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Advancing the Tamarillo Harvest by Induced Postharvest Ripening

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Abstract. **Tamarillo [*Cyphomandra betacea* (Cav.) Sendt., Solanaceae] dark-red-, red-, and yellow-type fruit were sorted into two maturity stages (green and turning); dipped in ethephon at 0, 250, 500, or 750 mg·liter^{-1}; and kept at 18 or 28C. Seven days later, fruit dipped in ethephon at 500 or 750 mg·liter^{-1} and stored at 28C showed a color score, maturity index, and ascorbic acid content similar to those tree-ripened, thus making it possible for harvesting to be advanced 36 days. Under these conditions, weight loss was always lower than 8.5%, resulting in only slight symptoms of shriveling that did not affect commercial quality. Postharvest ripening reduces the risk of crop failure, increases earliness, and concentrates harvesting. Chemical name used: (2-chloroethyl)phosphonic acid (ethephon).**

Tamarillo or tree tomato is a fast-growing, small tree native to South America. It is grown as a commercial crop in some Andean countries, New Zealand, and occasionally in Florida and California (Duke and duCellier, 1993). Tamarillo appears to have a bright future; its fruit are now becoming familiar in grocery stores as a specialty (Bohs, 1988). They can be eaten raw as a fruit or cut up in salads. Tamarillos also can be made into sauces, juices, jams, ice creams, and other desserts. There are apparently no named varieties, but three types are distinguished according to fruit color: dark-red, red, and yellow (National Research Council, 1989). The dark-red type is said to be much superior to the others. This large and higher quality type was developed in New Zealand around 1920 from material from Loja, Ecuador (Heiser, 1984; Morton, 1982).

In its original environment and in other climates with little climatic variations between seasons, tamarillo sets throughout the year (Azad-Thakur et al., 1988; Duke and duCellier, 1993; National Research Council, 1989). However, many references show that, in Mediterranean climates, flowering takes place in spring, while fruit ripening occurs in autumn or winter (Carnevali, 1974; Pileri, 1989; Rotundo et al., 1981). We also have noticed this behavior (unpublished data). After full size is attained, fruit ripening can take up to 10 or more weeks (Heatherbell et al., 1982; Pratt and Reid, 1976). Thus, the tree is heavily laden during the ripening season, which increases risk of crop failure and tree damage since laden branches are easily broken by gusts of wind (Carnevali, 1974; Morton, 1982; National Research Council, 1989). An effective system that would allow harvesting when fruit reach full size, followed by postharvest ripening, would not only contribute to reduce these risks, but it would also increase earliness, concentrate harvest, and presumably improve the next flowering.

Respiration and ethylene studies identified red tamarillo fruit as nonclimacteric (Pratt and Reid, 1976). Espina and Lizana (1991) pointed out that red tamarillos maintained constant pH, soluble solids concentration (SSC), and acidity values after storage for 15 or 35 days at 0 or 7C. However, El-Zeftawi et al. (1988) found that dark-red tamarillos continued to ripen after harvest, becoming softer and juicier, and suggested harvesting when fruit are purple (mature stage).

Some previous experiments have suggested that postharvest treatment with ethylene can ripen tamarillos when it is not possible to let them ripen naturally on the tree. Continuous ethylene treatment at 100 mg·liter^{-1} or higher for several days hastened senescence of red strain fruit of all ages (Pratt and Reid, 1976). Fruit treated with ethylene became soft and developed yellow flesh. El-Zeftawi et al. (1988) also noted that dipping in ethephon at 500 mg·liter^{-1} increased the color and SSC and improved the flavor of dark-red tamarillos stored for 21 days at 18 to 20C.

Our experiment was conducted to determine if it is possible to ripen tamarillo fruit, which have been harvested several weeks before attaining commercial ripening, after harvest with minimal loss in commercial quality compared to tree-ripened fruit.

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Materials and Methods

Tamarillo dark-red-, red-, and yellow-type (strains ECU-231, ECU-140, and ECU-155, respectively) fruit were obtained from 2-year-old trees grown on an experimental field at the Universidad Politécnica de Valencia. These strains were collected from commercial orchards in Ecuador (Nuez et al., 1993).

