Reprinted from Vol. 103(3), January 1978
Journal of the American Society for Horticultural Science
Mount Vernon, Virginia 22121, USA

J. Amer. Soc. Hort. Sci. 103(1):6–13. 1978.

Composition and Flavor Quality of Fresh Market Tomatoes as Influenced by Some Postharvest Handling Procedures[1]

Adel A. Kader, Leonard L. Morris, M. Allen Stevens, and Marjorie Albright-Holton
Department of Vegetable Crops, University of California, Davis, CA 95616

Additional index words. Lycopersicon esculentum, storage temperature, ethylene, reduced O_2 atmosphere, aeration, bruising, sensory evaluation

Abstract. **Sensory evaluations and chemical analyses were used to investigate the effects of various postharvest handling procedures on composition and flavor quality of 'Cal Ace' tomatoes (*Lycopersicon esculentum* Mill.) harvested at the mature-green and light-pink stages. Ethylene treatment to speed ripening of green tomatoes at 20°C resulted in a higher reduced ascorbic acid content at the table-ripe stage and did not influence flavor when compared with fruits ripened without added ethylene. Using a low-O_2 atmosphere to retard ripening had less of an effect on flavor than stage of ripeness at harvest. No differences were found between fruits where ripening was delayed by using 4% O_2-atmosphere at 20° or by using low temperature (12.5°). Exposing fruits to 5° for 7 days before ripening at 20° affected flavor; i.e., chilled fruits were more acid. Above the chilling range (0-12.5°); duration of holding after harvest was more important than storage temperature. Lower holding periods resulted in loss of characteristic "tomato-like" flavor and development of "off-flavors." Mature-green fruits, ripened at 20° under restricted air flow, had increased "off-flavors" when compared to those ripened under accelerated air exchange. Light-pink fruits subjected to impact bruising before ripening had more "off-flavor" and less "tomato-like" flavor than those without physical damage. Quantitative differences in a few volatile components were found with certain treatments, but no qualitative differences were detected and there was no significant difference in total volatile content among any of the treatments tested.**

Fresh tomato quality is determined by appearance, firmness, flavor, and nutritive value. Consumers buy fresh tomatoes primarily because of appearance and flavor. Although the initial decision to buy is usually made on the basis of appearance, the frequency and magnitude of subsequent purchases depend largely on consumer assessment of eating quality (flavor and texture). Weimer and Stevens (19) found tomatoes to be one of the most frequently served and liked vegetables. In another consumer survey (6) tomatoes received the highest dissatisfaction rating of 31 individual products which included, however, only two other vegetables, i.e., lettuce and potatoes. The complaints against tomatoes included price, ripeness, taste, and appearance. This dissatisfaction has been reflected in numerous newspaper and magazine articles criticizing tomato flavor. Although many of the press articles on tomatoes are full of inaccuracies and half-truths, there is good evidence that consumers are unhappy about the flavor quality of most fresh tomatoes.

Scott and Kramer (15) reported a loss in ascorbic acid during storage of green tomatoes at 21°C and of riper fruit at 2° and 10°. Craft and Heinze (3) observed that soluble solids increased slightly in mature-green tomatoes stored for short periods but decreased with longer storage, whereas ascorbic acid content, total acidity and pH did not change appreciably with storage temp or duration. Hall (4) reported a decrease in titratable acidity and no change in soluble solids in several tomato cultivars harvested at the breaker stage and held at 20° for 12 days. Hall (5) found that titratable acidity of fruits held at 3.3° was significantly higher than that of fruits held at 7.2° or 10°. Buescher (2) observed that malic acid concn declined during chilling of tomatoes, while citric acid increased. He also

[1]Received for publication July 18, 1977. Research supported in part by the California Fresh Market Tomato Advisory Board. The authors thank Margaret Algazi and Uy Vu Ly for their valuable technical assistance.

reported a decline in fructose and sucrose while glucose content remained fairly constant during storage. Chilled fruits (14 or 21 days at 2°) had lower levels of both glucose and fructose than non-chilled fruits. Pantos and Markakis (13) found a decline in ascorbic acid content of mature-green tomatoes with time of storage at 13°, 15°, 18° and 21°. House et al. (8) indicated that C_2H_4-ripened tomatoes were lower in ascorbic acid than vine-ripened fruit. Watada et al. (18) reported that ascorbic acid content was slightly higher in mature-green tomatoes treated with C_2H_4 than in those ripened without added C_2H_4. Salunkhe and Wu (14) found that 1 or 3% O_2 inhibited starch degradation and sugar synthesis in mature-green tomatoes during extended storage at 12.5°. Stevens (16) demonstrated a relationship between polyenecarotene content and volatile compound composition of tomatoes.

Since 1973, we have been evaluating tomato flavor and composition as affected by genotype, maturity, and ripeness at harvest, and postharvest handling procedures. Results on genotypic variation and stage of ripeness have been reported separately (10, 17). This paper describes studies designed to evaluate the effects of storage temp and duration, ethylene treatment, low-O_2 atm, aeration rates, and impact bruising on composition and flavor of tomato fruits harvested green or partially-ripe.

