Food Chemistry **49** (1994) 225–231

Effect of storage and ripening on fresh tomato quality, Part I

Donald J. Stern, Ron G. Buttery, Roy Teranishi, Louisa Ling
USDA, 800 Buchanan Street, Albany, CA 94710, USA

Kevin Scott
AgScience Inc., Sacramento, CA, USA

& Marita Cantwell
University of California, Davis, CA, USA

(Received 17 November 1992; revised version received and accepted 16 April 1993)

Four varieties of fresh tomato were grown, stored and treated under commercial conditions to assess the effects of storage and ripening conditions on tomato taste and flavor. The qualitative and quantitative changes in values for volatiles, non-volatiles and physical characteristics were determined.

The results are reported in two parts. This report discusses the effects of storage temperature and ethylene treatment on changes in the concentrations of 32 tomato volatiles with results expressed in terms of Odor Units (Uo) in order to best approximate human aroma effect. A second report discusses all other parameters along with general statistical analysis.

The average Odor Unit value for each of the tracked analytes showed that only half the tracked volatiles were present in concentrations great enough to contribute to over-all aroma. Statistical analysis by Anova showed that the levels of all significant volatiles, except methyl salicylate, can be correlated to changes in storage conditions.

The generation of volatiles decreases significantly with storage and ripening temperatures below 10° but the final ripening temperature is the most significant factor in determining levels of volatiles produced. If final ripening temperatures are raised to 20° for tomatoes initially stored at 10° or less, volatiles are produced at a level comparable to tomatoes stored above 10°. When final ripening takes place at temperatures below 10° volatile production is curtailed.

INTRODUCTION

The goal of this study is to determine which aspects of cultivars and storage conditions are the most important for producing a tomato with the best flavor. The effect of storage, ripening and variety on fresh tomato flavor was measured by changes in physical characteristics and in the volatile and non-volatile composition. Three major commercial and one experimental cultivars were selected for this study. Part I of this paper reports on volatile constituents, Part II discusses non-volatiles, physical measurements, and statistical analysis.

A number of investigators (Hardenburg *et al.*, 1986; Wang, 1989) have examined the effects of storage temperature on fruit and vegetable quality, especially chill damage. These studies centered, mainly, on gross changes. Other studies (Hayase *et al.*, 1984; Crouzet *et al.*, 1986) focused on changes in volatile composition during ripening but more recent techniques (Buttery *et al*, 1989) give a more accurate analysis of volatile composition. Another study (Baldwin *et al.*, 1991) has been comprehensive in correlating various parameters of tomato flavor. The authors have also reported previously on some of the methodology used in the data gathering and analysis of tomato volatiles (Stern *et al.*, 1990). The current study has quantified changes in the most important volatile and non-volatile compounds, along with physical properties. An attempt has been made to correlate these flavor factors with each other and with treatments, under conditions which closely simulate current commercial practices of storage and ripening.

Although more than 400 compounds have been

Table 1

(a) Tomato volatiles monitored

Aldehydes (12)	Alcohols (8)
3-Methylbutanal	1-Penten-3-ol
2-Methyl-2-butenal	3-Methylbutanol
(E)-2-Pentenal	Pentanol
(Z)-3-Hexenal	(Z)-3-Hexenol
(E)-2-Hexenal	Hexanol
Hexenal	6-Methyl-5-hepten-2-ol
Benzaldehyde	Linalool
Phenylacetaldehyde	2-Phenylethanol
(E)-2-Heptenal	
Beta-Cyclocitral	
Neral	Esters (1)
Geranial	
	Methyl salicylate
Ketones (6)	Nitrogen/hetero (5)
1-Penten-3-one	Isobutylcyanide
6-Methyl-5-hepten-2-one	Phenylacetonitrile
Damascenone	1-Nitro-3-methylbutol
Geranylacetone	1-Nitro-2-phenylethane
Beta-Ionone	2-Isobutylthiazole
Pseudoionone	

(b) Volatiles in order of average odor unit value (Fig. 2)