Full-sized tamarillos were tagged on the tree on 5 Sept. 1994. On the following day, some fruit were picked and brought to the laboratory while the others were left on the tree. Fruit were sorted on the basis of skin color into two maturity stages: green, when the skin was entirely green, and turning, when the green ground color of the skin was fading and an incipient ripe color characteristic of each type became apparent in the part of the fruit most exposed to the sun. Some of the harvested fruit were analyzed immediately, while the others were weighed and dipped in an ethephon solution at 0, 250, 500, or 750 mg·liter^{-1} for 10 sec; Tween 20 (0.1% v/v) was used as a wetting agent. Fruit were allowed to air-dry at the laboratory temperature and then were placed at 18 or 28C and 90% relative humidity. All stored fruit were analyzed when some treatments had reached the commercial ripeness stage (fully colored and somewhat soft), which occurred 1 week after picking. Fruit left on the tree were picked and analyzed on 12 Oct. At about this time, fruit tagged as turning on 5 Sept. had reached commercial ripeness stage.

All assessments were conducted on five-fruit samples of six replications in a completely randomized design. Just before the analysis, fruit samples were weighed and fruit color was scored using a 1 to 5 scale with 0.5 increments (1 = entirely green, 5 = fully colored). Color photographs of five tamarillos from each strain ranging from score 1 to 5 were used as a standard to assess fruit color. Fruit with a color score equal or superior to 4 are considered commercial, but fruit with a color score of 4.5 or 5 are preferred. Immediately after the fruit had been juiced using a domestic juice extractor, ascorbic acid was determined using metaphosphoric acid extraction and 2,6-dichlorophenolindolephenol dye reduction. SSC (percent) was measured using a hand-held refractometer. Titratable acidity was determined by titrating diluted juice with 0.1 N NaOH to the phenolphthalein-end point. Results are presented as percent anhydrous citric acid since this is the main acid in tamarillo fruit (Romero-Rodriguez et al., 1994). From these values, a maturity index (MI) was calculated as the SSC : acidity ratio.

Factorial analysis of variance with maturity stage, storage temperature, and ethephon dose as independent factors were performed on the data of stored fruit.

Results

On-tree ripening. Natural ripening increased skin color score, MI, and ascorbic acid concentration (AAC), while fruit weight was maintained (Table 1). Increases in MI were due to a decrease in acidity and an increase in SSC (data not shown).

Postharvest ripening. Skin color was affected by all factors studied (Table 2). Green and turning fruit showed an increase in color score with ethephon applications, with higher values at the higher doses of ethephon, but for red and yellow strains, the absolute increase when treated with the 250 mg ethephon/liter

Table 1. Characteristics of tamarillo fruit graded as green or turning on 5 Sept. and harvested on 6 Sept. or 12 Oct. (when fruit that were turning on 6 Sept. had reached commercial ripeness stage).[z]

Characteristic	6 Sept.		12 Oct.	
	Green fruit	Turning fruit	Green fruit	Turning fruit
	Dark-red strain			
Color score	1.00 ± 0.00	2.00 ± 0.00	3.58 ± 0.15	4.92 ± 0.08
MI[y]	3.60 ± 0.16	4.98 ± 0.25	5.82 ± 0.26	7.12 ± 0.53
Ascorbic acid (mg/100 g)	21.2 ± 2.4	23.5 ± 1.6	24.3 ± 2.5	26.1 ± 3.3
Fruit weight (g)	60.1 ± 0.7	64.6 ± 0.7	63.5 ± 2.6	66.4 ± 2.7
	Red strain			
Color score	1.00 ± 0.00	2.00 ± 0.00	3.00 ± 0.13	4.50 ± 0.18
MI	3.07 ± 0.05	3.80 ± 0.08	5.16 ± 0.19	6.28 ± 0.14
Ascorbic acid (mg/100 g)	15.1 ± 1.2	18.6 ± 2.2	21.6 ± 1.6	22.4 ± 3.3
Fruit weight (g)	47.0 ± 1.0	51.2 ± 0.8	49.6 ± 2.7	49.7 ± 1.3
	Yellow strain			
Color score	1.00 ± 0.00	2.00 ± 0.00	3.67 ± 0.10	4.58 ± 0.20
MI	3.06 ± 0.08	4.98 ± 0.02	4.92 ± 0.30	6.62 ± 0.44
Ascorbic acid (mg/100 g)	19.9 ± 2.1	21.9 ± 1.8	22.7 ± 2.5	25.1 ± 1.3
Fruit weight (g)	44.1 ± 0.5	48.2 ± 0.7	44.8 ± 1.3	46.7 ± 1.5

[z]Values are means of six samples ± SE, except for fruit weight on 6 Sept. in which data were taken on 54 samples.
[y]MI = maturity index.

