Quality Evaluation of Processed Tomato Juice

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Tomato juice color can be evaluated objectively using the Hunter D-6 Tomato Colorimeter or the Agtron M-400-A with the green mode. Color loss of tomato juice is materially accelerated by high-temperature storage. Flavor of tomato juice is a function of sugar acid ratio with high-quality tomato juice having a ratio not less than 10:1 nor more than 18:1. Consistency of tomato juice can be objectively evaluated using a modified efflux-tube viscometer (GOSUC). Fortified tomato juice retains ascorbic acid well if the product is stored at low temperature; however, if stored at or above 31 °C, only two-thirds of the vitamin C remains in the juice after 9 months shelf-life. Data are presented to show that the effect of temperature on rate of change in ascorbic acid concentration is a logarithmic function.

Tomato juice is the leader in quantity of canned juice packed in the United States. However, canned tomato juice consumption is declining while the consumption of other tomato products is increasing. Tomato juice quality, according to the U.S. Department of Agriculture Standards for Grades and factors of quality includes the following: color, consistency, absence of defects, and flavor (Table I) (Gould, 1974).

The objective of this paper is to report studies affecting the quality of tomato juice and suggest methods to improve the quality of tomatoes and to recommend methods to objectively standardize the evaluation of tomato juice quality. The work reported covers the following factors affecting tomato juice quality: (1) color, (2) flavor, and (3) consistency.

Color is the most prominent characteristic of most food products. Consumers associate color characteristics of a food item with other attributes of quality such as flavor and nutritional value. Consequently, the maintenance of color in a food item through processing and storage is of major importance. In addition, color control is used in foods for the: (1) standardization of the product, (2) index of economic worth, and (3) improvement of the quality of the product. Measurement of color should be related as closely as possible to the visual appearance of the product.

In the U.S. Standards for Grades of Canned Tomato Juice, flavor receives 40 points out of 100 points and is the most important quality factor of the scored factors. Flavor as defined in the U.S. Standards for Grades of Canned Tomato Juice is: "Flavor–Grade A possesses a distinct canned tomato juice flavor and odor characteristics of good quality tomatoes. Grade C means a characteristic canned tomato juice flavor. The flavor of the product as it may be affected by stems, leaves, crushed seeds, cores, immature tomatoes or the effects of improper trimming or processing: Grade A shall not be adversely affected; Grade C may be adversely affected but not seriously so" (Gould, 1974). At the present time, salt is the only optional flavoring ingredient permitted in tomato juice to improve the flavor.

Consistency of tomato juice is another important factor in the evaluation of tomato juice quality. Consistency is of importance to processors, Federal Grading agencies, and, moreover, for consumer acceptance. Variations with commercial juices as to the viscosity of the juice are not uncommon. These variations in consistency may be the result of different cultivars and/or processing methods used by the different tomato juice processors.

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Table I. USDA Standards for Grades for Tomato Juice

factors	points maximum	grade A	grade C
color	30	26–30	23–25
consistency	15	13–15	10–12
absence of defects	15	13–15	10–12
flavor	40	33–40	27–32
total score	100	85	70

PROCEDURES

Various processing procedures for given varieties or cultivars of tomatoes were used to determine the effects that different processing procedures have on the quality of tomato juice. In addition, several commercially available products of tomato juice were compared to the juice that was processed at The Ohio State University Food Processing Pilot Plant. Furthermore, variations due to use of food additives and shelf-live studies were conducted.

RESULTS AND DISCUSSION

The instruments used for objective color evaluation were the Hunter D25 Color and Color Difference Meter, Hunter D-6 Tomato Colorimeter, Agtron Model F, Agtron Model E-5, Agtron Model M-400-A, and the MacBeth-Munsell Disc Colorimeter. In all measurements, the instruments were standardized prior to evaluations and the viewing cells were filled 1-in. deep with the product.

After the data were collected, coefficients of correlation ("R"), coefficients of determination ("R^2"), lines of regression, and regression equations were calculated. The results were divided into two sections: one dealing with the comparison of the USDA Color Score to the data from the color instruments and, secondly, by comparing data from the color instruments among themselves.