ID No.	Name	ID No.	Name
9	(Z)-3-Hexenal	12	(Z)-3-Hexenol
28	Damascenone	29	Geranylacetone
30	Beta-Ionone	7	(E)-2-Pentenal
1	3-Methylbutanal	13	Hexanol
10	Hexanal	24	beta-Cyclocitral
2	1-Penten-3-one	32	2-Phenylethanol
27	1-Nitro-2-phenylethane	26	Geranial
11	(E)-2-Hexenal	31	Pseudoionone
20	2-Isobutylthiazole	5	2-Methyl-2-butenal
23	Methyl salicylate	3	1-Penten-3-ol
19	Phenylacetaldehyde	25	Neral
16	(E)-2-Heptenal	22	Phenylacetonitrile
17	6-ME-5-hepten-2-one	4	Isobutylcyanide
14	1-Nitro-3-me-butane	15	Benzaldehyde
6	1-Nitro-3-me-butanol	18	6-ME-5-hepten-2-ol
21	Linalool	8	Pentanol

identified as volatile constituents of tomatoes and tomato products (Petro-Turza 1986–7), only a limited number are essential to tomato flavor. Thirty-two compounds (Table 1) were selected as those critical to fresh tomato flavor (Buttery *et al* 1987, 1988, 1989). An estimate of odor contribution for each monitored compound was achieved by converting concentrations into odor units. The non-volatiles measured were: sugars, acids, pigments and total solids; the physical parameters were deformation, fruit weight, locular tissue weight loss and color, and are considered in a separate publication. This paper reports on volatiles measured in the first season of a two season study of tomato flavor.

MATERIALS AND METHODS

Fresh tomatoes

Fresh tomatoes were grown at Campbell Research and Development plots in Davis, CA under the same conditions as other fresh market varieties. Four varieties were used: Castlemont, Sunny, Jackpot and an experimental variety.

Storage

Tomatoes were stored at the University of California, Davis and the duration of storage, temperature and treatment are summarized below. The study was divided into seven groups of samples, A–G. Batches were harvested table-ripe (fully vine-ripened, red and soft textured), breaker (partially vine ripened to a light pink color and firm textured), and mature Green (fruit at full size, bright green and hard textured). All temperatures in °C.

- A Picked table-ripe, divided into four groups, each group stored respectively for 6 days at 5°, 10°, 15° and 20°.
- B Picked breaker, divided into four groups, each group stored respectively for 6 days at 5°, 10°, 15° and 20°, until ripe.
- C Picked mature-green divided into four groups, each group stored respectively for 6 days at 5°, 10°, 15° and 20°, and finally all ripened at 20°.
- D Picked mature-green, ethylene treated, divided into four groups, stored respectively, at 5°, 10°, 15° and 20° for a maximum of 6 days and all stored at 20°, for as long as necessary to ripeness.
- E Picked mature-green, divided into four groups, all ethylene treated, and stored respectively at 5°, 10°, 15° and 20° until ripe.
- F Picked mature-green, divided into four groups, all stored respectively for 6 days at 5°, 10°, 15° and 20° for 6 days. All ethylene treated after 6 days held at 20° until ripe.
- G Picked mature-green, divided into four groups, all held respectively at 5°, 10°, 15° and 20° for 6 days. All ethylene treated after 6 days and batch held respectively at 5°, 10°, 15° and 20°, until ripe.

Ethylene treatment was accomplished by passing humidified air containing 8O ppm ethylene over the tomatoes in a closed container until the fruit reached the light pink stage (3–4 days).

Volatiles

Gas chromatographic (GC) analyses were carried out on each sample using methods described in detail in previous publications (Buttery *et al.*, 1988; Stern *et al.*, 1990). Volatiles were isolated from the blended tomato using high flow dynamic headspace sampling and GC analysis using a 60 m DB–1 coated fused silica capillary column. The compounds monitored (Table 1) were those previously identified as most characteristic of fresh tomato (Buttery *et al.*, 1987, 1988, 1989). Internal standards, 3–pentanone, 2–octanone, and anethole, were selected on the basis of functional group similarity to monitored peaks, stability and advantageous retention time in the chromatogram. Concentrations were adjusted for recovery and FID response factors as described previously (Buttery *et al.*, 1988). Odor units (Uo) were derived from concentrations using odor thresholds reported in the literature (Buttery *et al.*, 1990). A summary of the concentration and odor unit values for all of monitored compounds in each of the 150 samples was generated.

