Tomizawa, C., Endo, T., Naka, H., *IAEA, Proc. Rep. Res. Coord. Meet.*, 59 (1974).
Verloop, A., Ferrell, C. D., in "Pesticide Chemistry in the 20th Century", Plimmer, J. R., Kearney, P. C., Kohn, G. K., Menn, J. J., Ries, S. K., Eds., American Chemical Society, Washington, DC, 1977, pp 237–270.
Walter, W., Voss, J., in "The Chemistry of Amides", Zabicky, J. Z., Ed., Interscience, London, 1970, pp 385–475.
Warthen, J. D., Jr., "Azadirachta Indica: A Source of Insect Feeding Inhibitors and Growth Regulators", ARM-NE-4, U.S. Department of Agriculture, 1979.
Watkins, T. I., Weighton, D. M., *Rep. Prog. Appl. Chem.* **60**, 404 (1975).
Wright, J. E., Harris, R. L., *J. Econ. Entomol.* **69**, 728 (1976).
Yamamoto, I., Kamimura, H., Yamamoto, R., Sakai, S., Goda, M., *Agric. Biol. Chem.* **26**, 709 (1962).
Zanno, P. R., Miura, I., Nakanishi, K., Elder, D. L., *J. Am. Chem. Soc.* **97**, 1975 (1975).

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REVIEW

Vitamin C Contents of Citrus Fruit and Their Products: A Review

Steven Nagy

Variability in the vitamin C (ascorbic acid) contents of citrus fruit and their products is influenced by variety, cultural practice, maturity, climate, fresh fruit handling, processing factors, packaging, and storage conditions. Aerobic and anaerobic mechanisms are mainly responsible for the destruction of vitamin C in processed products. The mode of breakdown of vitamin C can best be explained by a first-order reaction but a significant quadratic time effect has been determined by polynominal regression calculations. Plots of log rate (loss of vitamin C) vs. $1/T$ for canned orange juice showed two distinct Arrhenius profiles, whereas canned grapefruit juice showed only one. Retention of vitamin C is greater in canned than bottled juices because of the reducing activity of the tinplate.

It has been known for many centuries that certain fruits and vegetables possess the ability to prevent and cure scurvy. As early as 1564 (Beattie, 1970), citrus fruit were used empirically for the prevention and treatment of this disease. However, it was not until the middle of the 18th century that the role of citrus fruit in fighting scurvy was scientifically demonstrated. In 1752 James Lind, a British Naval physician, published his "Treatise of the Scurvy" with the clinical data to prove that scurvy was due to the lack of an essential food element, now recognized as vitamin C. In a controlled experiment James Lind supplied two oranges and a lemon to seamen with scurvy and found that they were ready for duty in only 6 days. The world voyage of Captain Cook, from 1772 to 1775, also demonstrated that scurvy did not occur if vegetables and fruits (especially oranges and lemons) were included in the seaman's ration (Araujo, 1977). Therefore, from this evidence and as a precaution against this dreaded disease, the British Admiralty in 1795 ordered that every member of the crew be given a ration of lime (or lemon) juice. British sailors, to this day, are often called limeys because of this early association.

A century and more was to pass before definitive efforts were made to isolate and characterize this antiscorbutic factor. Zilva (1927) concentrated an antiscorbutic factor from lemons whereas Szent-Gyorgyi (1928) isolated the same factor (he called it "hexuronic acid") from cow adrenal glands, oranges, and cabbage. Waugh and King (1932) isolated a crystalline antiscorbutic substance from lemon juice and identified it as the same "hexuronic acid" isolated by Szent-Gyorgyi. The earliest official name given to this antiscorbutic factor was cevitamic acid but this name was later dropped in favor of the more common name, ascorbic acid (vitamin C). Haworth and Hirst (1933) and Reichstein et al. (1933) were the first to chemically synthesize vitamin C.

Since citrus fruit and their products are one of the largest suppliers of dietary vitamin C, it is important to know what factors affect vitamin C levels in this important consumer food. Vitamin C levels are influenced by (1) production factors and climate conditions, (2) maturity state and position of fruit on the tree, (3) type of citrus fruit (species and variety), (4) parameters used for processing fruit into different products, (5) type of container for holding the processed product, and (6) handling and storage.

PRODUCTION FACTORS

Citrus trees grow on clay to very sandy soils with properties ranging from fertile to infertile, acid to alkaline pH (5.0–8.5), and good to poor water drainage. The native conditions of the soil are not important to the composition of the fruit, in particular vitamin C, as long as essential nutrients are supplied in adequate amounts, soil pH is maintained between about 5.0 and 7.5, effective control of water supply and drainage is observed, and proper tillage of the soil is practiced (Reuther, 1973).

The supply of essential nutrients to a growing plant is enhanced through fertilization (soil and/or foliar application). Of the 15 elements recognized as essential for citrus growth, namely, carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, zinc, manganese, copper, and molybdenum, only a few have a direct effect on the vitamin C contents of citrus fruit.

Several workers (Hilgeman and Van Horn, 1955; Smith and Rasmussen, 1961; Smith, 1969) have reported an inverse relationship between the quantity of nitrogen applied to grapefruit trees and the amount of vitamin C found in juices of those grapefruit. Reduced levels of vitamin C in

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juices of oranges (Jones and Parker, 1947; Jones et al., 1957), lemons (Jones et al., 1970; Marsanija, 1970), and mandarins (Marsanija, 1970) have also resulted from the application of elevated levels of nitrogen fertilizer to those crops.

Citrus fruit show variable responses to increasing phosphorus fertilization. Increasing the phosphorus contents of fertilizers from deficient to adequate levels markedly affects fruit quality, but increasing the phosphorus contents above these adequate levels results in debatable benefits (Embleton et al., 1973). The most consistent effect of phosphorus when applied in amounts beyond those necessary for normal crop yield is to cause the reduction of the juice's citric acid and vitamin C contents (Sinclair, 1961).

Potassium fertilization influences citrus fruit quality more so than crop yield. Increased concentrations of vitamin C in juices of oranges (Jones and Parker, 1949; Deszyck et al., 1958; Reitz and Koo, 1960), grapefruit (Sites 1947; Smith and Rasmussen, 1960) and lemons (Embleton and Jones, 1966) have resulted from the application of increased amounts of potassium to trees. In Florida, most citrus trees are grown on sandy soils which are naturally deficient in zinc, magnesium, manganese, and copper. Correction of these mineral deficiencies with proper fertilization results in improved fruit quality and enhanced vitamin C levels in the juice (Sites, 1944). However, according to Sites (1947), no improvement in fruit quality or vitamin C levels would result from the addition of these minerals in amounts exceeding those needed for normal maintenance.

CLIMATE

Climatic factors, principally temperature, have a strong influence on the quality and composition of citrus fruit. Three temperature parameters which strongly influence the fruit's composition are the total available heat and the extent of low and high temperatures during the growth and maturation periods of the fruit. Total available heat is probably the single most important factor in determining the growth rate and time of ripening of citrus fruit (Jones, 1961). Comparison of grapefruit grown in desert areas of Arizona (summer conditions of hot days and warm nights) to fruit of coastal areas of California (cooler climate) show that coastal fruit generally contain more vitamin C than desert fruit when harvested on the same date (Rygg and Getty, 1955). In a controlled study, Reuther and Nauer (1972) showed that Frost Satsuma fruit contained more vitamin C when grown under cool temperatures (20–22 °C day, 11–13 °C night) than hot temperatures (30–35 °C day, 20–25 °C night).

Tropical temperatures might have been responsible for the low vitamin C values reported for Nigerian sweet oranges (Mudambi and Rajagopal, 1977). In Central America, Munsell et al. (1950a,b) reported average vitamin C values for oranges of 47 mg/100 mL of juice (El Salvador) and 56 mg/100 mL (Nicaragua). These Central American values, however, agree with values obtained from fruit growing in subtropical climates. It appears that more studies are required before any conclusion can be reached regarding the effects of growing temperatures on the vitamin C contents of tropical and subtropical grown oranges. As a general rule, those environmental conditions which increase the acidity of the fruit will also increase the vitamin C contents.

POSITION OF FRUIT ON THE TREE

The concentration of vitamin C in a citrus fruit can be correlated with the position of that fruit on the tree. Although light is not essential for the synthesis of vitamin C in plants, exposure of citrus fruit to the sun's rays during the growing process has a definite influence on the amount of vitamin C formed. Isherwood and Mapson (1962) have stressed the fact that photosynthesis must be in progress in order to supply hexoses from which vitamin C is synthesized.