Materials and Methods

Fruits. 'Cal Ace' tomato fruits grown at Davis, Calif. were harvested at the desired stage of maturity or ripeness. Using standard cultural practices several plantings were made to provide fruits throughout the normal harvest period (August through Oct.). In all experiments, except those using C_2H_4 treatment, fruits were harvested at the mature-green (MG) and/or light-pink (LP) stages. Fruits intended for C_2H_4 treatments were harvested green, then separated, subsequently into 3 stages of maturity (9-10). The green fruit were held at 20°C. Fruit showing any red color after 5 days were separated as typical mature-green (TMG). Any fruit showing red color after another 5 days were classified as partially mature-green (PMG) and the remainder were considered as immature-green (IMG). Fruits treated with ethylene were sorted after 3 and 6 days into TMG and PMG, respectively. After harvest, fruits were washed, air dried, sorted to eliminate defects, then placed in 18.9-liter jars (about 5 kg per jar), and kept under humidified air stream or the desired gas mixture at indicated temp. The air flow rates used were selected to insure that CO_2 did not accumulate above 0.5% unless otherwise desired. The vine-ripened table-ripe fruits were picked the day before the evaluations and held overnight at 15°.

Postharvest treatments. Treatments used in 1975 are shown in Table 1. Ethylene was applied using a continuous flow treatment with 100 ppm C_2H_4 added to air for 48 hr. Low-O_2 atm (4 and 5%) were achieved by mixing air with nitrogen. Gas composition was monitored by gas chromatography. The no. of replicates per treatment varied with a minimum of 2. The mean no. of days required for fruits in each treatment to reach the table-ripe (TR) stage is shown in Table 1. Table 2 lists the 1976 treatments; each comparison was repeated 3 times. To minimize seasonal effects in 1976, all fruits were harvested during the period between August 27 and Sept. 28. Variable aeration rates and their influence on atm composition around the fruits are shown in Table 3.

Sampling. Prior to sensory evaluations, 50 table-ripe fruits of each treatment replication were visually sorted for uniform color and appearance. At least 10 fruits were diced (about 1 cm^3) and thoroughly mixed for sensory evaluation and a subsample taken for compositional analyses. Additional whole fruit were frozen at −40°C in Scotch-pak (heat sealable polyester film) bags for ascorbic acid analysis and, in 1976, for volatile analysis at a later date.

Sensory evaluation. In 1975 potential panelists were screened for taste acuity for tomatoes and trained to use the score sheet. The scoring system was the same as described by Kader et al. (10) for picking stage comparisons. Fruits harvested TR were used as a reference in all cases. In 1976 the treatment comparisons (Table 2) were presented randomly in 3 replications, between Sept. 15 and 28, 3 comparisons per day. The 15 panelists were experienced in scoring tomato flavor. However, for this study, we used the more sensitive triangle tests to detect simple differences and to describe the direction and the magnitude of these differences.

Table 1. List of postharvest treatments included in the 1975 study and their effect on the duration between harvest and table-ripeness when tomato fruit quality was evaluated.

Picking stage[z]	Postharvest treatment				Mean no. of days to attain table-ripeness
	Temp (°C)	Duration (days)	C_2H_4 treatment	Low-O_2 atm	
IMG	20.0	cont.	–	–	21.3
	20.0	cont.	+	–	17.5
PMG	20.0	cont.	–	–	16.4
	20.0	cont.	+	–	12.6
TMG	20.0	cont.	–	–	11.0
	20.0	cont.	+	–	9.7
	12.5	7[y]	–	–	15.5
	15.0	7[y]	–	–	14.5
	12.5	7[y]	–	+	17.5
LP	20.0	cont.	–	–	6.6
	10.0	7[y]	–	–	11.0
	12.5	7[y]	–	–	14.0[x]
	15.0	7[y]	–	–	8.0
	12.5	7[y]	–	+	12.0

[z]IMG = immature green, PMG = partially mature-green, TMG = typical mature-green, LP = light pink.

[y]Followed by holding at 20°C until table-ripe.

[x]Fruits harvested in late Oct.

Table 2. List of postharvest treatments included in the 1976 study on 'Cal Acc' tomatoes harvested at the mature-green (MG) or light-pink (LP) stage.

Variable	Comparison no.	Picking stage[y]	Postharvest treatments[z] — Days in storage (simulated transit and ripening) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
I. Time & temp	1	MG	H — 12.5°C — T — 20° — E
		MG	H — 20° — E
A. Non-chilling temp	2	LP	H — 12.5° — T — 20° — E
		LP	H — 20° — E
B. Chilling temp	3	MG	H — 5° — T — 20° — E
		MG	H — 20° — E
	4	LP	H — 5° — T — 20° — E
		LP	H — 20° — E
C. Ripening before holding vs. holding before ripening	5	MG	H — 20° — T — 12.5° — E
		MG	H — 12.5° — T — 20° — E
II. Delay of ripening by low-O_2-atm vs. low temp	6	MG	H — 12.5° in air — T — 20° in air — E
		MG	H — 20° under 4% O_2 — T — 20° in air — E
	7	LP	H — 12.5° in air — T — 20° in air — E
		LP	H — 20° under 4% O_2 — T — 20° in air — E
III. Ventilation (aeration) rate[x]	8	MG	H — 20° under normal air flow — E
		MG	H — 20° under restricted air flow — E
	9	MG	H — 20° under normal air flow — E
		MG	H — 20° under accelerated air flow — E
IV. Bruising (five 30-cm drops)	10	LP	H — 20° — E
		LP	H — bruised 20° — E

[z]H = harvest, T = transfer to different storage conditions as indicated, E = evaluation date (sensory and chemical analyses).

