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Ascorbic Acid (Vitamin C) Content Of Tomatoes and Apples

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Report on Department of Horticulture Research Project No. 212, entitled, "Conservation of Nutritive Value of Foods"

Ascorbic Acid (Vitamin C) Content Of Tomatoes and Apples

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This investigation has been carried on during the past few years as a phase of the general cooperative project on "Conservation of Nutritive Value of Foods." Since the vitamin content of foods was receiving wide recognition, it was thought desirable to assay the ascorbic acid content of Missouri grown tomatoes and apples. Both of these fruits are used extensively in the diet, especially of the rural population of our state. They are fair to good sources of this vitamin and, of course, have other valuable dietary properties.

While the variety is an important factor determining the ascorbic acid content of a fruit or vegetable, very wide variations seem to exist in this respect within the variety. This is shown in all compilations of the content of this vitamin in tomatoes, apples and many other horticultural crops. Apparently factors other than the genetic constitution of the plant affect the production and concentration of this rather unstable vitamin. Some of these seem to be operative in the garden or orchard while the fruit is developing and maturing; still others have a bearing during the post harvesting or the storage periods. The primary objective of this investigation was to obtain more information on this subject which might help (a) to clarify to some extent the existing situation and (b) to establish a "base line" for further studies on conservation of the ascorbic acid content of these two popularly used food products.

TOMATOES

Environmental Factors Affecting Ascorbic Acid Content of Tomatoes

Tomato fruits, when harvested either for immediate use or for the market, show great variability *within a variety* in ascorbic acid concentration, ranging from 7 to well over 40 milligrams per 100 grams of fresh tissue (29, 17, 16, 8, 45). In some rather rare instances, these differences may be due to genetic causes, permitting the possible isolation, perpetuation and even building up through seed progenies of strains producing fruit of relatively high ascorbic acid content (16, 8, 9). Most investigators, however, are of the opinion that intra-varietal differences are caused primarily by environmental effects, either on the plant as a whole or on the fruit during its development to maturity or while ripening[3] (17, 34, 24, 7, 18, 41, 36, 9).

[1]The authors acknowledge the interest and cooperation of A. G. Hogan and L. D. Haigh.

[2]Now professor of horticulture at Michigan State College.

[3]A tomato fruit may be considered *mature* (usually still green) when fully grown but *ripe* when it has reached an optimal "eating" stage (usually either red or pink, depending on variety).

Light: Of the many factors that make up the environment, light intensity and, to some extent, duration have been singled out as having a predominant role in ascorbic acid production in fruits and other aerial parts of plants (30, 1, 18, 21, 34, 19, 40, 26, 9). It is not quite clear whether all or most of the ascorbic acid found in the tomato at the time of harvesting is produced within the fruit or whether a portion, at least, is translocated into it from the leaves and possibly other parts of the plant, thus indicating a dual origin of this vitamin (1, 30, 21, 41, 19). Most of the evidence points to a more or less direct relationship between exposure of fruit to light and its ascorbic acid content.

Temperature: In addition to light, temperature undoubtedly has a considerable bearing on ascorbic acid of tomatoes, not only while they are developing but likewise when ripening off the plant, as is often the case under present systems of marketing. Tomato plants have a relatively high heat requirement, hence ascorbic acid will not reach a maximal content unless the temperature is fairly high while the fruit is produced (20). But relatively high temperature of maturing or ripening fruit, whether on or off the plant, coupled with low light intensity, probably leads to reduction in ascorbic acid due to oxidation (52). This apparently occurs despite the fact that with increasing maturity there is usually an augmentation in concentration of this vitamin in tomatoes. In general, information on the effects of temperature on ascorbic acid formation is still desultory.

The present investigation was undertaken with the object of securing additional and more exact information on the effects of temperature, light intensity, stage of maturity, nitrogenous fertilizer and "hormone" sprays on ascorbic acid content of tomatoes.

Materials and Methods

The Marglobe and Stokesdale varieties were selected for most of these tests. In a few cases other varieties of tomatoes were used for comparison or because of greater availability.

The plants were grown in the greenhouse, in large glazed crocks during the winter and spring seasons or outdoors in summer and fall. Accepted greenhouse and garden practices were used in soil fertilization, training the plants, pollination of flowers and harvesting the crop. When "hormone" sprays were given to increase fruit set and size, they were applied either once a week in water solution to open and previously pollinated flowers or to whole plants, barring the terminal parts. Light, in general, was determined by an Eppley pyrheliometer and Micromax recorder and expressed in gram-calories/cm.[2] Local differences in light were measured by means of a portable Weston photometer and expressed in foot-candles.

Ascorbic acid assays were usually made on eight carefully matched fruits. Not only the stage of maturity but also size was taken into consideration, since it has been shown that there is an inverse correlation between size and ascorbic acid in tomatoes (28, 8, 31, 38). After discarding the unusable hard stem end portion, the fruit was quartered, a slice was cut from each segment, including proportional parts of the skin and the seeds. The material, aggregating 200 grams in each case, was mascerated at once in Metaphosphoric-Sulphuric acid mix by a Waring blendor for exactly 3 minutes. Repeated determinations showed that 7 to 12 percent loss in ascorbic acid occurred in one hour from quartered tomato fruit segments (Table 10). Hence cutting of the material was done in 3 to 5 minutes.

The mascerated tissue extract was brought to definite volume and submitted immediately to analysis by means of the 4, 6-dichloro-phenolindophenol dye reduction procedure (5). Duplicate and triplicate determinations were run in all cases. To facilitate the work, two and sometimes three persons participated in preparation of the material and in chemical assay.

Results

Results are presented in tables in which more than one factor frequently has a bearing on the data. The ascorbic acid concentration, in all cases, is expressed in milligrams per 100 grams of fresh tissue.