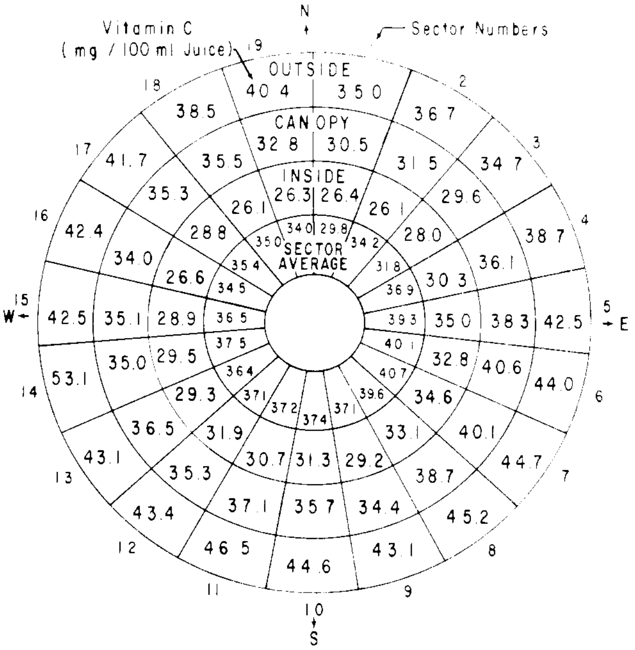

Figure 1. Effect of direction of exposure and amount of shading on mg of vitamin C/100 mL of juice of Valencia oranges. Reprinted with permission from Sites and Reitz (1951). Copyright 1951 American Society for Horticultural Science.

In an elegant experiment, Sites and Reitz (1951) determined the vitamin C contents of each orange from a single Valencia tree. Each fruit was removed from the tree and classified as to the direction of exposure to light and the amount of light or shade (outside, canopy, inside) which it received. Figure 1 shows that outside fruit grown on the north and northeast side contained lower amounts of vitamin C than outside fruit from the south side. Canopy fruit, that is fruit that are partially shaded at all times, were lower in vitamin C than outside fruit from their respective sector. Canopy fruit from the north side were generally lower than canopy fruit from the other sides. Inside fruit, that is the fruit which hung inside the main body of the leaf canopy, contained the lowest amounts of vitamin C for their respective sectors. The extensive data of Sites and Reitz (1951) confirmed preliminary results of other workers (Harding and Thomas, 1942; Winston and Miller, 1948) who reported that unshaded fruit had higher vitamin C content than shaded fruit, and that fruit exposed to maximum sunlight contained the largest amounts of vitamin C.

MATURATION

From fruit-set to maturity, citrus fruit pass through three well-defined stages (Bain, 1958): (1) rapid cell division, (2) cell enlargement, and (3) maturation. Biochemical changes occur throughout the fruit's growth and maturation periods with the result that its composition varies considerably depending upon its degree of ripeness. Harding and co-workers (Harding et al., 1940; Harding and Fisher, 1945; Harding and Sunday, 1949) have conducted extensive experiments on the relation of stage of maturity to the chemical composition of the fruit. As noted in Figure 2 of their work, vitamin C contents of oranges, grapefruit, and tangerines decreased during ripening.

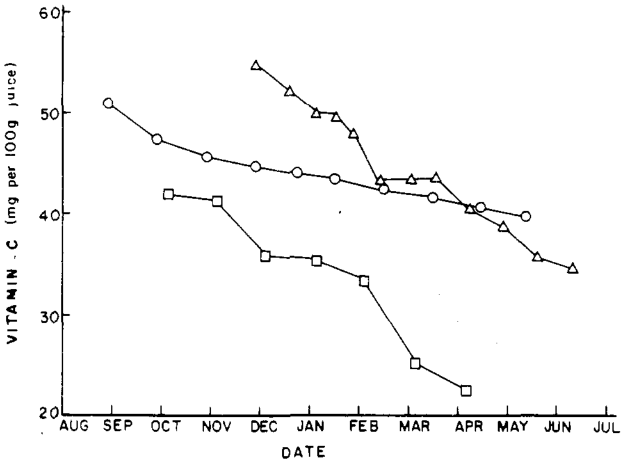

Figure 2. The effect of maturation on the vitamin C contents of Valencia orange (△), Duncan grapefruit (○), and Dancy tangerine (□).

Immature fruit contained the highest concentration of vitamin C (milligrams/milliliter of juice), whereas ripe fruit contained the least. Although there was a lowering of vitamin C concentration during ripening, the total vitamin C contents per fruit tended to increase because the volume of juice and size of fruit also increased with advancing maturity. Fruit harvested late in the season showed a reduction in water content (drying out) and the least amount of vitamin C (Harding et al., 1940).

Eaks (1964) analyzed lemon fruit and found that the vitamin C content per whole fruit increased up to a weight of about 20 g and then increased at a slower rate as the fruit weight increased. As noted previously with other citrus juices, the concentration of vitamin C in lemon juice decreased slightly as fruit weight increased. The highest concentration of vitamin C was found in the peel, followed by lower amounts in the pulp and juice. As noted previously by Rygg and Getty (1955) for grapefruit, climatic conditions also have an important influence on the lemon's vitamin C level. Eaks (1964) showed that coastal lemons contained more vitamin C than lemons grown inland.

ROOTSTOCK EFFECTS

The majority of citrus grown today are scions budded on rootstocks. The chemical composition of citrus fruit is often strongly influenced by the type of rootstock to which the scion is attached. There are numerous examples which show the effects of the rootstock on the scion fruit's juice volume (Harding et al., 1940), soluble solids (Sinclair, 1961), acids (Hutchison and Hearn, 1977), bitter components (Kefford and Chandler, 1961), lipids (Nordby et al., 1979), and carotenoids (Bowden, 1968).

Table I shows a select list of rootstocks and their effects on the vitamin C contents of different citrus fruit. In Valencia oranges, Bitters (1961) found the highest concentration of vitamin C when this scion was budded to Duncan grapefruit or Sampson tangelo (a hybrid formed by crossing a grapefruit with a tangerine is called a tangelo). Orange fruit from trees on rough lemon consistently showed lower amounts of vitamin C than on sour orange; this observation was previously noted by Harding et al. (1940) and by Cohen (1956). The Temple orange is believed to be a natural hybrid of mandarin and sweet orange parentage (Webber, 1943; Barrett and Rhodes, 1976). It is probably the most commercially important tangor (term used to designate a mandarin–sweet orange hybrid) grown in Florida. Table I shows that Temple fruit grown on sweet orange rootstock contained the least amount of vitamin C.

Table I. Effects of Rootstocks on the Vitamin C Contents of Fruit of Different Scion Varieties

	mg of vitamin C/100 mL of juice				
rootstock	Valencia[a] orange	Temple[b] orange	Marsh[c] grapefruit	Tahiti[d] lime	Orlando[e] tangelo
rough lemon	52.9	55.0	36.0	33.8	27.0
sour orange	55.4	54.0	42.0		30.0
Cleopatra mandarin	54.4	52.0		31.5	30.0
sweet orange		49.0			
Duncan grapefruit	59.9				
Leonardy grapefruit				31.3	
Troyer citrange				35.8	
Savage citrange	55.1				
Rusk citrange					25.0
Seminole tangelo				29.0	
Sampson tangelo	59.1				

[a] Bitters (1961). [b] Harding and Sunday (1953); Temple orange is a hybrid of orange and mandarin parentage. [c] Harding and Fisher (1945); average of samples collected between January 15 and March 16. [d] Colburn et al. (1963). [e] Harding and Sunday (1959); average of samples collected between December 1 and January 5.

According to Harding and Fisher (1945), the vitamin C content of Marsh grapefruit is lowest when grown on rough lemon rootstock. Tahiti lime showed the highest content of vitamin C when grown on Troyer citrange, whereas it contained the least when grown on Seminole tangelo. In contrast to Tahiti lime, the Orlando tangelo contained the least amount of vitamin C when grown on a citrange rootstock.

CITRUS VARIETIES

Due to the many horticultural and climatic variables involved in citrus growing, it is no wonder that most investigators report wide ranges in the vitamin C levels of different citrus fruit. A survey of vitamin C ranges for five principal citrus fruit, namely, sweet oranges, grapefruit, mandarins, lemons, and limes, from several countries is shown in Table II.

One of the first comprehensive studies on sweet oranges was conducted in Florida by Beacham and Bonney (1937). These workers reported a range of about 35 to 70 mg of vitamin C/100 mL of juice for all orange varieties and found no varietal differences in vitamin C levels. However, subsequent studies conducted on Florida orange juices by Fellers and Barron (1975), Ting (1977), and Nagy and Smoot (1977) showed that juices from early season (November to January, mostly Hamlin) and midseason (January to March, mostly Pineapple) contained more vitamin C than late season juices (April to July, mostly Valencia). Cruse and Lime (1977a) reported that Texas Hamlin and Marrs oranges contained more ascorbic acid than Valencia oranges, whereas Birdsall et al. (1961) reported that juice from California naval oranges contained about 15 mg/100 g more total vitamin C than the juice from Valencia oranges. Cohen (1956) studied 29 orange varieties growing in Israel and reported that the Pineapple orange contained the highest content of vitamin C (78 mg/100 mL of juice) and the Shamouti contained the least (51 mg/100 mL of juice).