Table 2. Effect of maturity stage, storage temperature, and ethephon on color score (1 = entirely green, 5 = fully colored) in tamarillo fruit after 7 days of storage.

Ethephon	Dark-red strain		Red strain		Yellow strain	
(mg•liter^{-1})	18C	28C	18C	28C	18C	28C
	Green fruit					
0	1.00	1.17	1.00	1.00	1.00	1.00
250	1.83	2.83	1.75	2.00	1.92	2.17
500	2.92	3.25	2.92	2.83	3.00	3.08
750	3.00	3.67	3.00	3.33	3.00	3.92
	Turning fruit					
0	2.00	2.00	2.00	2.33	2.00	2.00
250	3.67	3.75	3.58	4.00	3.50	4.17
500	4.33	4.83	3.75	4.08	4.00	4.33
750	4.42	4.92	4.00	4.33	4.08	4.58
Significance						
Maturity stage (M)	***		***		***	
Temperature (T)	**		**		***	
Ethephon (E)	L***, Q***		L***, Q***		L***, Q***	
M × T	NS		NS		NS	
M × E	NS		***		***	
T × E	NS		NS		**	
M × T × E	NS		NS		NS	

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. L = linear, Q = quadratic.

was higher for turning than for green fruit, although in most cases, the percent increase was the same (Table 2). Storage temperature also influenced response to ethephon in the yellow strain: fruit kept at 28C had a greater increase in color score with higher ethephon doses, while at 18C, there was saturation at the highest doses.

Ethephon effect on MI was influenced by maturity stage and storage temperature (Table 3). Green fruit showed an increase in MI value with increasing ethephon doses. Response to treatment with 250 mg ethephon/liter was high for turning fruit, but it reached saturation with the 500- or 750-mg•liter^{-1} doses. Thus, the higher response was at the higher doses of ethephon. The MI of red and yellow strains increased more for turning than for green fruit at the higher temperature. As with natural ripening, increases in MI were due to a decrease in acidity and an increase in SSC (data not shown). However, decreases in the MI at the highest ethephon dose were only due to a decrease in SSC (data not shown).

AAC was influenced by ethephon applications and storage temperature (Table 4). There was an increase in AAC with increasing ethephon doses. Storage temperature affected the AAC in red and yellow strains, which showed a higher concentration after storage at 18C than at 28C.

Weight loss percentage ranged from 2.5% to 3.4% at 18C and from 6.6% to 8.5% at 28C, regardless of the strain, maturity stage, and ethephon dose combination. However, mean weight loss was lower for the dark-red strain (4.8%) than for red or yellow strains (5.4% in both cases).

Discussion

As has been described for many other fruit, exogenous applications of ethephon stimulated postharvest ripening of tamarillos. The fact that ethephon can accelerate so many ripening processes in nonclimacteric fruit has been ascribed to nonspecific effects on membrane permeability (Elkashif and Huber, 1988).

Fruit stored at 28C ripened more quickly than those stored at 18C. This is probably related to reduced activity in biological processes at 18C, along with a decreased rate of absorption and degradation of ethephon (Beaudry and Kays, 1987; Flore and Bukovac, 1982).

Turning fruit reached a skin ground color similar to those tree-ripened (Table 1). However, green fruit treated with ethephon only developed a pale ground color, which would make them commercially unacceptable. Even when green ethephon-treated fruit were left in storage until the appearance of decay, the color did not increase further (unpublished data). Postharvest fruit color development is probably a result of chlorophyll degradation without *de novo* anthocyanin biosynthesis. Chlorophyll content decreases during storage in green fruit (El-Zeftawi et al., 1988), but there is no additional anthocyanin pigment development in the skin in response to treatment with ethylene (Pratt and Reid, 1976). However, anthocyanin content of the skin barely increases in the 4 to 6 weeks before commercial ripening stage is attained (El-Zeftawi et al., 1988; Heatherbell et al., 1982).