Stage of Maturity and Seasonal Trends: Tomatoes are often harvested at various stages of development, from unripe but mature (green) to ripe (red) condition. Unripe fruits are usually allowed to ripen at room or higher temperatures before they are consumed. Our records show (Tables 1 and 2)

TABLE 1 -- ASCORBIC ACID IN GREENHOUSE-GROWN TOMATOES, MARGLOBE VARIETY, PICKED "GREEN" AND ALLOWED TO RIPEN AT ROOM TEMPERATURE (70-78°F.) FOR 8-10 DAYS

Condition of fruit	March 13	Milligrams ascorbic acid/100 grams of fruit, April 10: Large: Above 85 grams	April 10: Small: 25-85 grams
Still green	16.0	11.7	11.4
Beginning to ripen (yellowish pink)	17.8	14.7	16.0
Half ripe (deep pink and firm)	18.9	16.0	19.3
Ripe (red and soft)	19.7	20.2	26.7

that when greenhouse-grown tomatoes are picked "green" they are comparatively low in ascorbic acid content. Upon ripening at average room temperature (70 to 78° F.) there was an increase in this vitamin, sometimes reaching almost as high a value as in vine-ripened fruit (Table 2, April; also Table 12).

TABLE 2 -- ASCORBIC ACID IN MARGLOBE TOMATOES, GROWN IN GREENHOUSE AND OUTDOORS AND HARVESTED AT THREE STAGES OF MATURITY; RIPENED AT 68-75°F. (APRIL) AND 78-90°F; (JULY-AUGUST)

Condition of Fruit	Milligrams ascorbic acid/100 grams			
	Grown in Greenhouse	Grown Outdoors		
	April	July	August	September
A. Picked "green"				
1. Vitamin determined at once	15.4	24.8	27.3	34.8
2. Vitamin determined when "pink"	23.7	24.5	19.1	
3. Vitamin determined when "red" (ripe)	24.6	19.8	13.0	
B. Picked when "pink"				
1. Vitamin determined at once	25.0	24.9	27.8	33.7
2. Vitamin determined when "red" (ripe)	27.7	27.0	23.2	
C. Picked when "red" (ripe)				
1. Vitamin determined at once	28.6	25.3	28.2	31.1

When grown outdoors during summer (July to September), while the days are longer and there is more sunlight, the concentration of ascorbic acid is often but not always higher, especially in early stages of ripeness. But while tomatoes picked "green" from plants grown indoors and allowed to ripen at average room temperature increased in ascorbic acid, "green" fruit grown outdoors lost a large proportion of this vitamin on ripening at temperatures relatively higher (78-90° F) than the prevailing temperature (Table 13). This loss most likely was due to oxidation, which also may occur if the fruit is ripened on the plant at a rather high temperature and out of direct sunlight. There was a considerable seasonal increase in ascorbic acid in tomatoes grown outdoors (Table 2, July to September).

Effects of Light Intensity: Ample evidence exists that light intensity is one of the major factors determining ascorbic acid content in plants. Whether the fruit is harvested from plants grown outdoors, in early, intermediate or fully ripe stages, the relative amount of light a few days previous to picking seems to determine the ascorbic acid content to some extent (Table 3). Similarly, ripe (red) fruit, picked from plants in greenhouses after a period of sunny days, contained 27.1 mg./100 grams, while fruit in the same stage of maturity and from the same plants, when harvested after a period of cloudy days, contained only 22.1 mg./100 grams. Thus, sunlight affects in a

TABLE 3 -- EFFECTS OF LIGHT INTENSITY ON ASCORBIC ACID CONCENTRATION IN TOMATOES, MARGLOBE VARIETY, GROWN OUTDOORS.

Stage of maturity	Milligrams ascorbic acid/100 grams	
	After a few sunny days - Sept. 18	After a few cloudy days - Sept. 8
Green	32.4	31.9
Pink	34.6	32.8
Red (ripe)	35.2	34.5

like manner the ascorbic acid content of tomatoes, both outdoors and in the greenhouse.

Direct exposure of the fruit to sunlight, or shading by the foliage, seems to have even a greater bearing on concentration of this vitamin in tomatoes than light affecting the plant as a whole. Fruit shaded by leaves, though attaining visibly the same red color when ripe, in comparison with fruit developing in a position of full exposure, have a lower ascorbic acid content (Table 4). Even the shading of fruit by one leaf of a tomato plant grown in

TABLE 4 -- EFFECTS OF LIGHT INTENSITY (AS DETERMINED BY POSITION ON THE SAME PLANTS) ON ASCORBIC ACID CONTENT OF THREE VARIETIES OF TOMATOES; PLANTS GROWN IN THE FIELD, NOT TRAINED BUT BRANCHES TIED TO A STAKE

	Milligrams ascorbic acid/100 grams			
	September 8		September 26	
Variety	In shade	In light	In shade	In light
Marglobe	25.0	31.5	22.4	25.1
Stokesdale	24.9	28.0	22.5	27.0
Pan American	28.0	29.0	24.9	30.2

the greenhouse during relatively cloudy weather reduced the ascorbic acid concentration from 19.6 mg. to 18.7 mg. per 100 grams. Naturally such shading occurs only during part of the day when the sun is in a certain position.

In order to test further the effects of shading on ascorbic acid, a large number of fruit of greenhouse raised Marglobe tomatoes were enclosed, when half grown, in perforated manila paper bags with ends left open for additional ventilation. The fruit was analyzed at 4 stages of development (Table 5). It will be observed that in all cases the artifically shaded fruits were comparatively lower in this vitamin than the non-shaded ones.

TABLE 5 -- EFFECTS OF ARTIFICIAL SHADING, FOR 10-12 DAYS, ON ASCORBIC ACID CONTENT OF GREENHOUSE-GROWN TOMATOES, MARGLOBE VARIETY; AFTER A PERIOD OF BRIGHT SUNLIGHT AND RELATIVELY LOW TEMPERATURE; APRIL
(Total light for 10 days preceding harvest: 4376.8 gram-calories/cm^2.)