The United States produces about 77% of the world's grapefruit crop (Florida Citrus Mutual, 1977). Except for Redblush and Star Ruby, all white, pink, and red mutant grapefruit of world importance originated in Florida and trace back to an original seedling planted in 1823 at Safety Harbor, FL (Cooper and Chapot, 1977). Table II shows

Table II. Vitamin C Contents of Juice from Principal Citrus Fruit

fruit and variety	origin	concn, mg of vitamin C/100 mL of juice	source
sweet orange			
seedling	United States (FL)	36-66	Beacham and Bonney (1937)
pineapple	United States (FL)	40-70	Beacham and Bonney (1937)
Parson Brown	United States (FL)	40-59	Beacham and Bonney (1937)
Conner's seedless	United States (FL)	48-61	Beacham and Bonney (1937)
Valencia	United States (FL)	34-63	Beacham and Bonney (1937)
Hamlin	United States (TX)	47-57	Cruse and Lime (1977a)
Marrs	United States (TX)	34-47	Cruse and Lime (1977a)
Valencia	United States (TX)	29-39	Cruse and Lime (1977a)
navel	South Africa	52-65	Hamersma (1938)
seedling	South Africa	69-79	Hamersma (1938)
Valencia	South Africa	41-68	Hamersma (1938)
navel	Australia	67-74	Council for Scientific and Industrial Research (1947)
Valencia	Australia	48-70	Council for Scientific and Industrial Research (1947)
early varieties	Israel	58-68[a]	Cohen (1956)
midseason varieties	Israel	51-78[a]	Cohen (1956)
late varieties	Israel	58-65[a]	Cohen (1956)
navel varieties	Israel	61-68[a]	Cohen (1956)
not specified	Lebanon	43-59	Maleki and Sarkissian (1967)
not specified	Egypt	40-69	El-Zorkani (1968)
not specified	Iran	30-64	Edrissi and Kooshkabadi (1975)
not specified	Italy	50-88	Pennisi (1977)
not specified	Spain	39-79	Royo Iranzo and Peris Toran (1977)
not specified	Nigeria	28-35	Mudambi and Rajagopal (1977)
grapefruit			
Marsh	United States (FL)	33-42	Beacham and Bonney (1937)
Duncan	United States (FL)	31-46	Beacham and Bonney (1937)
Duncan	United States (FL)	30-61	Harding and Fisher (1945)
Thompson	United States (TX)	35-47	Krezdorn and Cain (1952)
Marsh	United States (AZ)	26-60	Rygg and Getty (1955)
Ruby Red	United States (TX)	28-44	Cruse and Lime (1977b)
several varieties	Israel	47-56[a]	Cohen (1956)
not specified	Iran	33-43	Edrissi and Kooshkabadi (1975)
not specified	Nigeria	50-61	Mudambi and Rajagopal (1977)
mandarin tangerine			
Dancy	United States (FL)	19-30	Beacham and Bonney (1937)
Dancy	United States (FL)	21-48	Harding and Sunday (1949)
several varieties	Israel	37-54[a]	Cohen (1956)
not specified	India	14-33	Anand and Leisram (1963)
not specified	Iran	34-49	Edrissi and Kooshkabadi (1975)
Mediterranean			
Avana	Italy	29-60	Schachter (1977)
Tardivo de Ciaculli	Italy	25-48	Schachter (1977)
Comune	Italy	35-55	Schachter (1977)
not specified	Greece	22-42	Melas-Joannides (1939)
Satsuma			
not specified	United States (FL)	22-36	Beacham and Bonney (1937)
not specified	Japan	22-42	Inagaki (1953)
not specified	Israel	33-36	Cohen (1956)
not specified	Italy	33-47	Schachter (1977)
lemon			
Perrine	United States (FL)	22-35	Beacham and Bonney (1937)
not specified	United States (CA)	31-61	Swisher and Swisher (1977)
Lisbon	New Zealand	30-40	Dawes (1969)
Genoa	New Zealand	36-40	Dawes (1969)
Villa Franca	New Zealand	46-52	Dawes (1969)
not specified	Iran	28-45	Cohen (1956)
several varieties	Israel	32-51[a]	Cohen (1956)
lime			
Persian	United States (FL)	18-42	Hatton and Reeder (1971)
not specified	United States	23-33	Swisher and Swisher (1977)
not specified	Iran	20-23	Edrissi and Kooshkabadi (1975)
not specified	Nigeria	28-35	Mudambi and Rajagopal (1977)

[a] Range of averages for all varieties.

a range of about 25 to 60 mg of vitamin C/100 mL of grapefruit juice. This range agrees with the extensive list compiled by Sinclair (1972) for grapefruit juice. Varietal differences in the vitamin C contents of grapefruit are not as prevalent as with oranges, but Cohen (1956) has remarked that the Duncan grapefruit contained the highest and the Marsh Seedless the lowest contents of vitamin C in grapefruit grown in Israel. Metcalfe et al. (1940) examined the Marsh, Marsh Pink, Redblush, Foster Pink, and Duncan grapefruit in Texas and concluded that there were only small differences in the vitamin C contents among these varieties.

Table III. Vitamin C Contents of Component Parts of Citrus Fruit

	mg of vitamin C/100 g fresh weight					
	peel					
fruit, variety	flavedo	albedo	pulp	rag	seed[a]	juice
orange, pineapple[b]	377	208		68		68
orange, navel[c]	222		57			59
grapefruit, Duncan[b]	237	140		44		40
grapefruit, Marsh[b]	240	155		50		32
grapefruit, Duncan[d]					1.7	
lemon, Eureka[b]	129		53			44
lemon, Eureka[e]	158		44			34

[a] Nongerminated seed. [b] Atkins et al. (1945). [c] Birdsall et al. (1961). [d] Miller and Jablonski (1949). [e] Eaks (1964).

Mandarins are perhaps the most heterogeneous group of fruit of the genus *Citrus*. Although mandarin and tangerine (the name tangerine first came into common usage in the United States) are names used interchangeably to designate the various groups of "loose-skinned oranges", the name tangerine is now applied to those mandarin varieties producing deep orange or scarlet fruits. The Mediterranean (Willowleaf) mandarin originated under cultivation in Europe (Hodgson, 1967) and is the principal mandarin of the Mediterranean basin. The Satsuma mandarin or *Citrus unshiu* Marc. is the principal citrus fruit of Japan. It is an unstable mandarin taxon as over 100 bud variations have developed since first planted in Japan (Cooper and Chapot, 1977). As shown in Table II, pronounced fluctuations are noted in the vitamin C contents of these three mandarin groups. The approximate ranges for vitamin C of mandarin (as mg/100 mL of juice; Table II) are 15–55 (tangerine), 20–60 (Mediterranean), and 20–50 (Satsuma). The vitamin C contents of most mandarin hybrids fall within the above ranges (Cohen, 1956) but some, for example, Temple (42–72 mg/100 mL; Beacham and Bonney, 1937), exceed these limits. Apparently the introduction of orange parentage enhanced the vitamin C level in this hybrid. The ascorbic acid contents of mandarins are generally lower than for oranges and grapefruit.

In lemons and limes, vitamin C values show ranges of about 20–60 mg/100 mL of juice and about 15–45 mg/100 mL of juice, respectively. These ranges agree with those reported by Kefford (1973) for lemons (30–60 mg/100 mL) and limes (20–40 mg/100 mL). The wide vitamin C ranges might be due to the fact that lemons and limes are genetically complex biotypes and are regarded as introgressed trihybrids (Malik et al., 1974; Barrett and Rhodes, 1976). On the basis of overall averages, oranges are richest in vitamin C, followed by grapefruit, lemons, tangerines, and limes.

Fruit Parts. Although the juices of citrus fruit are recognized as providing an important source of vitamin C for human nutrition, there are other parts of the fruit which also contain this vitamin. These other parts are not recognized in nutrition because they are generally the nonedible components, viz., peel (flavedo and albedo), rag (core, carpellary membranes), pulp (vesicular membranes), and seeds. In fact, only about one-fourth of the vitamin C content of citrus fruit is found in the juice (Table III). Atkins et al. (1945) analyzed four orange varieties and found the following average percentages for vitamin C in the component parts: flavedo (34%), albedo (19%), pulp and rag (21%), and juice (26%). Examination of two grapefruit varieties by these same workers showed: flavedo (31%), albedo (33%), rag and pulp (19%), and juice (17%). In contrast to orange albedo, the albedo of grapefruit, which represents a larger portion of the fruit, contained about twice as much vitamin C.