Of the instruments and methods used, the Hunter D-6 Tomato Colorimeter, Hunter Lb_L/a_L, Hunter a_L/b_L, Agtron M-400-A, Agtron Model F, and Agtron E-5 correlated with the USDA Color Score (Table II). The Hunter D-6 Tomato Colorimeter had the highest correlation to the USDA Color Score for Tomato Juice (Table II). However, the Hunter a_L/b_L value is more widely used for the (Figure 1) determination of USDA Color Score of tomato juice. The Agtron M-400-A gave significant results but only when using the green mode (546 nm). Even so, the Agtron M-400-A and Agtron Model F gave better correlation coefficients than the Agtron E-5.

Factors affecting color standardization of tomato juice are time and temperature during storage. For this evaluation, tomatoes were processed into juice at The Ohio State University Food Processing Pilot Plant. During processing, different levels of ascorbic acid were added to

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Table II. Correlation Coefficients and Coefficients of Determination for USDA Color Score with Instruments and Methods Used for Tomato Juice Color Measurement

instruments and methods	coefficient of: correlation "r"	determination "r^2" (%)	significance
USDA Color Score vs. Hunter D-6 Tomato Colorimeter	0.881	77.62	0.01
USDA Color Score vs. Hunter Lb_L/a_L	−0.871	75.86	0.01
USDA Color Score vs. Hunter a_L/b_L	0.850	72.25	0.01
USDA Color Score vs. Agtron M-400-A (green mode)	−0.830	68.89	0.01
USDA Color Score vs. Agtron Model F	−0.801	64.16	0.01
USDA Color Score vs. Agtron E-5	−0.872	61.15	0.01
Hunter D-6 Tomato Colorimeter vs. Agtron M-400-A (green mode)	−0.892	79.57	0.01
Agtron E-5 vs. Hunter D-6 Tomato Colorimeter	−0.813	66.10	0.01
Agtron Model F vs. Hunter D-6 Tomato Colorimeter	−0.867	75.17	0.01
Agtron E-5 vs. Hunter a_L/b_L	−0.855	73.10	0.01
Hunter a_L/b_L vs. Agtron M-400-A (green mode)	−0.812	65.93	0.01
Agtron E-5 vs. Hunter Lb_L/a_L	0.853	72.76	0.01
Agtron E-5 vs. Agtron M-300-A (green mode)	0.795	63.20	0.01
Agtron Model F vs. Agtron M-400-A (green mode)	0.961	92.35	0.01

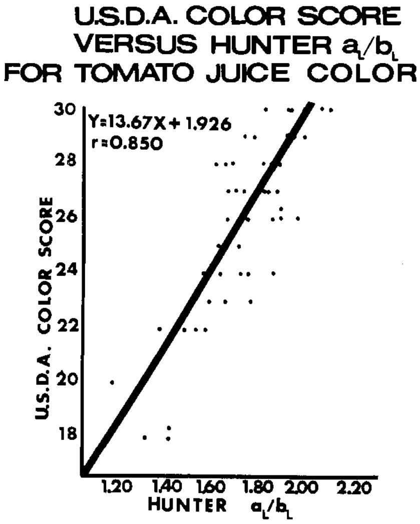

Figure 1. USDA color score vs. hunter a_L/b_L for tomato juice color.

the cans. A 30-grain (1.044 g) sodium chloride tablet was also added to the juice before sealing the cans after the juice was sterilized.

Color measurements were taken on duplicate samples of juice from each fortification level and storage temperature at 3, 6, 9, and 12 months. The Hunter Color and Color Difference Meter was used as an objective color measurement of the samples.

Data were analyzed in such a manner (analysis of variance) as to allow the singular effect of the factors: time, temperature, and the ascorbic acid fortification level, and any interaction among these factors.

Factors that were found to affect the degradation of tomato juice quality were time, temperature, and the time vs. temperature interaction. The level of ascorbic acid was not found to be a significant factor in the color degradation of tomato juice. Of all samples at storage temperatures and fortification levels, (1) a storage period of at least 12 months was necessary to significantly change the color of tomato juice (Table III), and (2) a storage temperature of 31 °C was needed to reduce the color of tomato juice (Figure 2). The time vs. temperature interaction did contribute to tomato juice color degradation of fortification levels at temperatures of 13 and 20 °C for storage longer than 9 months and at 31 °C for storage longer than 3 months. Although time vs. temperature did affect color degradation of tomato juice, a storage temperature of 31 °C was needed for 12 months to reduce the color of tomato juice to U.S. Grade C. These findings indicate that high temperatures (above 20 °C) and long storage periods (longer than 9 months) were necessary to change the color of the tomato juice. The interaction of time and temperature was also found to affect the degradation of tomato juice color.