[y]MG = mature green; LP = light pink.

[x]See Table 3.

Composition analyses. Soluble solids content was determined with a bench top model ABBE-3L Bausch & Lombe refractometer. Reducing sugars were determined using Hassid's method (7). An enzymatic method was used to determine glucose content (1) after precipitation of proteins and ascorbic acid with zinc sulfate. Titratable acidity was determined by titrating tomato juice to pH 8.1 with 0.1 N NaOH; pH was measured on a Corning digital 109 pH meter. Reduced ascorbic acid concn was determined by the method of Loeffler and Ponting (11). Volatile compounds collection and analysis methods have been described by Stevens et al. (17).

Statistical analyses. Means were compared using analysis of variance and mean separation tests for unequal (1975) or equal (1976) no. of replicates.

Table 3. Effect of aeration rate on atm composition above tomato fruits held for 12 days at 20°C, means of 6 replicates.

Aeration rate	O_2 (%)	CO_2 (%)	C_2H_4 (ppm)
Normal air flow (x)[z]	19.5	0.5	1.8
Restricted air flow (0.1x)	16.6	4.2	9.4
Accelerated air flow (10x)	20.3	0.1	0.2

[z]x = 40-45 liter/hr for about 5 kg (50 fruits) of tomatoes in a 18.9-liter container.

Results and Discussion

Influence of storage temperature and duration. Holding TMG fruits at 12.5° or 15°C for 7 days prior to ripening did not influence their flavor at the TR stage relative to those ripened directly at 20°. However, fruits from all three TMG storage treatments were rated lower in fruity-floral aroma and sweetness, and rated higher in sourness and "off-flavor" than fruits harvested at the TR stage (Table 4). These differences correlated well with differences in soluble solids, reducing sugars and ascorbic acid content. The sugar/acid ratio was lower in fruits harvested as TMG than those harvested as TR; this difference was significant at the 5% level using analysis of variance.

Sensory differences among fruits harvested at the LP stage and held at 10, 12.5, or 15°C for 7 days before ripening at 20° were small when compared with either LP fruits ripened directly at 20° or those harvested as TR. There was a trend, however, for fruits held at 10° to have a lower sugar/acid ratio than those held at higher temp (Table 4). The higher "off-flavor" score of fruits held at 12.5° and their lower content of soluble solids and reducing sugars were due to seasonal rather than postharvest temp effects. Fruits used for this treatment were harvested in late Oct. and took much longer than normal to ripen (Table 1), while fruits used for the other treatments were harvested earlier in the season. This was also true for LP fruits ripened at 20° and held at 12.5° for 7 days (ripening before holding). LP fruits, ripened before holding at 12.5°, had a lower sugar/acid ratio than those held for 7 days at 12.5°, then ripened at 20° (Table 4). Fruits harvested TR were generally rated higher in fruity-floral aroma and had a higher sugar/acid ratio

Table 4. Chemical analyses and sensory scores for 'Cal Ace' tomatoes harvested at the MG (mature-green) or LP (light pink) stage and held at various temp for 7 days (simulated transit) before ripening to TR (table ripe) at 20°C as compared with those harvested TR (table ripe) (1975).

Picking stage[y]	Postharvest treatment	No. of reps.	Chemical analyses[z]						Sensory evaluation scores[z]				
									Aroma		Taste		
			pH	Titratable acidity (% citric acid)	Total soluble solids (%)	Reducing sugars (%)	Sugar/acid ratio	Ascorbic acid (mg/100g)	Fruity-floral	Overall intensity	Sweetness	Sourness	Off-flavor
TR	None	8	4.62	0.30	5.8a	3.8a	12.7	19.9a	3.1a	4.3	3.3a	1.8a	0 a
TMG	Ripened @ 20°C	5	4.48	0.31	5.2b	3.2b	10.1	12.3b	1.7b	4.3	1.9b	2.9b	1.9b
TMG	Held 7days @ 15° → 20°	2	4.48	0.33	5.2b	3.3b	9.9	14.4b	1.9b	4.3	1.6b	3.1b	2.5b
TMG	Held 7 days @ 12.5° → 20°	2	4.49	0.34	5.3b	3.3b	9.7	15.5b	1.8b	4.1	1.6b	3.1b	2.6b
TR	None	9	4.60a	0.29a	5.6	3.5	12.2	18.7	3.6a	4.9a	3.9	2.7	0.4a
LP	Ripened @ 20°	7	4.54ab	0.30a	5.4	3.4	11.4	16.9	2.0b	3.8ab	3.8	3.1	0.6a
LP	Held 7 days @ 15° → 20°	2	4.45bc	0.32ab	5.6	3.6	11.2	20.7	1.8b	4.3ab	4.3	3.4	0.3a
LP	Held 7 days @ 12.5° → 20°	2	4.43bc	0.29a	4.7	3.2	10.8	18.1	0.7b	2.8b	3.4	3.6	3.8b
LP	Held 7 days @ 10° → 20°	2	4.36c	0.35b	5.7	3.5	10.0	17.9	2.2b	3.6ab	4.8	3.6	0.2a
LP	Ripened @ 20° and held 7 days @ 12.5°	2	4.50	0.31	4.7	2.9	9.3	20.2	1.8	3.6	2.6	3.4	2.3

[z]Mean separation within columns by SNK test, 5% level.