STABILITY OF VITAMIN C IN FRESH FRUIT

The pioneering investigations of James Lind during the 18th century showed that the antiscorbutic factor in whole citrus fruit was well retained during extended sea voyages. It was not until the 20th century before definitive studies could be conducted to assess the retention of ascorbic acid in citrus fruit during transport, storage, and distribution. In South Africa, Hamersma (1938) showed that when Valencia and navel oranges were stored at 3.3 °C (38 °F) for 12 weeks, no loss in vitamin C (mg/100 mL of juice) occurred. French and Abbott (1940), however, reported a slight loss of vitamin C when oranges and grapefruit were stored for 5 months at 5.6 °C. Slight losses in vitamin C contents were also observed by Harding (1954) during transit and marketing of Florida oranges to the northeastern states. Pritchett (1962) stored California Valencia oranges under various conditions simulating commercial distribution. His analysis of representative samples showed decreases in vitamin C of 0–7% during storage for 4–8 weeks under different combinations of refrigeration and room temperatures. Under his most severe conditions, involving 4 weeks at 3 °C, 2 weeks in an iced rail car, and 2 weeks at room temperature, ascorbic acid retention in the juice was 93%. Losses in vitamin C were noted by El-Zorkani (1968) during storage of Egyptian oranges at 5 °C and room temperature for 50 or 60 days. In Nigeria, Mudambi (1977) showed that peeled orange (a commercial practice for selling oranges) exposed to the sun for 9 h lost about 40% of their vitamin C contents, whereas those stored in the shade lost about 21%.

Bratley (1940) studied the effects of temperatures (0.5, 3, 8, 12 °C) on the retention of vitamin C in tangerines stored for 8 weeks. He noted that the greatest and most rapid loss (about 30–40% of original vitamin C) occurred in fruit held at 8 and 12 °C. Total acids in the juice also decreased at these temperatures and were closely correlated with the loss of vitamin C.

Lemon fruit are normally harvested by size rather than by color or ripeness and then stored for various periods, depending upon their condition and market demands. Harvesting lemons in the immature stage is advantageous because the fruit require storage conditioning to produce the maximum amount of juice and develop good color and flavor. Eaks (1961) showed that lemons held for 12 weeks at 24 °C lost considerable amounts of vitamin C whereas fruit held at 13 °C maintained about the same concentration of vitamin C in the juice. Storage of lemons at 4 °C also caused a loss in the vitamin C content of the juice but the loss was not as great at 24 °C. Storage of limes at 20 °C caused a decrease in the vitamin C concentration of the juice (Eaks and Masias, 1965). Apparently, all citrus fruit lose vitamin C (mg/100 mL of juice) if stored at high temperatures. The range of temperatures and the extent of vitamin C loss will depend, however, on the type of citrus fruit.

PROCESSED PRODUCTS

While citrus fruit were originally grown in the United States for the fresh-fruit market, fruit production had increased at such a rapid pace that by the 1930s surpluses over fresh-fruit consumption had become a serious problem. This fruit oversupply was the major stimulus for the development of a multitude of citrus products which the American consumer enjoys today. During the 1976–77 processing season, Florida utilized 93% of its entire orange crop to produce eight different products (Florida Canners Association, 1977). Of the oranges utilized, 81% were processed into frozen concentrate, 15% into chilled juice, 4% into single-strength juice, and the remaining 1% into blends, sections, and salads. Since consumers derive major nutritional benefits from processed citrus products, factors that affect vitamin C potency in these products are of considerable importance.

Effects of Seasonal Variability. The variability in vitamin C levels caused by different varieties (Table II) and by different maturity periods (Figure 2) is often reflected in the vitamin C contents of commercially processed juices. Extensive research on the vitamin C contents of chilled orange juice was conducted over five processing seasons by the Florida Department of Citrus (Fellers and Barron, 1975) (Table IV). Samples were taken directly from the processing lines of five plants and immediately analyzed. Any detrimental effects due to temperature and time of storage were negligible. Table IV shows uniform patterns in the vitamin C contents of juices over the five processing seasons. Early and mid-season fruit (primarily Hamlin and Pineapple oranges) processed into chilled juices between January 1 and April 1 consistently showed higher levels of vitamin C than fruit (primarily Valencia oranges) processed during the late season, April 1 to July 1. Of significance was that fruit processed into juice during June and July barely contained the 100% of the U.S. Recommended Daily Allowance (RDA) for vitamin C (60 mg) in a 6 fl oz. or 177 mL serving. Nagy and Smoot (1977) also showed that oranges processed into canned single-strength juice during June and July contained lower levels of vitamin C than oranges processed between November and March (early and mid-season fruit).

Frozen concentrated orange juice (FCOJ) was the first citrus product of its type to be produced in large commercial quantities. Since first marketed in 1945–46, it has grown rapidly in volume until today it far exceeds all other citrus products combined. Fellers and Barron (1975) showed that the vitamin C contents of FCOJ generally decrease during the latter part (April to August) of the processing season (Table V). Although vitamin C decreases were evident, only one FCOJ product out of the 114 samples fell below the 100% U.S. RDA value. The average vitamin C content of all samples was 89.6 mg/177 mL of reconstituted FCOJ or 149% of the U.S. RDA. The possibility that concentrates prepared from early season fruit were blended with concentrates from late season fruit was suggested by Fellers and Barron (1975). Blending has become common practice in the citrus industry and is undoubtedly the reason why lower vitamin C values were not found during that survey. Previous surveys conducted between 1953 and 1959 (Huggart et al., 1960) also showed that the vitamin C contents of FCOJ prepared from late season fruit were less than that from early and mid-season fruit. Apparently, blending was not as prevalent during the 1950s as the vitamin C contents of late season FCOJ were generally lower than observed for similar late season products during the recent survey by Fellers and Barron (1975).

Processing Effects. Extensive studies were conducted in the 1940s to determine the retention of vitamin C during manufacture of single strength and frozen concentrated citrus juices. The main features in processing single-strength juices are (1) extracting, (2) finishing, (3) blending, (4) pasteurizing, and (5) filling juice into cans and closing (Nagy et al., 1977). Moore et al. (1944a) in Florida and Wagner et al. (1945) in Texas studied the effects of com-

Table IV. Five Year Summary of Ascorbic Acid (AA) Content in Commercial Florida Chilled Orange Juice[a,b]

	1970–71			1971–72			1972–73			1973–74			1974–75		
		av AA content			av AA content			av AA content			av AA content			av AA content	
approx. sampling date	no. of samples	mg/100 mL	mg/6 fl oz	no. of samples	mg/100 mL	mg/6 fl oz	no. of samples	mg/100 mL	mg/6 fl oz	no. of samples	mg/100 mL	mg/6 fl oz	no. of samples	mg/100 mL	mg/6 fl oz
Jan 1[c]	7	52.8	93.7				3	45.1	80.1	5	48.9	86.8	2	45.2	80.2
Feb 1	5	47.6	84.5	5	48.6	86.3	5	53.6	95.1	6	45.4	80.6	3	50.5	89.6
Mar 1	5	50.3	89.3	5	48.7	86.4	6	51.3	91.1	4	42.4	75.3	4	49.9	88.6
Apr 1	4	42.3	75.1	3	39.7	70.5	5	47.7	84.7	4	37.7	66.9	1	32.0	56.8
May 1	4	43.2	76.7	4	38.4	68.2	4	38.7	68.7	4	35.9	63.7	2	38.5	68.3
June 1	6	33.7	59.8	3	35.5	63.0	3	38.5	68.3	5	31.2	55.4	2	36.0	63.9
July 1[d]							4	32.4	57.5	2	30.7	54.5			

[a] Fellers and Barron (1975). [b] The grand overall averages and percent U.S. RDA for all 125 samples collected over 5 years are as follows: mg of AA/100 mL of orange juice, 43.5; mg of AA/6 fl oz of orange juice, 77.2; percent U.S. RDA, 129. [c] For 4 years only. [d] For 2 years only.