Table III. Effect of Time and Temperature on Color (Hunter Values) of Tomato Juice

storage temp, °F	time,	Hunter L	a_L	b_L	a_L/b_L
35	0	25.3	26.3	12.6	2.16
	3	25.3	26.8	12.6	2.12
	6	24.6	26.1	12.4	2.10
	9	25.3	27.0	12.5	2.16
	12	25.8	26.5	12.5	2.12
55	0	25.3	26.3	12.6	2.16
	3	25.3	27.3	12.6	2.14
	6	24.9	26.3	12.5	2.10
	9	25.2	27.2	12.6	2.15
	12	24.6	25.3	12.5	2.02
68	0	25.3	26.3	12.6	2.16
	3	25.2	27.4	12.6	2.15
	6	24.8	26.4	12.5	2.11
	9	25.4	27.0	12.5	2.16
	12	25.1	25.0	12.5	2.00
88	0	25.3	26.3	12.6	2.16
	3	24.9	27.2	12.5	2.17
	6	24.4	25.6	12.5	2.05
	9	23.8	25.0	12.5	2.00
	12	23.1	21.0	12.5	1.68

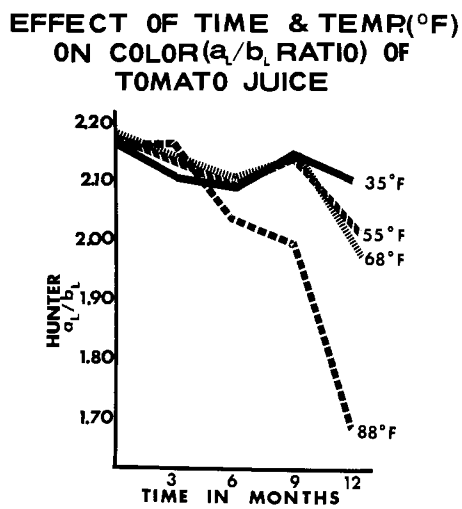

Figure 2. Effect of time and temperature (°F) on color (a_L/b_L ratio) of tomato juice.

Flavor. The factor of flavor in tomato juice has been studied in an attempt to improve the quality of the flavor and to standardize the flavor. The components in this research were tomato juice with sugar and acid as additives since salt is the only optional flavoring ingredient permitted by the Standard of Identity for tomato juice (Gould, 1974).

Commercial tomato juices and tomato juices processed at The Ohio State University Pilot Plant were used. The commercial juices were fortified with citric acid and/or sucrose prior to panel evaluation. The juice processed at The Ohio State University Pilot Plant had a 50-grain (3.240 g) salt tablet to a 303 × 406 size can or a 50-grain salt tablet with 10% ascorbic acid added to it. At this period, known amounts of citric acid, sucrose, or sucrose and citric acid combinations were also added.

Measurements were taken on the prepared juice samples by using taste panels for evaluation. Triangular taste evaluation methods and hedonic 10-point scoring evaluation methods were used. The tomato juice samples were analyzed for pH, percent total acidity and percent soluble solids. All of the samples were graded for quality according to the U.S. Standards for Grades of Canned Tomato Juice (Table I). All samples were in the Grade A range for all quality attributes except flavor.

The judges could discriminate between two samples having very small differences in soluble solids/total acidity ratios (less than 3.0). Judges could not discriminate when (1) the pH difference between samples was less than 0.16, or (2) the difference in percent total acidity in samples was less than 0.08. Results indicate that a tomato juice having a pH of less than 4.10, a soluble solids content of less than 5.8 or more than 8.0, and a percent total acidity value greater than 0.60 received low preference scores. Tomato juice samples receiving high preference scores had (1) pH values of 4.25 ± 0.05, (2) percent total acidity values of 0.50 ± 0.10, (3) percent soluble solids of 7.0 ± 1.0, and (4) soluble solids/total acidity ratios of 13.5 ± 1.5:1. Tomato juice samples with a soluble solids/total acidity ratio of less than 10:1 or greater than 18:1 are unacceptable for flavor and a percent total acidity content greater than 0.60 should have additional sucrose added for acceptable flavor. It is recommended that the addition of citric acid and sugar be permitted to be added to tomato juice to improve the quality and to help standardize tomato juice properties.