	Mgs./100 grams			
Stage of fruit development:	Green	Pale green	Pink	Red
Controls, fruit not covered	13.8	18.7	20.4	29.7
Covered with paper bags	11.4	16.5	18.7	25.8

A more detailed study of shading was conducted with a group of greenhouse-grown fruit of the Stokesdale variety. At the time of picking the specimens were marked so that the exposed and shaded (by the fruit itself) sides (halves) could be recognized. Groups of these halves were analyzed separately. The results are presented in Table 6. It will be noted that the shaded half had a lower ascorbic acid concentration than the exposed half, that it did

TABLE 6 -- ASCORBIC ACID IN GREENHOUSE-GROWN TOMATOES, STOKESDALE VARIETY, JUNE AND JULY

	Mgs./100 grams
After a period of cloudy weather (June)	
(Total light for 10 days preceding day of harvest: 3602.1 gram-calories/Cm.^{2})	
"Pink" fruit	18.2
Ripe fruit	22.2
Ripe fruit, exposed side	21.0
Ripe fruit, shaded side	16.2
After a period of bright sunlight (July)	
(Total light for 10 days preceding day of harvest: 6172.3 gram-calories/Cm.^{2})	
Ripe, exposed side	25.1
Ripe, shaded side	21.6
Fruit in direct light	24.4
Fruit shaded by leaves, same plant	19.8
Exposed, stem end half	24.0
Shaded (lower) half	19.0

not make much difference whether shading was lengthwise or across the fruit, and that the reduction was roughly of the same magnitude as when the whole fruit was shaded by leaves.

Effect of Nitrogen Nutrition: Evidence is accumulating that the soil nitrogen supply has a bearing on ascorbic acid content of fruit (18, 25, 12, 49, 34). Results of a preliminary test with a winter crop of Marglobe tomatoes raised in the greenhouse are presented in Table 7. Differences in ascorbic acid content as influenced by nitrogen supply may be slight, for example, when a tomato crop is grown under low light intensity, or they may be considerable in presence of bright sunlight, as will be seen further on.

TABLE 7 -- EFFECTS OF ABOVE AVERAGE NITROGEN SUPPLY ON ASCORBIC ACID CONTENT OF GREENHOUSE-GROWN TOMATOES, MARGLOBE VARIETY, WINTER CROP (FEBRUARY)

	Mgs./100 grams
Average N supply	15.4
Above average N supply	16.1

To test the possible effects of an above average supply of nitrogen, a group of plants were grown in 4-gallon glazed crocks containing fertile greenhouse soil. These plants, of the Break O'Day variety, were raised one per container and trained to a single stem. After four clusters of fruit had set, the stems were cut off below the fifth flower cluster.

Randomized groups of plants were grown under three levels of nitrogen nutrition (Table 8): (a) "No nitrogen fertilizer," excepting what nitrogen was furnished by the soil; (b) "moderate nitrogen fertilization" consisting of weekly application of 5 grams of $NaNO_3$ per plant; (c) "heavy fertilization with nitrogen," 15 grams of $NaNO_3$ per week per plant. In addition, one group of unfertilized plants received heavy fertilization with $NaNO_3$

TABLE 8 -- EFFECTS OF LIGHT AND NITROGEN FERTILIZERS ON ASCORBIC ACID CONTENT OF GREENHOUSE-GROWN TOMATOES, BREAK O' DAY VARIETY

	Mgs./100 Grams
February 14 . After a cloudy period	12.5
March 15. After period of moderate amount of light	
Well exposed fruit	17.9
Partly shaded fruit	16.8
March 26. After period of bright sunlight	
(a) No nitrogen fertilizer	23.7
Same, but maximal exposure to light	
Exposed half of fruit	25.7
Shaded half of fruit	21.1
(b) Moderate nitrogen fertilization	19.6
(c) Heavy fertilization with nitrogen	19.1
Same, but maximal exposure to light	
Exposed half of fruit	23.9
Shaded half of fruit	21.4

TABLE 9 -- EFFECTS OF NITROGEN FERTILIZERS AND LIGHT ON ASCORBIC ACID CONTENT OF GREENHOUSE-GROWN TOMATOES, BREAK O' DAY VARIETY, AFTER A PERIOD OF BRIGHT SUNLIGHT (APRIL)

	Mgs./100 grams
No nitrogen fertilization. All exposures.	
"Green" fruit	27.8
"Pink" fruit	32.8
Ripe fruit	32.5
No N fertilization, then $NaNO_3$ for 3 weeks. All exposures.	
"Green" fruit	21.4
"Pink" fruit	25.0
Ripe fruit	25.4
Heavy N fertilization	
(a) Fruit in shaded positions	
"Green" fruit	20.5
"Pink" fruit	23.5
Ripe fruit	23.8
(b) Fruit in exposed positions	
"Green" fruit	24.8
"Pink" fruit	24.0
Ripe fruit	25.4

for three weeks prior to taking samples of fruit for vitamin analyses (Table 9).

Within a few weeks there were conspicuous and graded differences in color of foliage, depending on the nitrogen supply. Plants grown without special nitrogen fertilization had markedly yellowish leaves and those with the most nitrogen ($NaNO_3$) supply were very dark green in color.

"Exposed" and "shaded" fruit, as given in Tables 8 and 9, refer to fruit that were or were not covered by leaves. In somes cases the leaves were moved and tied to obtain a desired exposure for a suffiient number of fruit of the same size.

The results, presented in Tables 8 and 9, show that a negative correlation existed between nitrogen supply to the plant and ascorbic acid content of the fruit. The difference is overcome to a great extent, and often nullified by two other factors: (a) The increase of this vitamin in the fruit with advance in ripening and (b) the effect of exposure to light. Both of these factors show a strong positive correlation with ascorbic acid concentration.