[y]TR = table ripe; TMG = typical mature-green; LP = light pink.

than those harvested LP and ripened at 20° following various simulated transit treatments. The effects of holding temp (10, 12.5, 15°) on flavor were less important than picking stage.

To separate the influence of picking stage from the effects of postharvest procedures, the 1976 comparisons were made on fruits harvested at the same stage of ripeness and subjected to various postharvest treatments until the TR stage (Table 5). Above the chilling range (0-12.5°C). duration of holding after harvest appeared to be more important than storage temp. Longer holding periods resulted in a decrease in the characteristic "tomato-like" flavor, development of "off-flavors," and increased acidity. Fruits harvested MG (same as TMG) or LP and ripened directly at 20° were described as sweeter and with more "tomato-like" flavor than those which were held for 7

Table 5. Chemical analyses and sensory evaluation of 'Cal Ace' tomatoes harvested at the MG or LP stage and held under various time and temp combinations (1976).

Comparison no.	Picking stage[z]	Postharvest treatments[y]	Chemical analyses[x]					Sensory evaluation	
								Triangle tests	
			pH	Titratable acidity (% citric acid)	Reducing sugars (%)	Glucose (%)	Sugar/acid ratio	No. of correct answers/No. of judgments	direction of difference
1	MG	Held 7 days @ 12.5° before ripening @ 20°C	4.56	0.36	3.38	1.28 *	9.4	35/44***	more acid, more "off-flavor,"
	MG	Ripened @ 20°	4.62	0.33	3.63	1.49	11.0		sweeter, more "tomato-like"
2	LP	Held 7 days @ 12.5° before ripening @ 20°	4.59	0.35	3.56	1.40 *	10.2	34/45***	more "off-flavor"
	LP	Ripened @ 20°	4.61	0.35	3.91	1.64	11.2		sweeter
3	MG	Held 7 days @ 5° before ripening @ 20°	4.52 *	0.39 **	3.49 *	1.37	9.0	20/44 NS	more acid
	MG	Ripened @ 20°	4.57	0.35	3.69	1.55	10.5		sweeter
4	LP	Held 7 days @ 5° before ripening at 20°	4.55 *	0.38 **	3.80	1.52	10.0	28/45***	more acid
	LP	Ripened @ 20°	4.67	0.34	3.69	1.54	10.9		sweeter
5	MG	Ripened @ 20° then held 7 days @ 12.5°	4.60	0.32	3.46	1.37	10.8	24/45**	no clear directional difference
	MG	Held 7 days @ 12.5° then ripened @ 20°	4.60	0.33	3.63	1.41	11.0		

[z]MG = mature green, LP = light pink.

[y]See Table 2 for details.

[x]Means of 3 replicates.

*, **, *** indicate significant difference at the 5%(*), 1%(**), and 0.1%(***) levels. NS= no significant difference.

Table 6. Volatile analysis of 'Cal Ace' tomatoes harvested at MG or LP stage and held under various time and temp combinations (1976). Only those compounds showing significant difference for any comparison are included.

Comparison no.	Picking stage[z]	Postharvest treatments[y]	Relative peak area[x] for indicated peak number(s)															
			17	20-21	25	39-41	45	46	51	52	53	91-92	105	112-113	120-123	145	160	172
1	MG	Held 7 days @ 12.5° before ripening at 20°C	4.6	383.0	7.8	631.3	17.9 *	5.2	10.3	710.3	38.9	10.4	2.6	70.3	34.6	7.7	9.4	7.2
	MG	Ripened @ 20°	1.9	327.4	12.6	484.4	8.1	7.1	10.6	413.6	30.5	9.8	4.1	44.9	27.7	11.5	6.1	10.5
2	LP	Held 7 days @ 12.5° before ripening at 20°	4.5	549.3	12.2	776.9	5.5	4.5	8.3 **	941.0	59.1	10.3	4.2	27.7	20.7	7.2	11.2	12.8 *
	LP	Ripened @ 20°	5.3	506.3	12.3	729.9	3.0	5.5	19.6	637.6	55.5	15.9	5.1	22.7	16.0	5.4	9.5	27.8
3	MG	Held 7 days @ 5° before ripening at 20°	3.0	324.8	9.4	233.3 **	4.4 **	3.5	8.0	396.4	22.1 *	7.9	3.3	19.3 **	16.5 *	4.1 *	4.2 *	10.7
	MG	Ripened @ 20°	4.0	378.9	21.7	697.4	14.3	7.5	13.7	541.3	52.4	18.7	6.0	53.5	38.0	19.2	12.4	15.3
4	LP	Held 7 days @ 5° before ripening at 20°	4.6	439.0	10.5 *	459.4	3.4	4.8	8.3	438.4	24.5	10.2 *	5.9 *	11.3 **	11.6	3.3	8.7	17.4
	LP	Ripened @ 20°	4.2	587.7	20.6	702.3	4.7	5.6	8.5	525.2	60.7	14.3	2.7	29.7	14.0	7.8	28.4	39.8
5	MG	Ripened @ 20°, then held 7 days @ 12.5°	4.2	224.1 *	2.9	547.9	18.0	3.1 *	10.3	345.8 *	34.2	8.1	4.2	97.1	67.8	7.9	8.9	3.7 *
	MG	Held 7 days @ 12.5° then ripened @ 20°	4.7	331.4	12.7	790.0	31.9	6.5	11.9	682.1	47.7	13.9	5.3	131.3	58.9	16.8	12.2	11.1

[z]MG = mature green, LP = light pink.