Statistical analysis

A multivariate statistical method was used to reveal the many relationships among the large number of variables. Principle Factor Analysis (using SAS FACTOR and SCORE Procedures) was used to characterize the effect of cultivars, schemes and storage temperatures.

RESULTS AND DISCUSSION

Previous studies (Hardenburg *et al.*, 1986) have shown that low storage temperatures (below 13 °C) can result in poor fruit quality, as well as chill damage. Our results quantify these effects on volatiles. We have also expanded on the results of the study by Baldwin (Baldwin *et al.*, 1991) by including a more comprehensive number of volatiles and a variety of ripening and storage conditions.

The relative importance of the tracked compounds (Table 1) to overall aroma can be most clearly visualized by converting concentrations into Odor Units (Uo). C/OT = Uo; C = adjusted concentration, OT = odor threshold concentration. As with any other model or derivation, this representation of aroma in the analysis of volatiles is an approximation (Guadagni *et al.*, 1966); nevertheless, the Odor Unit has a practical use in selecting the most important aroma contributors in a mixture. When C/OT for any peak is less than 1, it has no significant odor contribution because it exists in

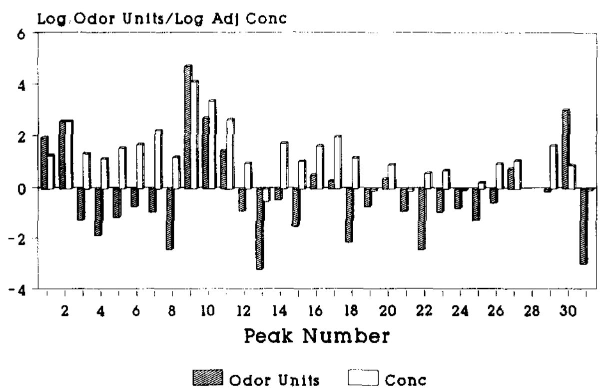

Fig. 1. Concentration versus odor units-typical sample.

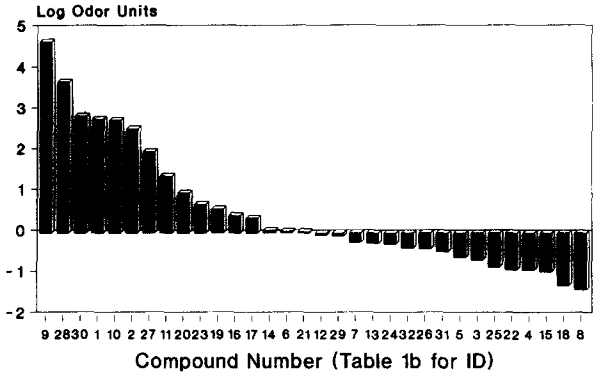

Fig. 2. Average odor units, all compounds, in decreasing order of intensity.

quantities below the odor threshold. All concentrations which are at threshold or above (C/OT = 1) are deemed to have a significant aroma contribution. The log relationships are represented in bar graphs of concentration versus odor units, for a typical sample in this study (Fig. 1)(Stern *et al.*, 1990). When log(Uo) of a compound is positive its odor contribution is significant; if its log(Uo) is negative it has no significant odor contribution. There is often a striking contrast between the log concentration and log odor units of a compound.