Relation to Fruit Setting "Hormone" Sprays: A desirable set of fruit is sometimes difficult to obtain when tomatoes are grown as a winter or early spring crop under subnormal conditions of light caused by short days and prolonged periods of cloudy weather (22). Similar difficulties are encountered during cool weather when the night temperature drops below 60° F with tomatoes planted outdoors early in the spring. In both instances the fruit set, and to some extent fruit size, can be increased profitably by a judicious application to the flowers and young fruit or to the whole plant of an appropriate plant hormone (synthetic growth regulating substance) (32, 33, 50, 46). It is of considerable interest to know of the possible bearing of such hormone treatments on the ascorbic acid content of the fruit.

Coincident with experimental studies of hormone applications to various tomato crops, grown both in greenhouses and outdoors, ample fruit material became available for ascorbic acid determination. Results presented in Tables 10 and 11 show that hormone treatments have not caused appreciable

TABLE 10 -- ASCORBIC ACID IN RIPE TOMATO FRUIT FROM "HORMONE" SPRAYED PLANTS, MARGLOBE VARIETY, GROWN IN GREENHOUSE (APRIL 13)

Treatment	Determined immediately	Determined 1 hour after slicing
Controls	24.4	21.0
Naphthalene acetamide, 20 ppm	24.3	22.7
Naphtoxyacetic acid, 20 ppm	24.4	22.2
Indolebutyric acid, 20 ppm	25.5	22.9
P-Chlorophenoxyacetic acid, 20 ppm	24.3	21.3

TABLE 11 -- ASCORBIC ACID IN RIPE FRUIT FROM "HORMONE" SPRAYED PLANTS, MARGLOBE VARIETY, GROWN IN GREENHOUSE, JUNE AND JULY

Treatment*	Milligrams ascorbic acid/100 grams		
	June 6[a]	July 3[b]	
		Green fruit	Ripe fruit
Controls	18.8	22.9	27.5
B-Naphthoxyacetic acid, 50 ppm[c]	19.5	24.2	25.2
P-Chlorophenoxyacetic acid, 5 ppm	16.8	23.1	23.9
P-Chlorophenoxyacetic acid, 10 ppm	18.0	----	----
P-Chlorophenoxyacetic acid, 20 ppm	16.2	27.3	31.5

*All materials applied once a week in water solution to flower clusters.
[a]Shaded by whitewash on greenhouse. High temperature.
[b]After a period of sunny weather and high temperature.
[c]Subscript figures refer to parts per million of chemical used.

differences in ascorbic acid content of tomatoes. Incidentally, however, the data supply other pertinent information. Observe from the records given in Table 10 that a delay of one hour in assay of ascorbic acid after the fruit was sliced, caused appreciable loss, undoubtedly due to rapid oxidation of this vitamin. Data presented in Table 11 show the usual differences in ascorbic acid concentration caused by light (June 6 vs. July 3) and due to ripening of the fruit ("green" vs. "ripe" fruit).

Considerably more detailed assays of ascorbic acid content were made on fruit from hormone treated and nontreated plants of a spring crop of tomatoes grown in the greenhouse and a summer crop raised outdoors. The fruit was harvested at various stages of development and ripened at prevailing room temperatures. The results, presented in Tables 12 and 13, do not indicate consistent or important differences in ascorbic acid in fruits at any stage of ripeness as a result of the hormone application. It will be observed in Table 12, however, that there was a marked increase in the vitamin as either the fruit ripened on the plant (from "green"→"pink"→"red") or was allowed to ripen at relatively low temperature (68-75° F). A similar trend or relationship in ascorbic acid was not exhibited by fruit of the summer crop grown outdoors (Table 13, also Table 2). Differences between green, pink and red fruit, in this respect, were slight and as the green fruit was ripened at comparatively high temperature (78-90° F) the ascorbic acid concentration decreased.

TABLE 12 -- ASCORBIC ACID CONTENT OF GREENHOUSE-GROWN TOMATOES, MARGLOBE VARIETY, SPRING CROP; DATA ON 100 GRAMS OF FRESH WEIGHT BASIS

Date of vitamin assay	Stage of Maturity	Controls	"Hormone" Sprayed
		Mgs./100 grams	
Apr. 8	A. Picked "green"		
	1. Vitamin determined at once.	15.4	14.1
Apr. 13	2. Vit. determ. when "pink"	23.7	24.1
Apr. 19	3. Vit. determ. when "red" (ripe)	24.6	24.4
Apr. 19	B. Picked when "pink"		
	1. Vit. determ. at once	25.0	25.6
Apr. 22	2. Vit. determ. when "red" (ripe)	27.7	28.0
Apr. 23	C. Picked when "red" (ripe)		
	1. Vit. determ. at once	28.6	27.9

Weather only partly cloudy, with many sunny days during period of maturing of sampled fruit. Plants vigorous. "Hormone" spray (B-Naphthoxyacetic acid, 20 ppm) applied once a week to whole plant. Light during 40 days preceding April 8 (date of first sampling): Total 136054 gram-calories/cm^2. Temperature: Mean max. 70.3°F; mean min. 54.0°F. Fruit ripened at room temp., 68-75°F., out of direct sunlight.

TABLE 13 -- ASCORBIC ACID CONTENT OF TOMATOES GROWN OUTDOORS, MARGLOBE VARIETY, SUMMER CROP, SAMPLED ON JULY 25, AFTER A PERIOD OF RELATIVELY HOT AND DRY WEATHER; DATA ON 100 GRAMS OF FRESH WEIGHT BASIS

Date of vitamin assay	Stage of maturity	Controls	"Hormone" Sprayed
		Mgs./100 grams	
July 25	A. Picked "green"		
	1. Vitamin determined at once	24.8	25.9
July 29	2. Vit. determ. when "pink"	24.5	24.7
Aug. 2	3. Vit. determ. when "red" (ripe)	19.8	21.4
July 25	B. Picked when "pink"		
	1. Vit. determ. at once	24.9	25.6
July 29	2. Vit. determ. when "red" (ripe)	27.0	29.7
July 25	C. Picked when "red" (ripe)		
	1. Vit. determ. at once	25.3	25.6

Growth of plants inhibited by drought in June. Irrigated on June 23 and 30, July 7 and 14. Plants moderately vigorous. Trained to a single stem. "Hormone" spray (B-Naphthoxyacetic acid, 20 ppm) applied once a week to whole plant. Light during 40 days preceding July 25 (date of sampling): Total 291236 gram-calories/cm^2. Temperature: Mean max. 91.5°F; mean min. 68.2°F. Fruit allowed to ripen at room temperature, 78-90°F., out of sunlight.