Postharvest increases found in the MI are in accordance with the increase in SSC and the decrease in acidity during storage as reported by El-Zeftawi et al. (1988). Lack of variation in ripening traits during postharvest storage found by Espina and Lizana (1991) probably were related to the low storage temperatures used (0 and 7C). These temperatures would inhibit most biological processes. Similar increases in AAC to those found in this experiment as a result of ethephon treatment have been reported in tomato following ethylene gassing (Watada et al., 1976).

The low weight loss of the dark-red strain is likely a consequence of its larger size. For most fruit and vegetables, the higher the ratio of surface area to unit volume, the greater the loss of water (Salunkhe and Desai, 1984).

After 7 days in storage, fruit of all treatment combinations looked good, especially when stored at 18C. Even when stored at 28C, weight loss did not surpass 8.5% in any case, resulting in slight shriveling symptoms that presumably would not have affected salability excessively. In other fruit, similar weight losses caused none to moderate shriveling symptoms (Hruschka, 1977). Although weight loss was much lower at 18C, ripening at 28C seems advantageous since it is faster and the increase in MI value per 1% weight loss was higher at 28C (0.23) than at 18C (0.20).

The green stage appears to be physiologically too early for fruit to be ripened after harvest. Although they ripened somewhat, weight loss along with the lack of ripe color when allowed to ripen for a longer period would make them unmarketable. El-Zeftawi et al. (1988) found weight loss as high as 20% in green fruit stored for 14 days at 20C. Weight losses of this magnitude are completely unacceptable for trade purposes.

Table 3. Effect of maturity stage, storage temperature, and ethephon on the maturity index (MI) of tamarillo fruit after 7 days of storage.

Ethephon	Dark-red strain		Red strain		Yellow strain	
(mg•liter^{-1})	18C	28C	18C	28C	18C	28C
			Green fruit			
0	3.52	4.32	2.94	3.23	3.04	3.44
250	4.01	5.23	3.26	3.81	3.42	4.36
500	4.10	5.28	3.53	4.45	3.97	4.83
750	4.28	5.72	3.88	4.66	4.43	5.24
			Turning fruit			
0	4.67	5.55	3.93	4.30	4.78	5.39
250	5.68	5.90	5.02	6.10	5.53	7.91
500	6.08	7.44	4.94	6.93	6.32	7.92
750	5.56	6.97	5.43	7.36	5.71	8.13
Significance						
Maturity stage (M)	***		***		***	
Temperature (T)	***		***		***	
Ethephon (E)	L***, Q***		L***, Q***		L***, Q***	
M × T	NS		***		***	
M × E	**		***		*	
T × E	NS		***		**	
M × T × E	NS		NS		NS	

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. L = linear, Q = quadratic.

Table 4. Effect of maturity stage, storage temperature, and ethephon on ascorbic acid concentration (milgram per 100 g) in tamarillo fruit after 7 days of storage.

Treatments	Dark-red strain	Red strain	Yellow strain
Maturity stage (M)			
Green	21.5	19.3	19.6
Turning	23.4	19.2	20.2
Temperature (T)			
18C	22.1	21.3	21.2
28C	22.8	17.2	18.6
Ethephon (mg•liter^{-1})			
0	20.1	16.3	17.0
250	20.8	18.5	18.0
500	23.3	19.8	20.7
750	25.7	22.4	23.8
Significance			
Maturity stage (M)	NS	NS	NS
Temperature (T)	NS	**	*
Ethephon (E)	L***, QNS	L***, QNS	L***, QNS
M × T	NS	NS	NS
M × E	NS	NS	NS
T × E	NS	NS	NS
M × T × E	NS	NS	NS

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. L = linear, Q = quadratic.

We have shown that harvesting at the turning stage, storage at 28C, and treatment with ethephon at 500 or 750 mg•liter^{-1} allowed turning tamarillo fruit to ripen in 7 days, reaching levels similar to those tree-ripened for the characters studied. This feature allows harvesting to be advanced by >1 month. Postharvest treatment with ethephon or ethylene to hasten ripening may contribute not only to a decreased risk of crop failure because of the advancement in the harvesting dates, but also to the ability to offer this fruit to the consumer at earlier dates, thus improving its marketability.

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