The results of odor unit values for each of the monitored volatiles showed that not all contributed to aroma and flavor; compounds with an average Uo value less than one (log ≤ 0) were considered to have little or no odor impact. Figure 2 shows the overall average log Uo value for each of the tracked

Table 2. Odor contributions affected by treatment

Av Uo	ID No.	Compound	Treatment
46845	9	(Z)-3-Hexenal	*
5149	28	Damascenone	*
720	30	Beta-Ionone	***
613	1	3-Methylbutanal	****
581	10	Hexanal	**
352	2	1-Penten-3-one	****
97	27	1-Nitro-2-phenylethane	*
25	11	(E)-2-Hexenal	****
9	20	2-Isobutylthiazole	****
4	19	Phenylacetaldehyde	****
3	16	(E)-2-Heptenal	***
2	17	6-ME-5-hepten-2-one	****
1	14	1-Nitro-3-me-butane	***
1	6	3-Methylbutanol	****
1	21	Linalool	**
0·9	12	(Z)-3-Hexenol	*
0·9	29	Geranylacetone	**
0·6	7	(E)-2-Pentenal	****

Av Uo = Average odor unit value for each compound for entire study.
Treatment = Significance of Uo variance with conditions of storage and ripening.
SAS calculations of mean value variance:
ns = not significant
* = significant at 0·05 level
** = significant at 0·01 level
*** = significant at 0·001 level
**** = significant at 0·0001 level.

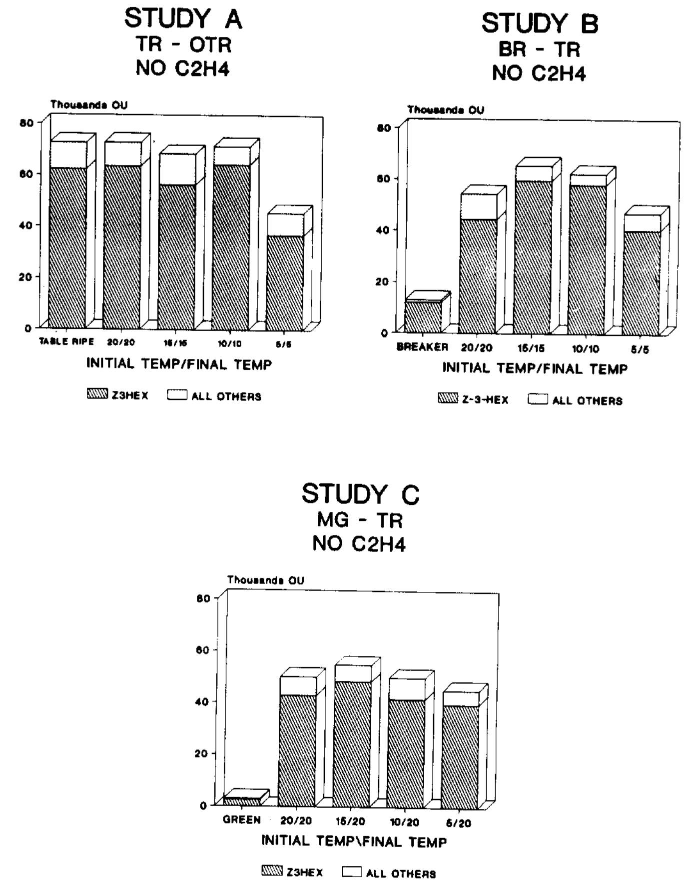

Fig. 3. Total odor units, studies A, B, C.