Consistency. A number of instruments have been used to evaluate consistency but they have not been evaluated concurrently. An instrument for standardization of tomato juice is needed as well as an understanding of the relationship of the insoluble tomato solids and serum viscosity to tomato juice consistency and what factors will affect the consistency of tomato juice.

An investigation of instruments was conducted on tomato juice samples processed at The Ohio State University Pilot Plant. The three instruments used were the USDA viscometer, the Efflux-tube viscometer, and the Modified Efflux-tube viscometer. All measurements were made at or near a temperature of 25 °C and timed to a tenth of a second. After experimentation, the Modified Efflux-tube viscometer was selected for consistency measurements of the tomato juice samples.

Further investigations dealt with the Capillary viscometer, the Modified Efflux-tube viscometer (GOSUC), the Stormer viscometer, the Brookfield viscometer, and the Gardner mobilometer. Consistency measurements were made on commercial tomato juice samples to determine their reproducibility. Consistency measured by the GOSUC consistometer and the Stormer viscometer gave a very high correlation (0.910) (Figure 3). A high correlation was found between the Efflux-tube viscometer and the Modified Efflux-tube viscometer, while the USDA viscometer resulted in low correlations with each of them. The values on the USDA viscometer could not be used to predict values obtained on either of the Efflux-tube instruments. The Modified Efflux-tube viscometer (GOSUC consistometer) was selected as the most acceptable means of comparative consistency measurements. Factors influencing this were its simplicity of design, reproducibility, sensitivity to consistency differences, and its correlation with other measuring devices. The variety of tomatoes did influence the consistency of tomato juice while storage did not have an effect. Increasing the soluble solids content by concentration increases the consistency of tomato juice (Figure 4).

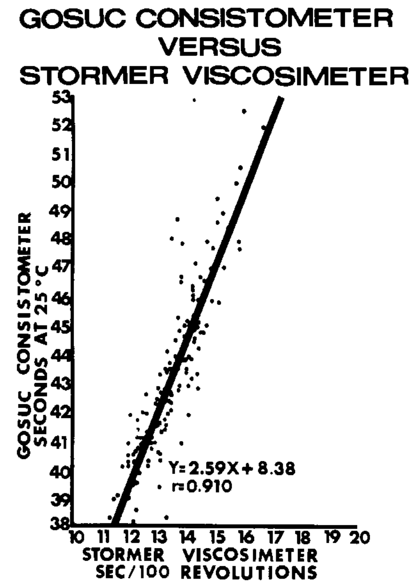

Figure 3. GOSUC Consistometer vs. Stormer Viscosimeter.

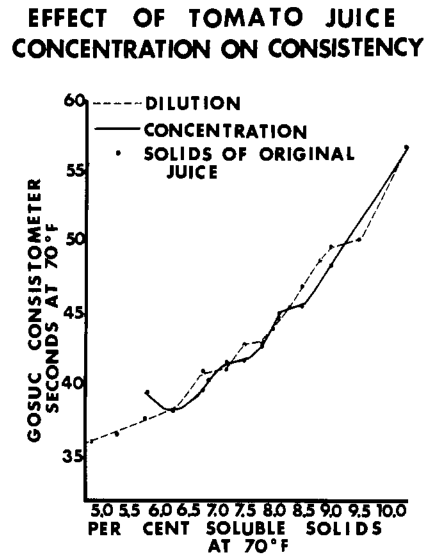

Figure 4. Effect of tomato juice concentration on consistency.

The standardization of tomato juice quality is an important aspect for industry to control. Data in Table IV indicate that the factors of color measurements and evaluation can be objectively evaluated. Flavor standardization and consistency control are also integral factors to consider when determining the quality of tomato juice. Standardization is a much needed facet to the tomato industry.

Table IV. Minimum Objective Color Score Values for USDA Grades A and C Tomato Juice

instrument	USDA Grade A	USDA Grade C
Hunter D-6 Tomato Colorimeter	65.8	61.6
Hunter Lb_L/a_L	15.17	17.63
Hunter a_L/b_L	1.76	1.54
Agtron M-400-A	45.6	53.2
Agtron Model F	41.7	49.2
Agtron E-5	36.1	46.9

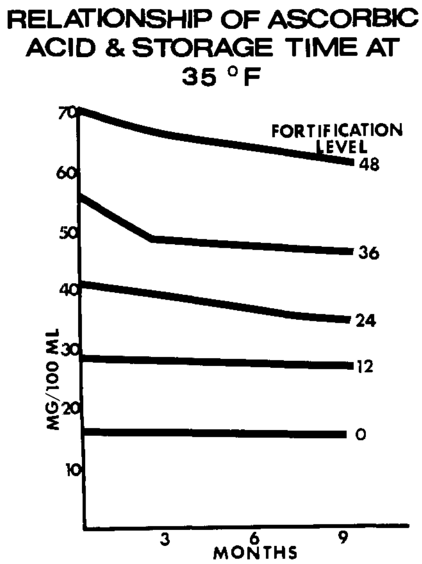

Figure 5. Relationship of ascorbic acid and storage time at 35 °F (2 °C).