APPLES

Analytical records on ascorbic acid content of apples show wide variations not only between varieties (39, 43) but also within the variety (43), similar to those of tomatoes. Quite clearly, this points to other factors than the genetic constitution of the plant as having an effect on the production and concentration of this vitamin in the apple. Some of these factors seem to be operative in the orchard while the fruit is developing, still others have a bearing during the post-harvest and storage periods. The current investigation was undertaken with the object of obtaining more information on the subject.

Materials and Methods

Apples used for this study came from standard trees growing in experimental orchards of the Missouri Agricultural Experiment Station. The fruit was harvested with care in the forenoon, taken to the laboratory at once and the vitamin assays were made on the same day, except in the case of storage tests. For a study of changes due to maturity and ripening, the harvesting was done at weekly intervals extending over a considerable period. By securing more fruit than was necessary, it was possible to make a careful selection of specimens of various groups for size, amount of color development and freedom from blemishes.

Eight well matched apples of average size, constituted a sample. They were quartered and a thin slice was cut from each segment, making a total of 32 sections per sample. Sections included the skin, cortical tissue, some of the pith, but no core. The total amount of material in each determination was 200 grams. All analytical work was done with dispatch to minimize loss of ascorbic acid as a result of oxidation. The chemical procedure was as described under "Tomatoes."

Varietal Differences and Seasonal Trends: Changes in ascorbic acid content of 2 summer and 5 fall varieties of apples were determined, beginning from what is known as the "hard ripe" stage of development to full maturity and some ripening.[4] The results are presented in Tables 14 and 15.

TABLE 14 -- ASCORBIC ACID CONTENT OF APPLES (FALL VARIETIES) WHILE MATURING ON TREES (MILLIGRAMS PER 100 GRAMS OF CORED BUT NOT PARED FRUIT)

Variety	Jonathan	Delicious	Golden Delicious	Rome	Winesap
Date of picking:					
Aug. 26	7.50	----	----	----	-----
Sept. 2	7.00	8.00	----	----	-----
Sept. 9	7.00	8.00	7.75	7.00	-----
Sept. 16	8.16	9.60	7.68	7.20	-----
Sept. 23	8.16	9.60	8.64	7.20	13.90
Sept. 30	7.69	8.64	8.50	7.69	12.62
Oct. 7	----	8.00	8.50	8.00	11.00
Oct. 14	----	----	8.50	7.20	11.50
Oct. 21	----	----	----	6.72	11.28
Oct. 28	----	----	----	----	9.60

TABLE 15 -- ASCORBIC ACID CONTENT OF APPLES (SUMMER VARIETIES) WHILE MATURING ON TREES AND AFTER A BRIEF PERIOD IN COMMON STORAGE, 70 TO 80 DEGREES F; (MILLIGRAMS PER 100 GRAMS OF CORED BUT NOT PARED FRUIT)

Variety	Yellow Transparent		Duchess	
	a*	b#	a	b
Date of picking:				
July 1	11.16	7.08	----	----
July 8	8.13	6.97	13.02	8.24
July 15	8.85	2.36	8.85	5.31
July 22	6.49	----	8.85	4.72
July 29	----	----	5.90	4.13

*Immediately.
#After 6 days in common storage.

It will be observed that in the fall varieties tested, excepting the Winesap, there was a slight but fairly consistent increase in the vitamin followed by a decrease as the fruit began to ripen. In some varieties, specifically Delicious and Rome, this decrease was more marked than in others.

Of considerable interest is the fact that the Winesap variety is considerably higher in ascorbic acid and shows a seasonal trend similar to that of

[4]An apple is *mature* when it is in a desirable condition for harvesting and *ripe* when in the best state for eating.

summer apples. When "green" it is relatively high in this vitamin, which, however, decreases with advance in maturity and ripening.

Effects of Storage: In harvesting, distributing and marketing apples, like most other fresh produce, the fruit is subjected to various periods of storage at ordinary room temperature. Most of the tests that have been reported deal with the effects of a prolonged storage (cold storage) on ascorbic acid content of apples (3, 13). The grower, distributor and the housewife usually expose the fruit from a few to several days to ordinary room temperature. It is worthwhile to know to what extent this might affect the ascorbic acid content of apples.

The records presented in Table 15 show that when summer varieties of apples, such as Yellow Transparent and Duchess, were kept for six days at a temperature of 70 to 80° F. there was a rapid reduction in the ascorbic acid content. The loss of this vitamin in fall apples stored at 70 to 75° F. for periods of four and eight days was not nearly so striking but still appreciable (Table 16).

TABLE 16 -- ASCORBIC ACID CONTENT OF ALL APPLES AFTER A BRIEF PERIOD IN COMMON STORAGE 70 TO 75 DEGREES F. (MILLIGRAMS PER 100 GRAMS OF CORED BUT NOT PARED FRUIT)

Variety	Harvest Date: Oct 7	After Storage: Oct 15
Golden Delicious	8.50	5.76
Delicious	8.00	5.28
Rome	8.00	4.80
Winesap	11.00	10.05
	Harvest Date: Oct 14	After Storage: Oct 18
Golden Delicious	8.70	8.16
Rome	7.20	5.32
Winesap	11.50	11.05

To test the effects of a prolonged storage (both common and cold) on ascorbic acid retention, carefully graded fruit, 2¼ to 2¾ inches in diameter, of several varieties of apples were stored for various periods up to the time they were considered overripe. The vitamin content was assayed on nonpeeled and peeled fruit. In both cases the apples were cored first. The common storage temperature was from 50 to 60°F. and the available cold storage temperature from 35 to 45°F. Softness of the flesh (maturity) was determined on eight apples, in three positions each, by means of a standard pressure tester with a plunger 7/16 inches in diameter.