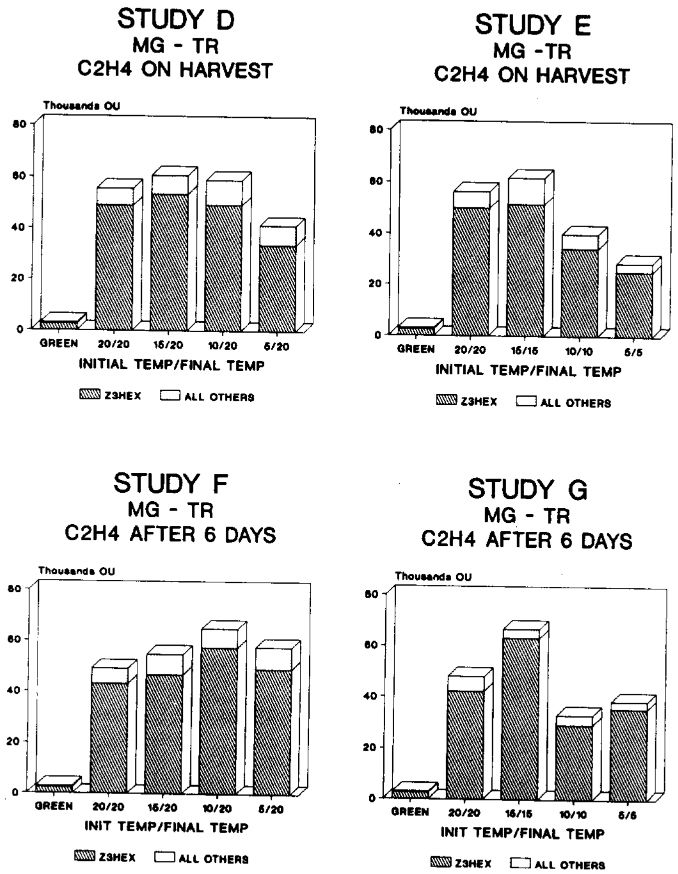

Fig. 4. Total odor units, studies D, E, F, G.

Table 3. Correlation of cultivar, treatment, planting with monitored compounds (analysis of variance)

ID NO.	Compound	Cultivar	Treatment	Planting	Av Uo
9	(Z)-3-Hexenal	****	*	****	46845
28	Damascenone	***	*	**	5149
30	Beta-Ionone	****	***	****	720
1	3-Methylbutanal	****	****	**	613
10	Hexanal	****	**	***	581
2	1-Penten-3-one	ns	****	*	352
27	1-Nitro-2-phenylethane	ns	*	ns	97
11	(E)-2-Hexenal	*	****	****	25
20	2-Isobutylthiazole	ns	****	****	9
23	Methyl salicylate	****	ns	***	5
19	Phenylacetaldehyde	**	****	ns	4
16	(E)-2-Heptenal	****	***	**	3
17	6-Me-5-hepten-2-one	ns	****	***	2
14	1-Nitro-3-me-butanol	****	***	**	1
6	3-Methylbutanol	****	****	****	1
21	Linalool	*	**	*	1
12	(Z)-3-Hexenol	*	*	**	0·9
29	Geranylacetone	ns	**	****	0·9
7	(E)-2-Pentenal	****	****	ns	0·6
13	Hexanol	ns	ns	ns	0·6
24	beta-Cyclocitral	ns	ns	**	0·5
32	2-Phenylethanol	*	**	*	0·4
26	Geranial	***	****	****	0·4
31	Pseudoionone	ns	ns	***	0·4
5	2-Methyl-2-butenal	ns	*	*	0·3
3	1-Penten-3-ol	ns	**	**	0·2
25	Neral	ns	ns	ns	0·1
22	Phenylacetonitrile	*	ns	ns	0·1
4	Isobutylcyanide	ns	ns	ns	0·1
15	Benzaldehyde	ns	****	*	0·1
18	6-Me-5-hepten-2-ol	*	****	*	0·05
8	Pentanol	ns	*	**	0·04

ID No. = Assignment number for tracked compounds.
Av Uo = Average odor unit value for each compound over entire study.
Cultivar = Significance of Uo variance with cultivar.
Treatment = Significance of Uo variance with conditions of storage and ripening.
Planting = Significance of Uo variance with one of two plantings.

SAS calculations of mean value variance:
ns = not significant
* = significant at 0·05 level
** = significant at 0·01 level
*** = significant at 0·001 level
**** = significant at 0·000 1 level.

compounds in this study. Table 1b lists all the compounds (referred to in Fig. 2 by Compound Number). Table 2 lists those compounds whose overall averaged Uo values were greater than one and three others with Uo values close to one. (See Part II of this paper for a discussion of the statistical associations between volatiles and variety.)

A rigorous statistical analysis shows the significant differences between means calculated by SAS Anova (Table 2). These results indicate that the values for compounds listed in Table 2 varied at significant levels when correlated with treatment (i.e. storage temperature/duration and ethylene treatment). Table 3 shows the effect of all factors on the variance of volatiles, listed in order of their average Uo value. Methyl salicylate is the only significant volatile which was not affected by treatment. All other significant volatiles were affected by treatment, or cultivar, or planting.