Retention of Ascorbic Acid in Fortified Juice. Five distinct fortification levels of ascorbic acid were produced by adding given amounts of a solution of ascorbic acid to seven different tomato cultivars made into tomato juice to increase the concentration in the final product by 0, 12, 24, 36, or 48 mg/100 mL of juice. These five levels were each significantly different from the other four levels and consistent over all lots of juice. Initial concentration of ascorbic acid among the five different lots, calculated as the average value of samples drawn after cooling and before storage, were as follows:

level	mg of ascorbic acid/100 mL of juice
0	15.5–17.5
12	24.2–32.2
24	38.0–46.0
36	50.2–55.2
48	70.0–76.5

No significant difference within the levels of fortification could be attributed to the tomato cultivars.

Time Effects. As occurred in unfortified tomato juice, retention of ascorbic acid decreased with time at fortification levels 12, 24, 36, and 48. The rate of loss in the fortified juice was constant over the 9 months storage at 2, 13, and 20 °C (Figures 5, 6, and 7). Storage at 31 and 42 °C produced an increasing rate of loss of ascorbic acid from tomato juice (Figure 8 and 9).

After 9 months at 13 °C, unfortified juice retained 15.8 mg/100 mL; fortified at level 24 retained 34.0 mg/100 mL; fortified at level 36 retained 44.8 mg/100 mL; and fortified at level 48 retained 64.9 mg/100 mL. Expressed as percent of initial concentration, juice stored 9 months at 13 °C retained 95, 93, 87, 86, and 85% in the levels 0, 12, 24, 36, and 48, respectively.

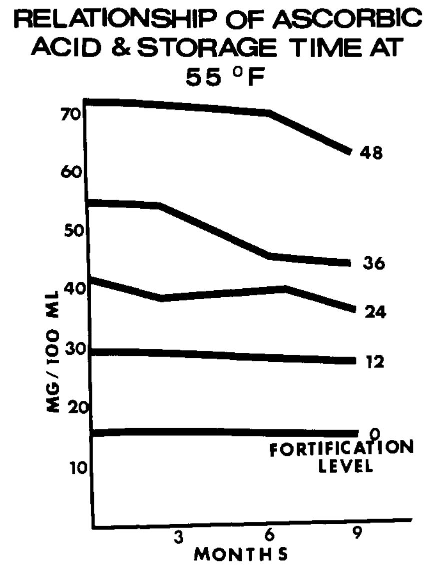

Figure 6. Relationship of ascorbic acid and storage time at 55 °F (13 °C).

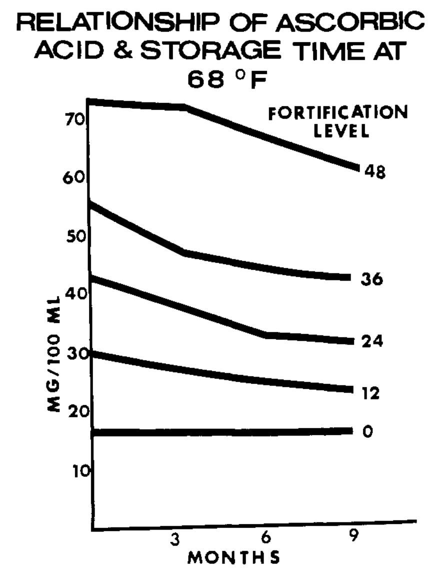

Figure 7. Relationship of ascorbic acid and storage time at 68 °F (20 °C).