The results are given in Tables 21, 22 and 23 for three varieties, Jonathan, Golden Delicious and Winesap.

The records show, in general, that there was an initial rapid decrease of this vitamin during the first month in cold storage (35-45° F). In common storage (50-60° F.), a similar decrease occurred during the first two weeks.

In both cases this was followed by a further relatively slow decrease to approximately 1.5 to 1.0 mg./100 grams.

Effects of Vigor of Trees and Nitrogen Supply: Evidence is accumulating that there is frequently a negative correlation between the soil nitrogen supply and ascorbic acid content of fruits (27, 49, 25, 47). In view of the fact that nitrogenous fertilizers are used generally in the production of apples, it seems to be desirable to ascertain whether and to what extent this relationship exists. The problem is also connected more or less directly with vigor of the tree.

Fruit samples of equal size and exposure to light were obtained from Rome trees, some of which had received the usual amounts of commercial nitrogen fertilizers for several years while others had been given three times the usual quantities. The results of ascorbic acid assays of the two groups of apples are given in Table 17, attention being paid to the relative exposure of the fruit to light.

TABLE 17 -- EFFECT OF HEAVY NITROGEN FERTILIZATION ON ASCORBIC ACID CONTENT OF APPLES (MILLIGRAMS PER 100 GRAMS)

	Average N Fertilization	Very Heavy N Fertilization
Rome, highly colored fruit	6.87	4.68
Rome, fruit of average color	5.63	4.56

It will be noted that the reduction in ascorbic acid due to a heavy supply of nitrogen to the trees was considerable, especially in the well exposed fruit. In agreement with this evidence, weak trees, as judged by the amount of shoot growth and condition of foliage, seemed to produce apples of a higher ascorbic acid value than vigorous trees (Table 18). Such trees, of course, are usually lower in their nitrogen status.

TABLE 18 -- ASCORBIC ACID CONTENT OF FRUIT FROM WEAK AND VIGOROUS TREES OF COMPARABLE AGE (MILLIGRAMS PER 100 GRAMS)

Variety and Condition of Tree	Weak Tree	Vigorous Tree
Golden Delicious, light crops	7.50	6.25
Jonathan, young trees	6.31	4.13

The Direct Effects of Light: It has been emphasized previously that light has a direct and strong effect on ascorbic acid concentration in plants. Moreover, literature is replete with additional references on the influence of light on the production of this vitamin, though investigations dealing with the apple are still limited. Far more ascorbic acid seems to be concentrated in and near the skin than in the pulp of the fruit (10, 4, 44, 14) and more in the flesh near the epidermis than in the area closer to the core (pith)

(10, 6). Because of a larger skin-to-pulp ratio, small fruit may be expected to contain relatively more of this vitamin per weight than larger specimens (4).

A detailed survey was made on groups of apples harvested at desirable stages of maturity from various typical trees, in regard to ascorbic acid content of fruit that was well exposed to light and fruit that was shaded. The results presented in Table 19, show that though the concentration of the

TABLE 19 -- ASCORBIC ACID CONTENT OF APPLES GROWN ON OUTSIDE AND INSIDE BRANCHES OF THE SAME TREES (MILLIGRAMS PER 100 GRAMS)

Variety and Condition of Tree	On Outside Branches	On Inside Branches
Jonathan, old tree, moderate crop	6.25	4.75
Golden Delicious, old tree, light crop	6.37	5.94
Golden Delicious, heavy crop	7.20	6.25
Golden Delicious, light crop	8.40	5.76
York, heavy crop	7.63	5.25
Stayman, heavy crop	7.25	5.88
Winesap, old tree	10.63	8.25
Winesap, moderate crop	11.52	10.05
Rome, light crop	6.72	5.28
Rome, light crop, large fruit	4.50	4.25
Rome, light crop, small fruit	5.56	4.90

vitamin is apt to be higher when the crop is relatively light, direct exposure to light has by far the greatest effect. In all cases, fruit borne on outside branches, where it received more sunlight, had considerably higher concentration of the vitamin than those on inside shaded branches.

Further evidence of this direct effect of light is presented in Table 20. It shows that the half of the apple that is exposed directly to sunlight is markedly higher in ascorbic acid content than the shaded half, very much like in the tomato. An appreciable quantity of the ascorbic acid is removed when apples are peeled.

TABLE 20 -- ASCORBIC ACID CONTENT OF EXPOSED (TO DIRECT LIGHT) AND SHADED HALVES OF THE SAME APPLES (MILLIGRAMS PER 100 GRAMS)

Variety and Condition of Tree and Fruit	Exposed Half	Shaded Half
Stayman, old tree, outside fruit	9.13	7.00
Stayman, old tree, outside fruit-peeled	6.38	5.19
York, old tree, outside fruit	8.50	5.75
York, old tree, outside fruit-peeled	6.13	5.25
Winesap, old tree, outside fruit	11.15	9.50
Winesap, old tree, inside fruit	8.88	8.38
Golden Delicious, young tree	3.75	3.13

Effects of Cooking on Ascorbic Acid Retention: It is a well known fact that in cooking fruits and other products a large proportion of the ascorbic acid is destroyed (10, 42, 23, 11, 37, 2). Since apples are frequently prepared or preserved by cooking (apple sauce) an extensive study was un-

TABLE 21 -- EFFECTS OF STORAGE ON ASCORBIC ACID CONTENT (MILLIGRAMS PER 100 GRAMS OF FRUIT) OF APPLES, JONATHAN VARIETY, SOFTNESS OF FRUIT EXPRESSED IN POUNDS RESISTANCE TO PRESSURE