The detailed differences in the production or maintenance of volatiles caused by treatment is shown by Table 4 and Figs 3 and 4. All values shown are in Odor Units, partitioned between (Z)–3–hexenal, all other volatiles, and total Uo.

Study A samples, picked table ripe, were untreated and stored at indicated temperatures. Total volatiles were maintained at about initial table ripe level even though storage temperature varied from 20° to 10°; however, storage at 5° showed a marked decrease in volatiles (total Uo) (Fig. 3). The largest contributor was (Z)–3–hexenal, the odor unit value of which averaged thousands of times greater than threshold. Damascenone and beta-ionone were significant contributors together with hexanal and 3–methylbutanal.

Study B samples picked at breaker stage, and stored at the indicated temperatures until ripe, as in Study A, showed maximum development of volatiles at 10° and 15° (Fig. 3). Samples stored at 5° developed volatiles at a significantly lower level.

Study C samples were picked mature green, stored 6 days at indicated temperatures, then all samples were allowed to ripen at 20°. All samples showed (Fig. 3) comparable development of volatiles probably because they were all allowed to ripen at 20°.

Study D was identical to C except for ethylene treatment at the onset of storage. Samples stored at 20°, 15°, and 10° developed volatiles (Fig. 4), as in C except

Table 4. Total odor unit values of (Z)-3-Hexenal and all others

	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
Study A	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	Table ripe	72671	10355	14%	62315	86%
	20/20	72913	9396	13%	63518	87%
	15/15	68429	12217	18%	56212	82%
	10/10	71412	7196	10%	64216	90%
	5/5	45458	8650	19%	36808	81%
Study B	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	breaker	12955	1000	8%	11955	92%
	20/20	54157	9849	18%	44308	82%
	15/15	65336	5938	9%	59397	91%
	10/10	62144	4252	7%	57892	93%
	5/5	46878	6551	14%	40326	86%
Study C	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	green	2983	300	10%	2683	90%
	20/20	50068	7322	15%	42746	85%
	15/15	54814	6472	12%	48342	88%
	10/20	50001	8335	17%	41666	83%
	5/20	45215	5413	12%	39803	88%
Study D	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	green	2983	300	10%	2683	90%
	20/20	55572	6675	12%	48897	88%
	15/15	60629	7245	12%	53384	88%
	10/10	58901	9743	17%	49158	83%
	5/20	41320	7620	18%	33700	82%
Study E	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	green	2983	300	10%	2683	90%
	20/20	56249	6376	11%	49873	89%
	15/15	61543	10178	17%	51365	83%
	10/10	39897	5683	14%	34213	86%
	5/20	28628	3443	12%	25185	88%
Study F	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	green	2983	300	10%	2683	90%
	20/20	49031	5947	12%	43085	88%
	15/20	54763	8164	15%	46599	85%
	10/20	64835	7509	12%	57326	88%
	5/20	57572	8689	15%	48883	85%
Study G	Init/final	Tot Uo	Others	% Tot	Z-3-Hex	% Tot
	green	2983	300	10%	2683	90%
	20/20	47971	5762	12%	42209	88%
	15/15	66859	3559	5%	63300	95%
	10/10	33000	3778	11%	29222	89%
	5/5	38458	2909	8%	35549	92%

Init/final = Initial storage temperature/Final storage temperature.
Table ripe, Breaker, Green = Initial stage of ripeness when harvested for each study.
Tot Uo = Total odor units.
Others = Total odor unit value of all volatiles except (Z)-3-Hexenal.
% Tot = Percent non (Z)-3-hexenal volatiles of total odor units.
Z-3-Hex = Odor unit value of (Z)-3-Hexenal.
% Tot = Percent (Z)-3-Hexenal of Total Odor Units.

for those kept at 5°, even though all were allowed final ripening at 20°.