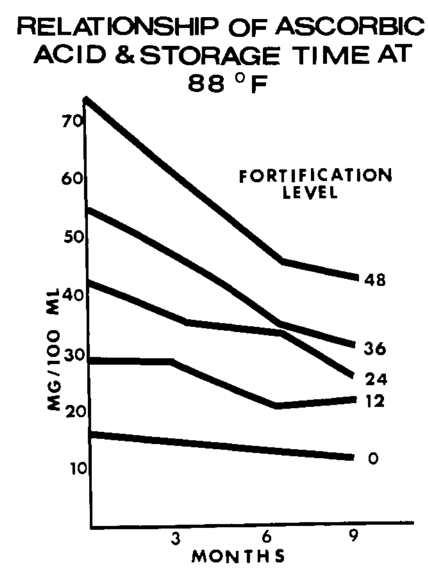

Figure 8. Relationship of ascorbic acid and storage time at 88 °F (31 °C).

Table V. Initial Concentration of Ascorbic Acid Necessary to Produce Final Concentration (C) for Tomato Juice Stored at Various Temperatures and Times

		final ascorbic acid concentration desired (mg/100 mL)				
		30	40	50	60	70
time, months	temp, °F	initial ascorbic acid concentration (mg/100 mL)				
3	35	30.3	40.4	50.4	60.3	70.8
3	55	30.9	41.3	51.9	62.2	72.2
3	68	33.0	45.2	56.3	67.4	79.0
3	88	59.1	79.0	99.5	119.1	138.0
6	35	30.6	40.5	50.9	60.9	70.8
6	55	32.1	42.9	53.5	64.1	73.7
6	68	38.1	50.9	63.4	75.9	88.2
6	88	120.0	158.1	196.4	235.1	270.4
9	35	30.6	40.9	50.9	61.6	71.5
9	55	33.1	44.3	55.1	66.7	77.5
9	68	42.9	57.4	71.5	85.6	100.5
9	88	232.8	314.0	400.7	468.7	544.6

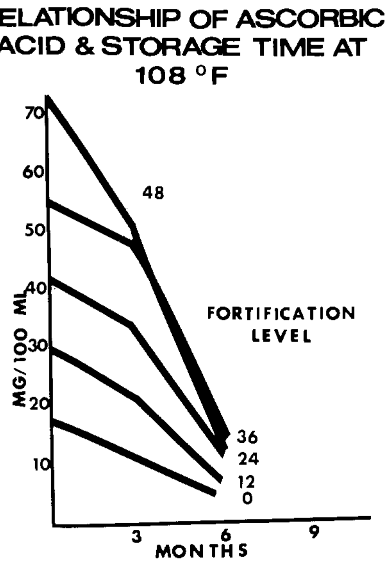

Figure 9. Relationship of ascorbic acid and storage time at 108 °F (42 °C).

Decrease in ascorbic acid concentration was more rapid in juice stored at room temperature (20 °C). Expressed as percent of initial concentration before storage, retention was 88, 85, 78, 78, and 79% for levels 0, 12, 24, 36, and 48, respectively. When juice was held at elevated temperatures, decrease in ascorbic acid concentration was rapid. Loss in the 31 °C storage shows differences in rate of loss over time. Loss was more rapid during 3 to 6 months of storage than for either 0 to 3 months or 6 to 9 months storage period. This was 64, 77, 65, 66, and 56% of initial concentration for levels 0, 12, 24, 36, and 48, respectively.

The retention of ascorbic acid was higher in juice stored at refrigerated temperatures and lower in juice stored at room temperatures. When storage was at room temperature (20 °C), loss increased over the refrigerated juice. A more rapid loss of ascorbic acid was observed in juice stored at 31 and 42 °C when compared to room temperature and refrigerated storage.

Fortification Effects. The initial concentration of ascorbic acid in the tomato juice affected the rate of loss of ascorbic acid and changed the percent retention within each storage temperature (Table V). As fortification increased from level 0 to level 48, a decrease in percent retention was observed.

Addition of ascorbic acid did not affect the maintenance of can vacuum. The pH (Table VI) was not altered by addition of ascorbic acid although total acid (Table VII) increased with time and level of fortification. The pH did decrease with length of storage from an average of 4.55 at 3 months to 4.51 at 6 months and 4.43 after 9 months. Total acid measured as citric increased with ascorbic acid concentration and time. No significant difference in change in total acid was observed due to temperature of storage.