No. of days in storage	Pressure, Lbs.	Common Storage, 50-60°F. Not Peeled	Common Storage, 50-60°F. Peeled	Cold Storage, 35-45°F. Not Peeled	Cold Storage, 35-45°F. Peeled
7	16.5	3.62	2.92		
21	11.5	1.40	1.04		
31	12.0			1.94	1.82
35	8.5	1.37	.74		
50	7.5	1.32	.88		
64	10.5	1.20	.80		
90	10.2			1.76	1.32
148	8.3			1.50	1.14

TABLE 22 -- EFFECTS OF STORAGE ON ASCORBIC ACID CONTENT (MILLIGRAMS PER 100 GRAMS OF FRUIT) OF APPLES, GOLDEN DELICIOUS VARIETY, SOFTNESS OF FRUIT EXPRESSED IN POUNDS RESISTANCE TO PRESSURE

No. of days in storage	Pressure, Lbs.	Common Storage, 50-60°F. Not Peeled	Common Storage, 50-60°F. Peeled	Cold Storage 35-45°F. Not Peeled	Cold Storage 35-45°F. Peeled
6	13.5	4.14	2.2		
15	10.0	2.59	1.5		
31	7.8	2.15	1.40		
40	9.2			2.46	1.18
46	7.0	1.90	1.16		
68	8.8			2.26	1.13
95	8.4			2.05	1.45
130	8.0			1.90	1.10
158	7.1			1.26	1.08

TABLE 23 -- EFFECTS OF STORAGE ON ASCORBIC ACID CONTENT (MILLIGRAMS PER 100 GRAMS OF FRUIT) OF APPLES, WINESAP VARIETY, SOFTNESS OF FRUIT EXPRESSED IN POUNDS RESISTANCE TO PRESSURE

No. of days in storage	Pressure, Lbs.	Common Storage, 50-60°F. Not Peeled	Common Storage, 50-60°F. Peeled	Cold Storage, 35-45°F. Not Peeled	Cold Storage, 35-45°F. Peeled
2	19.3	7.56	5.58		
16	12.3	6.78	3.58		
29	11.5	2.97	2.12		
34	14.8			2.90	2.11
43	11.0	2.83	.99		
56	10.1	2.44	.94		
64	14.3			2.41	.90
73	9.5	1.95	1.00		
85	8.5	1.80	.90		
92	11.5			1.81	.91
125	10.5			1.18	.75
153	9.6			1.16	.71

TABLE 24 -- ASCORBIC ACID CONTENT OF APPLES WHILE MATURING ON THE TREE, (IN MILLIGRAMS PER 100 GRAMS OF CORED BUT NOT PARED FRUIT), SUMMER VARIETIES, SOFTNESS OF FRUIT EXPRESSED IN POUNDS RESISTANCE TO PRESSURE.

Variety	Yellow Transparent					Duchess					Wealthy				
Date of	Pressure,	Raw		Cooked		Pressure,	Raw		Cooked		Pressure,	Raw		Cooked	
picking:	Lbs.	a*)	b*)	a	b	Lbs.	a	b	a	b	Lbs.	a	b	a	b
July 1	21.0	11.16	7.08	7.10	3.58										
July 8	19.2	8.13	6.97	5.00	3.80	23.8	13.02	8.24	3.65	2.56					
July 15	16.1	8.85	2.36	5.10	2.24	19.3	8.85	5.31	3.94	2.10					
July 22	7.2	6.49		4.15		15.8	8.85	4.72	4.05	1.22					
July 29						12.5	5.90	4.13	2.80	1.28	15.1	4.13	3.54	1.55	.64
Aug. 5											14.5	2.95	2.24	1.45	1.28
Aug. 12											14.0	2.54	2.34	1.38	1.29
Aug. 19											13.9	3.50	2.50	1.38	1.25

a*) - Immediately
b*) - After 6 days in common storage

TABLE 25 -- ASCORBIC ACID CONTENT OF APPLES WHILE MATURING ON THE TREE (IN MILLIGRAMS PER 100 GRAMS OF CORED BUT NOT PARED FRUIT), FALL VARIETIES, SOFTNESS OF FRUIT EXPRESSED IN POUNDS RESISTANCE TO PRESSURE

Variety	Jonathan			Delicious			Golden Delicious			Rome			Winesap		
Date of	Pressure			Pressure			Pressure			Pressure			Pressure		
picking:	Lbs.	Raw	Cooked	Lbs.	Raw	Cooked	Lbs.	Raw	Cooked	Lbs.	Raw	Cooked	Lbs.	Raw	Cooked
Aug. 26	18.9	7.50	3.00												
Sept. 2	17.2	7.00	2.25	19.5	8.00	2.25									
Sept. 9	15.8	7.00	2.25	19.0	8.00	2.00	16.6	7.75	2.00	23.0	7.00	1.25			
Sept. 16	14.7	8.16	1.92	17.8	9.60	1.68	15.0	7.68	1.92	22.0	7.20	1.92			
Sept. 23	14.0	8.16	2.40	17.2	9.60	1.92	14.7	8.64	1.92	20.2	7.20	1.44	26.1	13.90	4.80
Sept. 30	13.5	7.69	1.92	16.3	8.64	1.82	13.2	8.50	1.94	21.0	7.69	1.50	24.5	12.62	3.95
Oct. 7				13.3	8.00	1.75	12.5	8.50	1.75	17.8	8.00	1.50	22.5	11.00	4.50
Oct. 14							11.3	8.50	1.65	17.0	7.20	1.20	21.0	11.50	2.10
Oct. 21										17.2	6.72	1.44	20.2	11.28	2.44
Oct. 28													19.9	9.60	2.40

dertaken on the effects of careful cooking on this vitamin. Both summer and fall apples were used for this purpose.

The fruit was harvested at weekly intervals beginning with the "hard green" stage, as indicated by pressure tests, and extending to maturity for cooking purposes. Ascorbic acid was assayed immediately on the raw apples and after six days in common storage (summer varieties only) and on both groups after cooking. The fruit was cored but not pared before cooking.