Table V. Five Year Summary of Ascorbic Acid (AA) Content in Commercial Florida Frozen Concentrated Orange Juice[a],[b]

approx sampling date	1970-71			1971-72			1972-73			1973-74			1974-75		
		av AA content			av AA content			av AA content			av AA content			av AA content	
	no. of samples	mg/100 mL	mg/6 fl oz[c]	no. of samples	mg/100 mL	mg/6 fl oz[c]	no. of samples	mg/100 mL	mg/6 fl oz[c]	no. of samples	mg/100 mL	mg/6 fl oz[c]	no of samples	mg/100 mL	mg/6 fl oz[c]
Jan 1	12	196.3	104.8	10	195.9	104.6	4	187.7	100.2	17	184.0	98.3	18	184.1	98.3
Feb 1	17	181.0	96.7	19	192.2	102.6	18	194.1	103.6	20	187.8	100.3	19	188.1	100.4
Mar1	16	175.2	93.6	18	188.6	100.7	20	195.5	104.4	20	178.0	95.1	15	179.6	95.9
Apr 1	16	175.6	93.8	20	172.2	92.0	18	175.9	93.9	15	165.6	88.4	12	177.3	94.7
May 1	22	160.6	85.8	20	154.2	82.3	19	159.0	84.9	15	140.7	75.1	16	155.5	83.0
June 1	16	147.2	78.6	16	143.3	76.5	19	153.8	82.1	18	137.7	73.5	11	147.6	78.8
July 1[d]							5	156.8	83.7	13	145.2	77.5	9	137.4	73.4
Aug 1[e]							14	148.1	79.1				9	149.8	0.0

[a] Fellers and Barron (1975). [b] The grand overall averages and percent U.S. RDA for all 546 samples collected over 5 years are as follows: mg of AA/100 g of FCOJ, 169.8; mg of AA/6 fl oz of 12.8° Brix equivalent juice, 90.7; percent U.S. RDA, 151. [c] All values are computed on a 12.8° Brix equivalent basis. [d] For 3 years only. [e] For 2 years only.

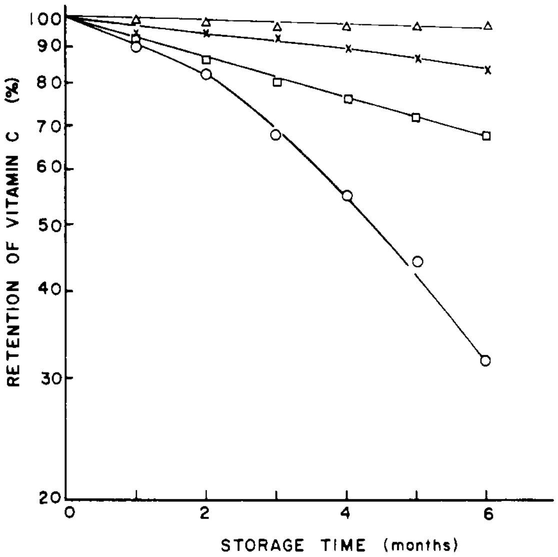

Figure 3. Percent vitamin C retention (logarithmic scale) vs. months of storage at 4 °C (△), 24 °C (x), 32 °C (□), and 37 °C (○) for canned single-strength orange juice.

mercial canning on the vitamin C contents of single-strength grapefruit juice. Moore and co-workers reported that retention of vitamin C during canning ranged from 89 to 100% with an average retention of 97% (12 plants surveyed), whereas Wagner and colleagues reported a range of 92 to 100% with a similar average retention of 97%.

Vitamin C is also well retained during the commercial manufacture of canned single-strength orange juice. Ranges of 92 to 95% (Ross, 1944), 94 to 98% (Lamb, 1946), and 92 to 100% (Sale, 1947) were reported for juices canned in Florida, California, and Texas. Limited information is available on vitamin C retention during manufacture of frozen concentrated juices but in one study Roy and Russell (1948) determined that less than 4% of the total vitamin C content of orange juice is lost during concentration into FCOJ. Their concentration procedure was conducted under high vacuum (10–15 mmHg) and at 10–16 °C.

Storage Time and Temperature. Citrus products lose vitamin C potency because of two major factors, namely, temperature and storage time. After processing, products are subjected to varying temperatures and storage periods during warehousing and during transit to retail markets. Once purchased, the product may again be subject to different storage conditions. Because of the nutritional importance of citrus juice, many studies have been conducted during the past four decades to quantitate the loss of vitamin C during storage. Results of representative studies on orange, grapefruit, and tangerine juices are presented in Table VI. As evident from these studies, low temperatures are imperative if adequate amounts of vitamin C are to be retained during storage. For canned and bottled single-strength juices, storage at 21 °C (this temperature may be near the average of year-round nonrefrigerated commercial storage conditions) for upwards of a year results in vitamin C retentions of greater than 75% (Guerrant et al., 1945; Feaster et al., 1949; Freed et al., 1949). Studies by Ross (1944) and by Nagy and Smoot (1977) have shown that storage temperatures in excess of about 28 °C caused vitamin C destruction at markedly accelerated rates in canned products. Prolonged storage at temperatures in excess of 38 °C (100 °F) caused the destruction of considerable amounts of vitamin C.

Typical time–temperature profiles for vitamin C retention in canned single-strength orange juice are shown in

Table VI. Studies on Vitamin C Retention in Processed Orange, Tangerine, and Grapefruit Juices

	storage			
product[a]	temp, °C	months	% retention of vitamin C	source
SSOJ (canned)	9, 24, 37	12	94, 75, 17	Ross (1944)
SSOJ (canned)	10 to 26.5	24	95 to 50	Sheft et al. (1949)
SSOJ (canned)	4.5, 24.5	18	93, 60	Moore (1949)
SSOJ (canned)	1.7, 22.2, 37.8	12	100, 80, 5	Freed et al. (1949)
SSOJ (bottled)	4.5, 24.5	18	89, 51	Moore (1949)
SSGJ (canned)	21	11	89	Lamb (1946)
SSGJ (canned)	10, 20, 30, 40, 50	3	99, 97, 90, 70, 29	Smoot and Nagy (1979)
SSGJ (canned)	10, 18, 27	18	93, 84, 62	Sheft et al. (1949)
SSGJ (canned)	23.9	12	83	Jones and Blanchard (1956)
FCOJ	−20, −15, −12.2	60	100, 100, 100	Kew (1957)
FCOJ	−22, −12, −7, 0, 4	12	99, 98, 98, 97, 96	Huggart et al. (1954)
FCGJ	−22, −12, −7, 0, 4	12	98, 98, 98, 98, 97	Huggart et al. (1954)
FCTJ	−22, −12, −7, 0, 4	12	94, 94, 91, 91, 90	Huggart et al. (1954)
FCTJ	−29, −18, −12, −4	3	100, 98, 95, 98	Marshall et al. (1955)

[a] SSOJ = single-strength orange juice; SSGJ = single-strength grapefruit juice; SSTJ = single-strength tangerine juice; FCOJ = frozen concentrated orange juice; FCGJ = frozen concentrated grapefruit juice; FCTJ = frozen concentrated tangerine juice.

Figure 3. As expected, the retention of vitamin C decreases as temperature and time of storage increase. Brenner et al. (1948) and Freed et al. (1949) studied vitamin C retention in canned, single-strength orange juice at 21, 32, and 38 °C and concluded that the logarithm of vitamin C retention was linearly related to storage time. Kefford et al. (1959) constructed data nomographs (log vitamin C retention vs. storage time) for different temperatures to predict ascorbic acid loss in orange juice and concluded that the linear relation premise of Brenner et al. (1948) and Freed et al. (1949) was inaccurate. The study of Nagy and Smoot (1977) agreed with Kefford and co-workers and concluded that plots between log (vitamin C retention) and storage time were linear for storage temperatures up to 30 °C but that departures from this linear relationship were evident at temperatures above 30 °C.

VITAMIN C DESTRUCTION

Enzymic. Enzymes found in citrus fruit that oxidize vitamin C are cytochrome oxidase, ascorbic acid oxidase, and peroxidase. During juice processing, loss of vitamin C potency due to these enzymes is minimal because (1) they are found at low concentrations in the endocarp, (2) a deaeration step during processing minimizes the amount of oxygen in the juice, and (3) high pasteurization temperatures readily destroy their oxidative activities.

Ascorbic acid oxidase and peroxidase are found at the highest concentration in the flavedo of the peel, and can cause a reduction in the vitamin C contents of peel products if not deactivated. Huelin and Stephens (1944) reported rapid losses in vitamin C in orange peels during marmalade preparation. These workers found that boiling the peel in water prior to marmalade preparation substantially reduced the loss of vitamin C.

Nonenzymic. The main loss of vitamin C potency in processed products is due to aerobic and anaerobic reactions of nonenzymic nature. The incorporation of air into the juice during extraction, finishing, blending, and container filling have long been recognized by investigators (Eddy, 1936; Pulley and von Loesecke, 1939; Henry and Clifcorn, 1948) as causing vitamin C loss. Current industrial practice has been to keep air in juice as low as possible, and this has been accomplished by use of deoiling–deaeration equipment and by the injection of live steam into the headspace of the can during closure (steam displaces the air and creates a vacuum) (Peterson, 1949). Although vacuum deaeration and live steam injection substantially reduce the oxygen content of the product, there is still some oxygen dissolved in the juice (about 0.05%) and entrapped within the headspace atmosphere of the can. Kefford and co-workers (1959) described canned citrus juice as one in which there is competition for oxygen among a number of reactions, including corrosion reactions, ascorbic acid oxidation, and oxidations contributing to off-flavor and color change. After free oxygen has disappeared, anaerobic reactions predominate and influence these same factors; in particular, vitamin C destruction but at a much slower rate under the same conditions.