Table VI. Effect of Ascorbic Acid Fortification Level and Storage Time on pH of Tomato Juice

ascorbic acid fortification level, mg/100 mL	storage time, months		
	3	6	9
	pH		
0	4.57	4.50	4.43
12	4.56	4.52	4.44
24	4.55	4.51	4.43
36	4.55	4.51	4.42
48	4.54	4.50	4.41

Table VII. Effect of Ascorbic Acid Fortification Level and Storage Time on Total Acid in Tomato Juice

ascorbic acid fortification level, mg/100 mL	storage time, months		
	3	6	9
	total acid (citric)		
0	0.382	0.373	0.445
12	0.392	0.394	0.451
24	0.399	0.399	0.455
36	0.405	0.422	0.461
48	0.411	0.418	0.471

The loss of ascorbic acid from anaerobic food systems has been shown to follow first-order kinetics and may be expressed as a rate constant (k):

$$\text{ascorbic acid} \xrightarrow{k} \text{degradation products}$$

The following differential equation may be used to describe the reaction at constant temperature:

$$-kC = \mathrm{d}C/\mathrm{d}t \quad (1)$$

where C = concentration of ascorbic acid and t = time in months.

Rearranging $\mathrm{d}C/C = -k\mathrm{d}t$ and integrating yield

$$\ln C = -kt + \text{constant} \quad (2)$$

at time t, $C = C_0$, the initial concentration, and

$$\ln C_0 = -k(0) = \text{constant} \quad (3)$$

Substracting eq 3 from eq 2 yields:

$$\ln (C/C_0) = -kt$$

Thus

$$k = -(1/t) \ln C/C_0 \quad (4)$$

Table VIII. Values of k at Constant Temperature [$k = -(1/T) \ln C/C_0$][a]

temperature, °F	k
35	0.0024
55	0.0112
68	0.0400
88	0.2280

[a] T = time in months, C = final concentration, and C_0 = initial concentration.

If eq 4 expresses the effect of fortification on retention, then the slope of a plot of k vs. initial ascorbic acid concentration should be 1 for each temperature. This is indeed the result from these values of k at constant temperature, the rate of loss of ascorbic acid which may be expected in fortified tomato juice can be developed. Table VIII lists the rate constant k which could be used in eq 4 to determine the initial concentration C_0 after t months of storage at a given temperature.

Given the lack of interaction between the factors time, temperature, and fortification level and the lack of any unexpected effect of fluctuation of temperature, the initial concentration C_0 necessary to yield final concentration C after several months of unequal temperatures could be calculated from an average value of k determined from the equation:

$$\frac{ak_1 + bk_2 + ck_3 + ... + ik_n}{a + b + c + ... + i} = k_{av}$$

where a = months at storage temperature 1 and b = months at storage temperature 2, etc., and k_1 = rate constant at temperature 1 and k_2 = rate constant at temperature 2, etc.

It should be noted that juice held at 42 °C while following the predicted equation for rate of loss of ascorbic acid did not maintain its other characteristics which identify it as tomato juice. Therefore values for k above 31 °C, while valid, do not give any information about the acceptability of the tomato juice.

GENERAL DISCUSSION

It is clear from the data presented that the effect of temperature on rate of change in ascorbic acid concentration is a logarithmic function. The data from this study did not, however, fit the Arrhenius equation satisfactorily. The rate of loss, b, did not change smoothly with temperature nor was the alteration due to temperature exactly parallel in each fortification level. Other factors acting in fortified tomato juice may have altered the data collected from exact adherence to the principles of mass action expressed in the Arrhenius equation.

More specific prediction formulae for fortified tomato juice would be useful. Rearranging the equation:

$$k = \frac{-1}{t} \ln \frac{C}{C_o} \text{ yields } \ln \frac{C}{C_o} = -kt$$

Changing to log

$$2.3 \log \frac{C}{C_o} = -kt \quad (5)$$

$$2.3 \log \frac{C_o}{C} = kt \quad (6)$$

From eq 6

$$C_o/C = 10^{kt2.3}$$

and

$$C_o = 10^{kt/2.3}C \quad (7)$$

From equation 5

$$C/C_o = 10^{-kt/2.3}$$

and

$$C = 10^{-kt/2.3}C_o \quad (8)$$

The initial concentration C_o, after processing and cooling before storage necessary to produce a final concentration C, can be predicted from eq 7 if the storage temperature and time are known. Similarly, the final concentration C may be predicted from eq 8.

From these fortification–shelf-life studies, one can conclude that for proper labeling of fortified juice, the time and temperature of storage must be controllable factors.

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REFERENCES

(1) Gould, W., "Tomato Production, Processing and Quality Evaluation", Avi Publishing Co., 1974.

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