Study E showed a greater temperature effect on ripening, Fig. 4. In this variation samples were picked mature green as in C and D, treated with ethylene as in D but kept at indicated temperatures until ripe. There was less development of volatiles at 10° and 5° than at 20° and 15°.

Study F differed from E in that samples were held at the indicated temperatures first then treated with ethylene and held at 20° until ripe. In this study, the development of volatiles is comparable regardless of storage temperatures, because the final ripening conditions are the same, Fig. 4.

Study G parallels Study F as Study D parallels E shown in Fig. 4. In G the volatiles develop to a higher level at 20° and 15° than that of samples maintained at 10° and 5° because all samples are held at their initial temperatures through the ripe stage.

CONCLUSION

In summary, the general effect of storage temperature and treatment on volatile development seems to be a function of final ripening temperatures rather than initial stage of ripeness and storage temperatures or ethylene treatment. It can also be noted that the level of total volatiles developed in the stored samples (Studies B–G) never reaches that of the samples picked table ripe (Study A). This finding quantifies the lack of volatile development and verifies earlier reports of flavor diminution due to storage under chilling conditions.

ACKNOWLEDGEMENT

We wish to thank Campbell Food Research, Davis, CA for providing plots and planting of tomatoes, along with some of the physical analytical data. The authors wish to express deep appreciation to Dr M. Allen Stevens for his cooperation in making this study possible. The authors are indebted to Mr Simon Gazdik of WRRC for information and guidance in computerizing our data systems and to Ms Janie John at WRRC for help in the data entry of tomato volatiles.

REFERENCES

Baldwin, E.A., Nisperos-Carriedo, M.O., & Moshanas, M.G. (1991). Quantitative Analysis of flavor and other volatiles and for certain constituents of two tomato cultivars during ripening. *J. Am. Soc. Hort. Sci.*, **116**, 265–9.

Buttery, R.G., Teranishi R. & Ling, L.C. (1987). Fresh tomato aroma volatiles: a quantitative study., *J. Agric. Food Chem.*, **35**, 540–4.

Buttery, R.G., Ling, L.C., Flath, R.A. & Stern, D.J. (1988). Quantitative studies on origins of fresh tomato aroma volatiles., *J. Agric Food Chem.*, **36**, 1247–50.

Buttery, R.G., Teranishi, R., Flath, R.A. & Ling, L.C. (1989). Fresh tomato volatiles, composition and sensory studies. *Flavor Chemistry, Trends and Developments*, ACS Symposium Series No.388, ed. R. Teranishi, R.G. Buttery & F. Shahidi. American Chemical Society, Washington, DC.

Buttery, R.G., Teranishi, R., Ling, L. & Turnbaugh, J. (1990). Quantitative and sensory studies on tomato paste volatiles. *J. Agric. Food Chem.*, **38** , 336–40.

Crouzet, J., Signoret, A., Coulibaly, J. & Roudsari, M. (1986). Influence of controlled atmosphere storage on tomato volatile components. *Proceedings of the 4th International Flavor Conference*, Rhodes, Greece, 23–26 July, 1985. Elsevier Science Publishers, Amsterdam.

Guadagni, D.G., Buttery, R.G. & Harris, J. (1966). Odour intensities of hop oil components. *J. Sci. Food Agric.*, **17**, 142–4.

Hardenburg, R.E., Watada, A.E. & Wang, C.Y. (1986). *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks*, Agriculture Handbook Number 66, US. Department of Agriculture.

Hayase, F., Chung, T. & Kato, H. (1984). Changes of volatile components of tomato fruits during ripening. *Food Chem.*, **14**, 113–24.

Petro-Turza, M. (1986–87) Flavor of tomato and tomato products. *Food Rev. Int.*, **2**, 309.

Stern, D.J., Buttery, R., Teranishi, R., Ling, L., Scott, K. & Cantwell M. (1990). Computer enhanced flavor analysis in tomatoes. *J. Food Qual.*, **13**, 309–16.

Wang, C.Y. (1989). Chilling injury of fruits and vegetables. *Food Rev. Int.*, **5**(2), 209–36.