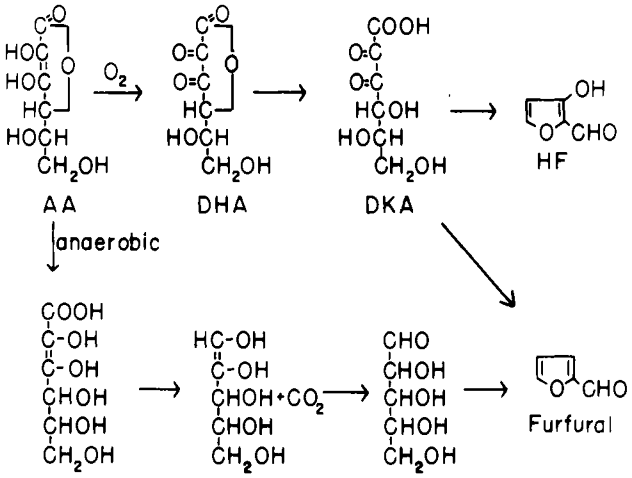

Figure 4. Possible vitamin C (ascorbic acid) degradation pathways: AA, ascorbic acid; DHA, dehydroascorbic acid; DKA, diketogulonic acid; HF, hydroxyfurfural.

Aerobic and anaerobic pathways (Figure 4) for the degradation of vitamin C in an aqueous medium have been proposed by Bauernfeind and Pinkert (1970). Although pathways for vitamin C breakdown in citrus juices have not been studied, it is reasonable to assume that the pathways shown in Figure 4 also occur in citrus juice. A number of intermediates and end products shown in Figure 4, namely, furfural, hydroxyfurfural (HF), dehydroascorbic acid (DHA), and diketogulonic acid (DKA), have been identified in citrus products during storage.

Storage studies (Kefford et al., 1959; Nagy and Smoot, 1977) on the loss of vitamin C potency in canned, single-strength orange juice have shown an initial period (about 1–2 weeks) of rapid loss of vitamin C that was caused by the presence of free oxygen. After oxygen was consumed, vitamin C degraded anaerobically at rates lower than by

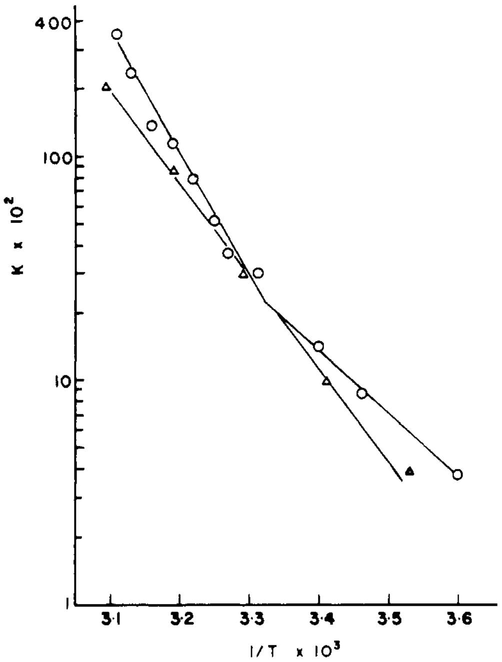

Figure 5. Arrhenius plots of log K (mg of vitaimin C loss/100 mL of juice per week) vs. reciprocal of absolute storage temperature. The grapefruit (△) plot shows one linear profile, whereas the orange (○) plot shows two distince profiles. The Arrhenius plots for orange indicate a change in kinetics around 28 °C.

the aerobic process. Moore and co-workers (1944b) have shown during initial stages of storage that juice packed in cans retained vitamin C better than when packed in glass because the tinplate of the can competed with vitamin C for headspace oxygen. After this aerobic stage, the rates of breakdown were similar for both canned and bottled juices.

Reaction Order. Many workers (Joslyn and Miller, 1949; Freed et al., 1949; Huelin 1953; Waletzko and Labuza, 1976) have assumed that loss of vitamin C in citrus juice and intermediate aqueous systems is a first-order reaction in which log (vitamin C content) is linearly related to storage time. Kefford et al. (1959), however, showed that the relation between log (vitamin C content) and time was not linear, and when polynominal regression equations were fitted to their data, significant linear and quadratic functions of time were required to explain the degradation mode. Studies on canned, single-strength grapefruit juice by Smoot and Nagy (1979) showed that correlation coefficients for plots of log vitamin C vs. time at different storage temperatures were 10 (0.78), 20 (0.83), 30 (0.72), 40 (0.77), and 50 (0.84). Although a first-order reaction could not be excluded based on correlation coefficients, polynomial regression equations contained a significant quadratic time function for the 20, 30, 40, and 50 °C stored juices. Departures from a pure first-order reaction plot were also noted for canned, single-strength orange juice stored at high temperatures (Nagy and Smoot, 1977).

Reaction Rates. Evenden and Marsh (1948) and Freed et al. (1949) suggested that the rate of vitamin C loss in single-strength orange juice obeyed the Arrhenius equation:

$$K = A \exp(-E_a/RT)$$

Thus, if log (reaction rate) were plotted vs. the reciprocal of absolute temperature, a straight line would result. Figure 5 shows plots of rate constants vs. the reciprocal of absolute temperatures for canned single-strength grapefruit and orange juices (Nagy and Smoot, 1977; Smoot and Nagy, 1979). The plot of K vs. $1/T$ for grapefruit juice shows a linear profile for the temperature region 10–50 °C. Regression analysis of the slope, $-Ea/4.58$, yielded an energy of activation (E_a) equal to 18.2 kcal and also showed that a temperature rise of 10 °C (Q_{10}) caused an increase in the reaction rate of about 2.7.

The K vs. $1/T$ plot for single-strength orange juice presents a strikingly different picture to grapefruit juice. Within the temperature region, 4–50 °C, two distinct Arrhenius profiles are evident. One profile covers the region of 4–~28 °C and the other the higher temperature region of ca. 28–50 °C. The Arrhenius equation was obeyed within each of the two temperature regions but two different E_a's and Q_{10}'s were evident. It is apparent that a change in reaction kinetics occurred around 28 °C, and the data suggest two different reaction mechanisms. For the region, 4–28 °C, regression analysis of the slope yielded an E_a value of 12.8 kcal and a Q_{10} value of 2.2, whereas the region 28–50 °C showed an E_a value of 24.5 kcal and a Q_{10} value of 3.7. These Q_{10} values agree with values reported by Ross (1944) for canned orange juice. Ross showed that between 10 and 27 °C the rate of loss of vitamin C doubled for each 10 °C rise, whereas from 27 to 37 °C the rate quadrupled. Figure 5 confirms early speculations by Ross (1944) and Lamb (1946) that vitamin C loss is greater in orange juice than in grapefruit juice at similar storage temperatures.

Dehydroascorbic Acid (DHA) and Diketogulonic Acid (DKA). DHA and DKA are formed as breakdown products of vitamin C under aerobic conditions. DHA possesses antiscorbutic activity whereas no activity is shown by DKA; thus, total active vitamin C (TAVC) of citrus products is based on the combined levels of vitamin C and DHA. Moore et al. (1944b) showed that the levels of DHA in canned and bottled orange and grapefruit juices stored for 6 months at 4 and 27 °C remained constant at about 1–2% of TAVC. Neither container type nor storage temperature appeared to influence the DHA level. Single-strength grapefruit juice stored at 10, 20, 30, 40, and 50 °C showed that the DHA (0.6–1.2 mg %) and DKA (0.3–0.7 mg %) contents remained virtually unchanged during a 12-week period (Smoot and Nagy, 1979). In the 10, 20, 30, and 40 °C juices, DHA was about 1–3% of TAVC, whereas it was about 3–9% in the 50 °C juice.

Lopez et al. (1967) showed that freshly squeezed orange juice kept at a refrigerated temperature for 1 week contained DHA at 5.2% of TAVC; however, when stored at room temperature for 1 week, DHA increased to 9.5%. DKA accumulates in orange juice at low storage temperatures (ca. 4 °C) (Lamden et al., 1960) but degrades rapidly at high temperatures (>22 °C) (Lopez et al. 1967; Horton and Dickman, 1977). Citrus juices in unopened bottles and cans contain low, uniform levels of DHA and DKA, whereas those juices exposed to air (open containers, reconstitution of concentrate by blending) and stored at warm temperatures contain higher levels of DHA and DKA.