[y]See Table 2 for details.

[x]Means of 3 replicates, x 10^{-2}.

*, **Significant difference at the 5%(*) and 1%(**) level.

days at 12.5° before ripening at 20° (Table 5). Results of the triangle tests were very highly significant. Although only the differences in glucose content were statistically significant, other differences showed a trend that supported sensory evaluation results. Fruits ripened directly at 20° had a higher content of reducing sugars than those held for 7 days at 12.5° before ripening. Tomatoes harvested at the MG stage and ripened directly at 20° had lower titratable acidity than those held at 12.5° prior to ripening. The sugar/acid ratios were in line with the sensory evaluation data. No directional differences in sensory evaluation or chemical analyses were found between fruits harvested as MG and ripened at 20° before holding for 7 days at 12.5° and those held at 12.5° for 7 days before ripening at 20°, similar to current practices (comparison no. 5 in Table 5).

Volatile analyses showed significant differences for 16 compounds (Table 6). There were no qualitative differences in volatile composition and no significant differences in total peak areas for all volatiles among the treatments. MG fruits ripened directly at 20°C had a lower content of peak 17 and

Table 7. Chemical analyses and sensory scores for 'Cal Ace' tomatoes harvested "green" and ripened to TR at 20°C with or without ethylene treatment as compared with those harvested TR (1975).

Picking stage[z]	Postharvest treatment	No. of reps.	Chemical analyses[y]						Sensory evaluation score[y]				
									Aroma		Taste		
			pH	Titratable acidity (% citric acid)	Total soluble solids (%)	Reducing sugars (%)	Sugar/acid ratio	Ascorbic acid (mg/100g)	Fruity-floral	Overall intensity	Sweetness	Sourness	Off-flavor
TR	None	7	4.60a	0.32	5.7a	3.6	11.2	19.2a	3.1	4.4	3.1a	1.9a	0.1a
TMG	Ripened to TR @ 20°C	5	4.48b	0.31	5.2b	3.2	10.1	12.3b	2.4	4.6	2.1b	3.6b	2.2b
TMG	Ripened to TR @ 20° ethylene-treated	4	4.49b	0.32	5.3b	3.2	10.2	15.5ab	2.4	4.6	2.1b	3.0b	2.5b
TR	None	6	4.63a	0.32	5.6a	3.6	11.3	19.7a	3.1	4.3	3.1a	1.8a	0.1a
PMG	Ripened to TR @ 20°	5	4.52b	0.32	5.2b	3.2	10.1	10.8b	2.7	3.8	1.9b	3.7b	1.7b
PMG	Ripened to TR @ 20° ethylene-treated	3	4.40b	0.32	5.1b	3.2	10.0	15.5a	2.4	4.3	2.4ab	3.3b	2.7c
TR	None	5	4.67a	0.29	6.0	3.9	13.3a	19.2a	3.2	4.7	3.7a	1.8a	0.1a
IMG	Ripened to TR @ 20°	4	4.52b	0.33	5.3	3.3	9.9b	9.9b	2.6	4.6	1.6b	4.1b	1.5b
IMG	Ripened to TR @ 20° ethylene-treated	2	4.42b	0.34	5.3	3.2	9.5b	16.2a	2.4	3.9	2.0b	4.2b	1.6b

[z]TR = table ripe, TMG = typical mature green, PMG = partially mature-green, IMG = immature-green.

[y]Mean separation within columns by SNK test, 5% level.

Table 8. Chemical analyses and sensory scores for 'Cal Ace' tomatoes harvested at the MG or LP stages and held at 12.5°C for 7 days (simulated transit) in air or 5% O_2 before ripening to TR at 20° as compared with those harvested TR (1975).

			Chemical Analyses[y]						Sensory evaluation scores[y]				
									Aroma		Taste		
Picking stage[z]	Postharvest treatment	No. of reps.	pH	Titratable acidity (% citric acid)	Total soluble solids (%)	Reducing sugars (%)	Sugar/acid ratio	Ascorbic acid (mg/100 g)	Fruity-floral	Overall intensity	Sweetness	Sourness	Off-flavor
TR	None	9	4.62	0.29	5.8	3.7	12.9	20.0a	4.5a	4.6	3.1a	2.8	0 a
TMG	Held at 12.5° (7 days) in air → 20°C	2	4.49	0.34	5.3	3.3	9.7	15.5b	1.5b	2.5	0.8b	3.6	3.3b
TMG	Held at 12.5° (7 days) in 5% O_2 → 20°	2	4.49	0.32	5.3	3.4	10.9	15.0b	1.6b	3.7	1.3b	2.5	3.0b
TR	None	8	4.63a	0.29a	5.6	3.6	12.6	19.2	4.0a	4.3	2.7	1.9	0.2a
LP	Held at 12.5° in air → 20°	2	4.43b	0.29a	4.7	3.2	10.8	18.1	2.3b	3.6	2.5	2.2	3.0c
LP	Held at 12.5° (7 days) in 5% O_2 → 20°	2	4.41b	0.33b	5.3	3.4	10.4	17.1	2.2b	3.8	2.1	2.4	1.7b

[z]TR = table ripe, TMG = typical mature-green, LP = light pink.