The detailed procedure was as follows: The apples were quartered, cored and cooked immediately in aluminum pans at 100° C. Definite quantities of distilled water and sugar were added in each case. The cooking time varied from a low of 5 minutes in case of some summer apples to as high as 45 minutes for some fall varieties. Testing for ascorbic acid was made as soon as the product was cooled. In some cases the cooked apples were kept in covered glass jars for further assay of the vitamin after intervals of 24 and 48 hours. The data appear in Tables 24 and 25.

It was apparent that cooking, even when done with care, destroyed an appreciable proportion of the ascorbic acid in apples. By and large, this destruction was greater in the fall than in summer apples, possibly because of the more prolonged cooking required to make a product of desirable consistency.

Attention is called to the fact that the summer apples, Yellow Transparent in particular and Duchess to some extent, were relatively high in ascorbic acid, even when kept six days in storage and cooked. The Wealthy apples were rather low in this vitamin (Table 24).

An unusually large amount of ascorbic acid was present in the five varieties of fall apples throughout the season of maturity when the cooking tests were conducted (Table 25). Moreover, there was little or no seasonal decrease during the period of picking with the exception of the Winesap variety. These strikingly high values in ascorbic acid content most likely were due to ample sunlight and relatively low temperature. During the period of maturing of the fruit, clear days and cool nights were a characteristic feature. Hence an excellent color and quality was attained by all varieties of apples.

When the cooked product was tested after storage in a household refrigerator for 24 and 48 hours, in most cases there were no differences in ascorbic acid values between the non-stored and stored samples. Where reduction occurred as a result of storage, this likely was due to the procedure or speed of handling of the product.

SUMMARY

This investigation deals with the effects of major environmental factors that influence the ascorbic acid content of fresh tomato and apple fruits

and of cooked apples. Several varieties were taken into consideration over a prolonged period.

Tomatoes

1. Greenhouse-grown tomatoes, of the same variety and size were usually lower in ascorbic acid than those grown outdoors. This was due chiefly to lower light intensity and shorter days during late fall, winter and early spring.

2. There seems to be a seasonal increase in concentration of this vitamin in field-grown fruit from early summer to late summer. This, however, is modified greatly by the prevailing amount of sunlight and shading by the leaves.

3. "Mature" (green) greenhouse tomatoes are lower in ascorbic acid content than "ripe" (red) fruit. But field-grown tomatoes that are comparatively high in ascorbic acid at maturity may be lower in this vitamin upon ripening on the plant, especially when the temperture is high during this period.

4. The larger the fruit the lower the vitamin content.

5. When picked "green," hothouse tomatoes increase in ascorbic acid concentration while ripening at relatively low room temperature. Field tomatoes of initially high vitamin content will lose much of it when ripened at comparatively high temperature (80-90°F).

6. There is a strong positive correlation between ascorbic acid concentration and light intensity. Hence the vitamin content, of greenhouse-grown tomatoes, in particular, may vary greatly depending on the weather, specifically the amount of sunlight.

7. Both direct exposure of the developing fruit to light and shading by the foliage have a considerable bearing on ascorbic acid concentration. The side of a tomato that is directly exposed to light is invariably higher in this vitamin than the shaded side.

8. With increasing soil nitrogen supply there is usually a *decrease* in ascorbic acid concentration in the fruit. Differences due to nitrogen supply may be slight when the tomato crop is grown under a prevailing low light intensity but considerable in the presence of bright sunlight.

9. Growth regulating substances ("hormone" sprays), used to improve fruit set and size of tomatoes under subnormal conditions of light and temperature, do not seem to have an appreciable direct effect on ascorbic acid concentration.

Apples

1. Considerable differences in ascorbic acid concentration are shown by various varieties of Missouri grown apples. In general, summer apples

have a higher concentration than fall and winter varieties, but they lose this vitamin faster upon ripening in common storage (70-80° F). Of winter apples, the Winesap was found unusually high in ascorbic acid. Moreover, it seemed to retain it well.

2. As apples mature and then ripen on trees, the ascorbic acid content first increases and then diminishes. In some varieties this trend is more rapid and intense than in others.

3. All varieties of apples investigated lost this vitamin rapidly when kept for relatively brief periods in common storage, the only exception being the Winesap. Even when stored at low temperatures (50-60° and 35-45° F., respectively), there was a rapid decrease of ascorbic acid during the first two weeks which was followed by a comparatively slower decrease thereafter to a low of 1.5 to 1.0 milligrams per 100 grams of fresh tissue.

4. A negative correlation seems to exist between soil nitrogen supply, or vigor of the tree and ascorbic acid in apples. Comparatively weak trees, therefore, produce fruit of higher vitamin content than vigorous trees.

5. Light has a marked direct positive effect on ascorbic acid formation of apples, quite similar to that of tomatoes. Fruit grown on well exposed outside branches was found conspicuously higher in this vitamin in comparison to fruit of the same size developing on inside shaded branches. The usually better colored, exposed half of an apple is relatively richer in the vitamin than the shaded half.

6. When apples are cooked, even with great care and rapidity, most of the ascorbic acid is destroyed. This loss was greater with the fall than with the summer apples, possibly because of the longer cooking time required to attain a uniform product. In paring the fruit, up to 50 percent or more of the vitamin may be removed with the peelings. Pared and cooked apples may have only 20 percent of the vitamin content of the original fresh fruit.

Ascorbic acid is rapidly destroyed in both tomatoes and apples when the cut and/or the ground tissue is exposed to air. A delay of one hour may easily result in a loss of 10 percent or more. Of even greater importance in assay of this vitamin is the selection of specimens from plants of similar vigor and use of fruit of the same size, stage of maturity, exposure to light and, when necessary, storage at a uniform temperature. Undoubtedly, much of the reported variability in ascorbic acid content of fruits and other products is due to the unforseen or unappreciated effects of various environmental factors on its concentration and loss.

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