EFFECTS OF CONTAINER

The type of container in which citrus juice is packed has an important influence on the retention of vitamin C. Several investigators (Riester et al., 1945; Curl, 1949; Moore et al., 1951) have shown that the loss of vitamin C in enamel-lined cans is greater than in plain tin cans. The difference is due to residual oxygen reacting with the tin in one case and with vitamin C in the other. Higher tin contents are found in plain cans than in enamel-lined cans shortly after processing (Riester et al., 1945), thus indicating preferential and rapid oxidation of tin. Glass-packed citrus products are, in turn, inferior to canned products for vitamin C retention (Moore et al., 1944b; Bissett and Berry, 1975; Edrissi and Kooshkabadi, 1975).

Bissett and Berry (1975) studied single-strength orange juice packed in glass, polyethylene and polystyrene bottles, and wax-coated cardboard cartons. Glass-packed juice lost about 10% of its initial vitamin C content after 4 months of storage at refrigerated temperatures, whereas the plastic and cardboard-packed products lost about 20% in only 3–4 weeks. Of the four types of containers, glass bottles resulted in the best vitamin C protection, hermetically sealed polyethylene containers were next, whereas losses were greatest in polystyrene bottles and waxed cartons. In contrast to glass containers, plastic bottles and cardboard cartons are permeable to oxygen; thus, lowered vitamin retentions are expected. Frozen concentrated orange juice packed in foil-lined cardboard cartons and polyethylene-lined fiber cans retained greater than 90% of their vitamin C after 12 months at −20 °C (Berry et al., 1971). These authors concluded that the commercial containers used for frozen orange concentrates are entirely satisfactory so long as the concentrate remains frozen.

INFLUENCE OF JUICE CONSTITUENTS

While it is recognized that oxygen is the most destructive ingredient in juice, there are also other components which influence vitamin C stability. Of the three major sugars (fructose, glucose, sucrose) found in citrus juice, fructose has been implicated in the enhancement of vitamin C breakdown. Curl (1947) showed that the higher level of fructose in a concentrated orange juice product, the greater the loss of vitamin C. Curl (1949) suggested that a reaction between the carbonyl groups of fructose (or a conversion product) and vitamin C was responsible for the reduction in vitamin C potency in orange juice products. Other investigators (Issac, 1944; Huelin, 1953) also confirmed the degradative effects of fructose. The hydroxy acids, citric and malic, stabilize vitamin C by chelating prooxidant metals and increasing juice acidity (Richardson and Mayfield, 1944; Joslyn and Miller, 1949). The rate of vitamin C breakdown is inversely proportional to the square root of the hydrogen ion concentration in acid solutions.

CONCLUSION

Citrus fruit and their products are significant sources of dietary vitamin C. The variability of vitamin C in fresh fruit is due to variety, climate, horticultural practice, maturity stage, and storage conditions. Processing fruit into juice products results in minimal loss of vitamin C potency but subsequent storage of the finished product at high temperatures results in considerable loss. The differences in the rates of vitamin C breakdown (Figure 5) for canned orange juice indicates that care must be exercised in the selection of a storage temperature. On the basis of Figure 5, it is incorrect to assume that a mean storage temperature determined by averaging could be employed for prediction of vitamin C retention in orange juice stored at fluctuating warehouse temperatures over an extended period.

From the point of view of the consumer, numerous investigations (Scoular and Willard, 1944; Moore et al., 1945; Feaster et al., 1950; Lopez et al., 1967; Horton and Dickman, 1977) have shown that fresh processed single-strength and reconstituted citrus juices may be kept in a refrigerator for a reasonable length of time (about 4 weeks) without serious loss of vitamin C. Degradation of vitamin C in open containers (glass, plastic, or cans) is minimal if juice is stored at cold temperatures. Even when juice is stored at room temperature, storage time is limited more by loss of palatability than by loss of vitamin C potency (Moore et al., 1945). A 6 fl oz. (177 mL) serving of properly stored orange juice will usually provide vitamin C in excess of the 100% U.S. RDA level.

LITERATURE CITED

Anand, J. C., Leisram, M. S., *Indian J. Hortic.* **20**, 146 (1963).

Araujo, P. E., in "Citrus Science and Technology", Vol. 1, Nagy, S., Shaw, P. E., Veldhuis, M. K., Ed., Avi Publishing Co., Westport, CT, 1977, p 1.

Atkins, C. D., Wiederhold, E., Moore, E. L., *Fruit Prod. J.* **24**, 260 (1945).

Bain, J. M., *Aust. J. Bot.* **6**, 1 (1958).

Barrett, H. C., Rhodes, A. M., *Syst. Bot.* **1**, 105 (1976).

Bauernfeind, J. C., Pinkert, D. M., in "Advances in Food Research", Vol. 18, Chichester, C. O., Mark, E. M., Stewart, G. F., Ed., Academic Press, New York, 1970, p 219.

Beacham, L. M., Bonney, V. B., *J. Assoc. Off. Agric. Chem.* **20**, 517 (1937).

Beattie, G. B., *Flavour Ind.* **1**, 395 (1970).

Berry, R. E., Bissett, O. W., Veldhuis, M. K., *Citrus Ind.* **52**(6), 12 (1971).

Birdsall, J. J., Derse, P. H., Teply, L. J., *J. Am. Diet. Assoc.* **38**, 555 (1961).

Bissett, O. W., Berry, R. E., *J. Food Sci.* **40**, 178 (1975).

Bitters, W. P., in "The Orange: Its Biochemistry and Physiology", Sinclair, W. B., Ed., University of California Press, Riverside, 1961, p 56.

Bowden, R. P., *Queensl. J. Agric. Anim. Sci.* **25**, 93 (1968).

Bratley, C. O., *Proc. Am. Soc. Hortic. Sci.* **37**, 526 (1940).

Brenner, S., Wodicka, V. O., Dunlop, S. G., *Food Technol.* **2**, 207 (1948).

Cohen, A., *Bull. Res. Counc. Isr.* **50**, 181 (1956).

Colburn, B., Gardner, F. E., Horanic, G. E., *Proc. Fla. State Hortic. Soc.* **76**, 24 (1963).

Cooper, W. C., Chapot, H., in "Citrus Science and Technology", Vol. 2, Nagy, S., Shaw, P. E., Veldhuis, M. K., Ed., Avi Publishing Co., Westport, CT, 1977, p 1.

Council for Scientific Industrial Research, and *J. Counc. Sci. Ind. Res.* **20**, 1 (1947).

Cruse, R. R., Lime, B. J., *J. Rio Grande Val. Hortic. Soc.* **31**, 59 (1977a).

Cruse, R. R., Lime, B. J., *J. Rio Grande Val. Hortic. Soc.* **31**, 53 (1977b).

Curl, A. L., *The Canner* **105** (13), 14 (1947).

Curl, A. L., *Food Res.* **14**, 9 (1949).

Dawes, S. N., *N.Z. J. Sci.* **12**, 129 (1969).

Deszyck, E. J., Koo, R. C. J., Ting, S. V., *Proc. Soil Crop Sci. Soc. Fla.* **18**, 129 (1958).

Eaks, I. L., *J. Food Sci.* **26**, 593 (1961).

Eaks, I. L., *Bot. Gaz.* **125**, 186 (1964).

Eaks, I. L., Masias, E., *J. Food Sci.* **30**, 509 (1965).

Eddy, C. W., *Ind. Eng. Chem.* **28**, 480 (1936).

Edrissi, M., Kooshkabadi, H., *Iran J. Agric. Res.* **3**, 81 (1975).

El-Zorkani, A. S., *Agric. Res. Rev. (Cairo)* **46**, 84 (1968).

Embleton, T. W., Jones, W. W., *Calif. Citrogr.* **51**, 269 (1966).

Embleton, T. W., Reitz, H. J., Jones, W. W., in "The Citrus Industry", Vol. 3, Reuther, W., Ed., University of California Press, Riverside, 1973, p 122.

Evenden, W., Marsh, G. L., *Food Res.* **13**, 244 (1948).

Feaster, J. F., Braun, O. G., Riester, D. W., Alexander, P. E., *Food Technol.* **4**, 190 (1950).

Feaster, J. F., Tompkins, M. D., Pearce, W. E., *Food Res.* **14**, 25 (1949).

Fellers, P. J., Barron, R. W., Florida Department of Citrus, unpublished results, 1975.

Florida Canners Association, Statistical Summary, 1976–77 Season, Fla. Canners Assoc., Winter Haven, FL, 1977.

Florida Citrus Mutual, "Annual Statistical Report, 1976–77", 1977, p 9.

Freed, M., Brenner, S., Wodicka, V. O., *Food Technol.* **3**, 148 (1949).

French, R. B., Abbott, O. D., *J. Nutr.* **19**, 223 (1940).

Guerrant, N. B., Vavich, M. G., Dutcher, R. A., *Ind. Eng. Chem.* **37**, 1240 (1945).

Hamersma, P. J., *Union S. Afr., Dep. Agric., Sci. Bull.* **163** (1938).