[y]Mean separation within columns by SNK test, 5% level.

peak 45 than those held for 7 days at 12.5° before ripening at 20°. LP fruits ripened at 20° were higher in peak 51 and peak 172 than those held for 7 days at 12.5° before ripening at 20°. MG fruits held at 12.5° for 7 days before ripening generally had a higher content of volatile components than those ripened and held at 12.5°; this difference was significant for peaks (20-21), 46, 52, and 172. The importance of these differences in volatile components cannot be evaluated until their identity and flavor characteristics have been determined.

The possible influence of chilling injury on tomato flavor was tested in comparisons 3 and 4 (Table 2). Because of chilling injury symptoms (uneven ripening, excessive softening, decay), about 25% of the fruits in the original sample were discarded before evaluation. This probably influenced the reported

Table 9. Chemical analyses and sensory evaluation of 'Cal Ace' tomatoes harvested at the MG or LP stage and subjected to various postharvest treatments (1976).

			Chemical analyses[x]					Sensory evaluation	
Comparison no.	Picking stage[z]	Postharvest treatment[y]	pH	Titratable acidity (% citric acid)	Reducing sugars (%)	Glucose (%)	Sugar/acid ratio	Triangle tests (no. of correct answers/no. of judgments)	Direction of difference
6	MG	Held 7 days @ 12.5° before ripening @ 20°C	4.60	0.33	3.32	1.34	10.1	17/44 NS[x]	No clear directional difference
	MG	Held 7 days under 4% O_2 before ripening in air @ 20°	4.61	0.34	3.58	1.49	10.5		
7	LP	Held 7 days @ 12.5° before ripening @ 20°	4.63	0.35	3.54	1.39	10.1	24/45 **	No clear directional difference
	LP	Held 7 days under 4% O_2 before ripening in air @ 20°	4.64	0.36	3.67	1.51	10.2		
8	MG	Ripened @ 20° under normal air flow (×)	4.63	0.33	3.72	1.59	11.3	29/44 ***	More acid
	MG	Ripened @ 20° under restricted air flow (0.1×)	4.75	0.31	4.00	1.75	12.9		Sweeter, more "off-flavor"
9	MG	Ripened @ 20° under normal air flow (×)	4.60	0.35	3.54	1.53	10.1	22/45 *	No clear directional difference
	MG	Ripened @ 20° under accelerated air flow (10×)	4.57	0.37	3.53	1.48	9.5		
10	LP	Ripened @ 20°	4.64	0.35	3.70	1.47	10.6	36/46 ***	More "tomato-like"
	LP	Bruised, then ripened @ 20°	4.73	0.31	3.82	1.56	12.3		More "off-flavor", sweeter

[z]MG = mature green, LP = light pink.

[y]See Table 2 for details.

[x]Means of 3 replicates.

*, **, *** indicate significant difference at the 5%(*), 1%(**), and 0.1%(***) level,; NS = no significant difference.

Table 10. Volatile analyses of 'Cal Ace' tomatoes harvested at the MG or LP stage and subjected to various postharvest treatments (1976). Only those compounds showing significant difference for any comparison are included.

Comparison no.	Picking stage[z]	Postharvest treatments[y]	Relative peak area[x] for indicated peak number(s)							
			17	51	53	60-61	91-92	120-123	145	172
6	MG	Held 7 days @ 12.5° before ripening @ 20°C	7.3	14.2	66.2 *	62.7	11.2	197.7	17.0	12.4
	MG	Held 7 days under 4% O_2 before ripening in air @ 20°	3.8	16.2	50.9	74.7	11.5	58.1	22.5	14.2
7	LP	Held 7 days @ 12.5° before ripening @ 20°	5.3	9.8	49.6	47.0	9.7 *	21.1	5.9	11.1 *
	LP	Held 7 days under 4% O_2 before ripening in air @ 20°	3.7	10.4	44.3	63.7	19.9	17.6	4.7	34.9
8	MG	Ripened @ 20° under normal air flow (x)	5.2	34.2	35.4	56.9	11.9	30.8	13.4	18.0
	MG	Ripened @ 20° under restricted air flow (0.1x)	5.3	28.6	50.3	80.0	15.2	25.3	9.4	32.3
9	MG	Ripened @ 20° under normal air flow (x)	4.1	12.5 **	56.8	52.4	13.9	33.6	13.0	19.3
	MG	Ripened @ 20° under accelerated air flow (10x)	6.7	26.5	53.6	59.2	12.9	48.4	23.1	21.3
10	LP	Ripened @ 20°	8.2	12.2	59.5	40.3 **	14.3	16.9 *	9.5 *	14.9
	LP	Bruised, then ripened @ 20°	4.2	8.9	46.4	61.6	12.7	10.4	6.9	17.3

[z]MG = mature green, LP = light pink.

[y]See Table 2 for details.

[x]Means of 3 replicates, x 10^{-2}.

