resistance. *Fruit Var. J.* 46:145-166.
- Glenn, G.M. and B.W. Poovaiah. 1990. Calcium-mediated postharvest changes in texture, cell wall structure and composition in 'Golden Delicious' apple. *J. Amer. Soc. Hort. Sci.* 115:962-968.
- Greene, D.W. and W.R. Autio. 1990. Evaluation of ripening and fruit quality of 'Gala' and 'McIntosh' apples at harvest and following air storage. *Fruit Var. J.* 44:117-123.
- Imaseki, H., N. Nakagawa, and N. Nakajima. 1990. Wound-induced ACC synthase, an immunochemical comparison of the wound-induced and auxin-induced enzymes, p. 113-122. In: R.P. Pharis and S.B. Rood (eds.), *Plant growth substances 1988*. Springer-Verlag, Berlin, Heidelberg, and New York.
- Jobling, J., D. Dille, and B. McGlasson. 1990. Chilling initiates ethylene production in 'Granny Smith' apples. *HortScience* 25:146. (Abstr.)
- Kim, W.T., A. Silverstone, W.K. Yip, J.G. Dong, and S.F. Yang. 1992. Induction of 1-Aminocyclopropane-1-carboxylic acid synthase mRNA by auxin in mung bean hypocotyls and cultured apple shoots. *Plant Physiol.* 98:465-471.
- Knee, M. 1984. 1-Aminocyclopropane-1-carboxylic acid levels in ripening apple fruits. *J. Expt. Bot.* 35:1794-1799.
- Knee, M., N.E. Looney, S.G.S. Hatfield, and S.M. Smith. 1983. Initiation of rapid ethylene synthesis by apple and pear fruits in relation to storage temperature. *J. Expt. Bot.* 34:1207-1212.
- Lau, O.L., Y. Liu, and S.F. Yang. 1986. Effects of fruit detachment on ethylene biosynthesis and loss of flesh firmness, skin color, and starch in ripening 'Golden Delicious' apples. *J. Amer. Soc. Hort. Sci.* 111:731-734.
- Lieberman M., A. Kunishi, L.W. Mapson, and D.A. Wardale. 1966. Stimulation of ethylene in apple tissue slices by methionine. *Plant Physiol.* 41:376-382.
- Looney, N.E. 1968. Inhibition of apple ripening by succinic acid 2,2-dimethylhydrazide. *Plant Physiol.* 43:1133-1137.