* and ** indicate significant difference at the 5%(*) and 1%(**) level.

chilling effects on chemical analyses and sensory tests (Table 5). Although the triangle test between chilled and non-chilled fruits harvested as MG was not significant, those panelists finding differences indicated that chilled fruits were more acid. Compositional data support this conclusion since chilled fruits were significantly higher in acids and lower in reducing sugars than non-chilled fruits (Table 5). Exposing LP fruits to 5°C for 7 days before ripening at 20° also affected their flavor, and the panelists were able to detect the differences between chilled and non-chilled fruits. Chilled fruits contained significantly more acid than non-chilled fruits. In both comparisons, Nos. 3 and 4, non-chilled fruits had higher sugar/acid ratio than chilled fruits. Panelists did not detect "off-flavors" in chilled fruits. The observed effect of chilling temp on increased acidity and decreased reducing sugars relative to non-chilled fruits is in agreement with previous reports (2, 5).

Fruits subjected to chilling temp before ripening at 20°C were generally lower in volatiles (Table 6). These differences were significant for peaks (39-41), 45, 53, (112-113), (120-123), 145, and 160 in fruits harvested MG and for peaks 25, (91-92), 105, and (112-113) in fruits harvested LP. Although not statistically significant, non-chilled fruits had a 54% and 49% higher total volatile concn than chilled MG and LP fruits, respectively.

Effect of enhancing ripening by ethylene treatment. Using C_2H_4 to enhance ripening of green tomatoes at 20°C did not influence their flavor or sugar/acid ratio when compared with fruits harvested at the same maturity stage and ripened without added C_2H_4 (Table 7). However, fruits ripened with added C_2H_4 had a significantly higher ascorbic acid content than those ripened without applied C_2H_4. We do not know if this difference is due to smaller losses in reduced ascorbic acid because of the shorter ripening period, actual synthesis of reduced ascorbic acid, and/or change of dehydroascorbic acid into ascorbic acid resulting from C_2H_4 action on some enzyme activity. It is likely that the reduced ripening time is the principal cause.

The effect of ripeness at picking on flavor and composition was illustrated again in these comparisons (Table 7). Fruits harvested green and ripened at 20°C with or without added C_2H_4 were lower in sugar/acid ratios and were perceived to be less sweet, more sour, and with more "off-flavor" than fruits harvested TR. Also, fruits ripened off the plant were lower in ascorbic acid than those ripened on the plant.

Effect of delaying ripening by low-O_2 atmosphere. For fruits harvested at the MG stage, the use of 5% O_2 to retard ripening did not influence their flavor attributes relative to those held in air (Table 8). This was also generally true for fruits harvested at the LP stage except for less of an "off-flavor" score than fruits held at low temp. The effect of using 5% O_2 to retard ripening was less important than the ripeness stage at harvest on the flavor of tomatoes.

No significant differences in sensory evaluation or chemical analyses were found between MG fruits ripened at 20°C following a 7-day delay in ripening using 4% O_2-atm or using low temp of 12.5° (Table 9). For LP fruits, although the panelists were able to detect a difference, no clear direction was indicated. This is supported by the compositional analyses data. Differences in volatile content (Table 10) were limited to 2 compounds in each comparison. MG fruits held for 7 days at 12.5° before ripening at 20° had a higher content of peaks 17 and 53 than those held for 7 days under 4% O_2 before ripening in air at 20°. Low-O_2-held LP fruits had a higher concn of peaks (91-92) and 172 than low-temp-held fruits. No significant differences were observed in the total concn of volatiles among any of these treatments.

Influence of aeration rates. MG fruits ripened at 20°C under restricted air flow had increased "off-flavors" and greater sweetness than those ripened under normal or accelerated air flow (comparisons 8 and 9 in Table 9). Differences in acidity and reducing sugars, though not statistically significant, are in

line with the sensory observations. Although restricting the air flow rate resulted in accumulation of CO_2 and C_2H_4 (Table 3), it did not appreciably affect ripening rate. MG fruits, ripened at 20° under either restricted or accelerated aeration rates, attained table-ripeness at about the same time (12 ± 2 days after harvest).

No significant differences in volatile components were observed between fruits ripened under normal air flow and those ripened under restricted air flow. Fruits ripened under accelerated air flow differed only in one component; (peak 51) was greater than in fruits ripened under normal air flow (Table 10).

Effect of physical damage. LP fruit subjected to impact bruising before ripening were sweeter but had more "off-flavors" and less "tomato-like" flavor than control fruits. Bruised fruits were slightly lower in titratable acidity and higher in reducing sugars than control fruits, but these differences were not statistically significant (Table 9). MacLeod et al. (12) reported similar observations with impact-bruised MG 'Cal Ace' tomato fruits. Bruised fruits contained about 50% more of peaks (60-61) and about 50% less of peaks (120-123) and 145 than control fruits (Table 10).

Conclusions

The 1975 data reported here and data on several cultivars published previously (10), indicated that many of the problems associated with the flavor quality of fresh market tomatoes were related to maturity and/or ripeness stage at harvest. The best way to ensure good flavor for the consumer is to harvest the fruits as near TR as possible and move them rapidly and carefully from the field to the consumer. But since this is not feasible or practical within the constraints of the current handling and marketing system, alternatives must be accepted. Several improvements in the present handling system for fresh market tomatoes should be considered in light of the data reported in this paper and the previous one (10); these include:

1. The use of ethylene treatment to enhance ripening of MG fruits can be advantageous from the standpoint of shortening the duration between harvest and consumption, and of maintaining a higher reduced ascorbic acid content at the TR stage relative to MG fruits ripened without added ethylene.

2. Avoiding exposure of the fruits to chilling temp throughout postharvest handling is not only important for avoiding quantitative losses of fruits, but also qualitative losses in flavor. The adverse effects of chilling on flavor can take place before any visual symptoms of injury are apparent.

3. Shortening the time between harvest and consumption can also be helpful in terms of flavor quality. Our data showed that a recommended transit temp, the longer the holding period the greater the losses of characteristic aroma and the development of "off-flavors."

4. Adequate air exchange (aeration) in ripening rooms seems to be important in reducing accumulation of "off-flavors" in fruits harvested MG. This merits further investigation.

5. Reduction of bruising damage throughout the harvesting and postharvest handling operations can reduce losses of fruits and of fruit quality. Impact bruising can have an adverse effect on flavor of fresh tomatoes.

Before any new postharvest handling procedure is recommended for use on fresh market tomatoes, it should be evaluated for its possible effects on flavor quality. While chemical analyses for sugars, acids, and the sugar/acid ratio can be good indicators of possible effects, they are not an adequate substitute for sensory evaluation. The significance of quantitative differences in a few volatile compounds reported here will depend upon their identification and a study of flavor characteristics which are under way in our laboratory.

Literature Cited

1. Anon. (undated). Glucostat for the enzymatic determination of glucose. Section 9-65, in: Worthington enzymes and enzyme reagents. Worthington Biochemical Corp., Freehold, N.J.
2. Buescher, R. W. 1975. Organic acid and sugar levels in tomato pericarp as influenced by storage at low temperature. *HortScience* 10:158-159.
3. Craft, C. C. and P. H. Heinze. 1954. Physiological studies of mature-green tomatoes in storage. *Proc. Amer. Soc. Hort. Sci.* 64:343-350.
4. Hall, C. B. 1966. Quality changes in fruits of some tomato varieties and lines ripened at 68°F for various periods. *Proc. Fla. State Hort. Soc.* 79:222-227.
5. ———. 1968. Changes in titratable acidity of tomato fruits subjected to low temperatures. *HortScience* 3:37-38.
6. Handy, C. R. and M. Pfaft. 1975. Consumer satisfaction with food products and marketing services. U. S. Dept. Agric., Econ. Res. Serv., Agric. Econ. Rpt. 281.
7. Hassid, W. Z. 1936. Determination of reducing sugars and sucrose in plant materials. *Indust. & Eng. Chem. Anal. Ed.* 8:138-140.
8. House, M. C., P. M. Nelson, and E. S. Haber. 1929. The vitamin A, B, C content of artificially versus naturally ripened tomatoes. *J. Biol. Chem.* 81:295-304.
9. Kader, A. A. and L. L. Morris. 1976. Correlating subjective and objective measurements of maturation and ripeness of tomatoes. p. 57-62, *In* Proc. 2nd Tomato Quality Workshop, Univ. of Calif., Davis. Veg. Crops Series 178.
10. ———, M. A. Stevens, M. Albright-Holton, L. L. Morris, and M. Algazi. 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. *J. Amer. Soc. Hort. Sci.* 102:724-731.
11. Loeffler, H. J. and J. D. Ponting. 1942. Ascorbic acid determination in fresh frozen, or dehydrated fruits and vegetables. *Indus. & Eng. Chem. Anal. Ed.* 14:846-849.
12. MacLeod, R. F., A. A. Kader and L. L. Morris. 1976. Stimulation of ethylene and CO_2 production of mature-green tomatoes by impact bruising. *HortScience* 11:604-606.
13. Pantos, C. E. and P. Markakis. 1973. Ascorbic acid content of artificially ripened tomatoes. *J. Food. Sci.* 38:550.
14. Salunkhe, D. K. and M. T. Wu. 1973. Effects of low oxygen atmosphere storage on ripening and associated biochemical changes of tomato fruits. *J. Amer. Soc. Hort. Sci.* 98:12-14.
15. Scott, L. E. and A. Kramer. 1949. The effect of storage upon the ascorbic acid content of tomatoes harvested at different stages of maturity. *Proc. Amer. Soc. Hort. Sci.* 54:277-280.
16. Stevens, M. A. 1970. Relationship between polyene-carotene content and volatile compound composition of tomatoes. *J. Amer. Soc. Hort. Sci.* 95:461-464.
17. ———, A. A. Kader, M. Albright-Holton and M. Algazi. 1977. Genotypic variation for flavor and composition in fresh market tomatoes. *J. Amer. Soc. Hort. Sci.* 102:680-689.
18. Watada, A. E., B. B. Aulenbach and J. T. Worthington. 1976. Vitamins A and C in ripe tomatoes as affected by stage of ripeness at harvest and supplementary ethylene. *J. Food Sci.* 41:856-858.
19. Weimer, J. and P. Stevens. 1974. Consumer's preferences, uses, and buying practices for selected vegetables, a nationwide survey. U. S. Dept. Agric., Econ. Res. Serv., Mktg. Res. Rpt. 1019.