Harding, P. L., *Food Technol.* **8**, 311 (1954).

Harding, P. L., Fisher, D. F., *U.S. Dep. Agric. Tech. Bull.* **886** (1945).

Harding, P. L., Sunday, M. B., *U.S. Dep. Agric. Tech. Bull.* **988** (1949).

Harding, P. L., Sunday, M. B., *U.S. Dep. Agric. Tech. Bull.* **1072** (1953).

Harding, P. L., Thomas, E. E., *J. Agric. Res.* **64**, 57 (1942).

Harding, P. L., Sunday, M. B., *U.S. Dep. Agric. Tech. Bull.* **1205** (1959).

Harding, P. L., Winston, J. R., Fisher, D. F., *U.S. Dep. Agric. Tech. Bull.* **753** (1940).

Hatton, T. T., Jr., Reeder, W. F., *Proc. Trop. Reg. Am. Soc. Hortic. Sci.* **15**, 89 (1971).

Haworth, W. N., Hirst, E. L., *Chem. Ind.*, 645 (1933).

Henry, R. E., Clifcorn, L. E., *Canning Trade* **70**(31), 7 (1948).

Hilgeman, R. H., Van Horn, C. W., *Univ. Ariz. Agric. Exp. Stn. Bull.* **238** (1955).

Hodgson, R. W., in "The Citrus Industry", Vol. 1, Reuther, W., Batchelor, L. D., Webber, H. J., Ed., University of California Press, Riverside, 1967, p 431.

Horton, P. B., Dickman, S. R., *J. Food Protect.* **40**, 584 (1977).

Huelin, F. E., *Food Res.* **18**, 633 (1953).

Huelin, F. E., Stephens, M. I., *Food Manuf. Distrib.* (Feb, 1944).

Huggart, R. L., Barron, R. W., Hill, E. C., Wenzel, F. W., *Proc. Fla. State Hortic. Soc.* **73**, 247 (1960).

Huggart, R. L., Harman, D. A., Moore, E. L., *J. Am. Diet. Assoc.* **30**, 682 (1954).

Hutchison, D. J., Hearn, C. J., *Proc. Fla. State Hortic. Soc.* **90**, 47 (1977).

Inagaki, C., *Ochanomizu Joshi Daigaku Shizenkagaku Hokoku* **4**, 96 (1953).

Issac, W. E., *Nature (London)* **154**, 269 (1944).

Isherwood, F. A., Mapson, K. W.,.*Annu. Rev. Plant Physiol.* **13**, 329 (1962).

Jones, W. W., in "The Orange: Its Biochemistry and Physiology", Sinclair, W. B., Ed., University of California Press, Riverside, 1961, p 25.

Jones, J. B., Blanchard, J. F., *Chem. Can.*, 112 (June 1956).

Jones, W. W., Embleton, T. W., Boswell, S. B. Goodall, G. E., Barnhart, E. L., *J. Am. Soc. Hortic. Sci.* **95**, 46 (1970).

Jones, W. W., Embleton, T. W., Steinacker, M. L., *Calif. Citrogr.* **43**, 3, 12 (1957).

Jones, W. W., Parker, E. R., *Am. Soc. Hortic. Sci. Proc.* **50**, 195 (1947).

Jones, W. W., Parker, E. R., *Proc. Am. Soc. Hortic. Sci.* **53**, 91 (1949).

Joslyn, M. A., Miller, *J. Food Res.* **14**, 325 (1949).

Kefford, J. F., *World Rev. Nutr. Diet.* **18**, 60 (1973).

Kefford, J. F., Chandler, B. V., *Aust. J. Agric. Res.* **12**, 56 (1961).

Kefford, J. F., McKenzie, H. A., Thompson, P. C. O., *J. Sci. Food Agric.* **10**, 51 (1959).

Kew, T. J., *Proc. Fla. State Hortic. Soc.* **70**, 182 (1957).

Krezdorn, A. H., Cain, R. F., *Proc. Rio Grande Val. Hortic. Inst.*, 48 (1952).

Lamb, F. C., *Ind. Eng. Chem.* **38**, 860 (1946).

Lamden, M. P., Schweiker, C. E., Pierce, H. B., *Food Res.* **25**, 197 (1960).

Lopez, A., Krehl, W. A., Good, E., *J. Am. Diet. Assoc.* **50**, 308 (1967).

Maleki, M., Sarkissian, S., *J. Sci. Food Agric.* **18**, 501 (1967).

Malik, M. N., Scora, R. W., Soost, R. K., *Hilgardia* **42**, 361 (1974).

Marsanija, I. I., *Trudy Sukhum. Opytn. Stan. Efiromaslichn. Kul't.* **9**, 49 (1970); *Hortic. Abstr.* **41**, 1167 (1971).

Marshall, J. R., Hayes, K. M., Fellers, C. R., DuBois, C. W., *Quick Frozen Foods* **17**(12), 50 (1955).

Melas-Joannides, Z., *Bull. Soc. Chim. Biol.* **21**, 809 (1939).

Metcalfe, E., Rehm, P., Winters, J., *Food Res.* **5**, 233 (1940).

Miller, E. V., Jablonski, J. R., *Food Res.* **14**, 492 (1949).

Moore, E. L., *Citrus Ind.* **30**, 11 (1979).

Moore, E. L., Atkins, C. D., Huggart, R. L., MacDowell, L. G., *Citrus Ind.* **32**(5), 8, 11, 14 (1951).

Moore, E. L., Atkins, C. D., Wiederhold, E., MacDowell, L. G., *J. Home Econ.* **37**, 290 (1945).

Moore, E. L., Wiederhold, E., Atkins, C. D., MacDowell, L. G., *Canner* **98** (9), 24 (1944a).

Moore, E. L., Wiederhold, E., Atkins, C. D., *Fruit Prod. J.* **23**, 270 (1944b).

Mudambi, S. R., Rajagopal, M. V., *J. Food Technol.* **12**, 189 (1977).

Munsell, H. E., Williams, L. O., Guild, L. P., Troescher, C. B., Nightingale, G., Kelley, L. T., Harris, R. S., *Food Res.* **15**, 263 (1950a).

Munsell, H. E., Williams, L. O., Guild, L. P., Troescher, C. B., Harris, R. S., *Food Res.* **15**, 355 (1950b).

Nagy, S., Shaw, P. E., Veldhuis, M. K., Ed., "Citrus Science and Technology", Vol. 2, Avi Publishing Co., Westport, CT, 1977.

Nagy, S., Smoot, J. M., *J. Agric. Food Chem.* **25**, 135 (1977).

Nordby, H. E., Nagy, S. Smoot, J. M., *J. Am. Soc. Hortic. Sci.* **104**, 280, (1979).

Pennisi, L., *Essenze Deriv. Agrum.* **47**, 167 (1977).

Peterson, G. T., *Continental Can Co. Bull.* 18 (1949).

Pritchett, D. E., *Calif. Citrogr.* **48**, 29 (1962).

Pulley, G. N., von Loesecke, H. W., *Ind. Eng. Chem.* **31**, 1275 (1939).

Reichstein, T., Gussner, A., Oppenauer, R., *Nature (London)* **132**, 280 (1933).

Reitz, H. J., Koo, R. C. J., *Proc. Am. Soc. Hortic. Sci.* **75**, 244 (1960).

Reuther, W., Ed., "The Citrus Industry", Vol. III, University of California Press, Berkeley, 1973.

Reuther, W., Nauer, E. M., unpublished data, Univ. Calif. Exp. Stn., Riverside, 1972.

Richardson, J. E., Mayfield, H. H., *Mont. Agric. Exp. Stn. Bull.* **423** (1944).

Riester, D. W., Braun, O. G., Pearce, W. E., *Food Ind.* **17**, 742 (1945).

Rose, E., *Food Res.* **9**, 27 (1944).

Roy, W. F., Russell, H. E., *Food Ind.* **20**, 110 (1948).

Royo Iranzo, J., Peris Toran, J., *Essenze Deriv. Agrum.* **47**, 491 (1977).

Rygg, G. L., Getty, M. R., *U.S. Dep. Agric. Tech. Bull.* **1130** (1955).

Sale, J. W., *J. Assoc. Off. Agric. Chem.* **30**, 673 (1947).

Schachter, S. *Essenze Deriv. Agrum.* **47**, 381 (1977).

Scoular, F. I., Willard, H., *J. Am. Diet. Assoc.* **20**, 223 (1944).

Sheft, B. B., Griswold, R. M., Tarlowsky, E., Holliday, E. G., *Ind. Eng. Chem.* **41**, 144 (1949).

Sinclair, W. B., Ed., "The Orange: Its Biochemistry and Physiology", University of California Press, Riverside, 1961, p 29.

Sinclair, W. B., "The Grapefruit: Its Composition, Physiology, and Products", University of California Press, Riverside, 1972.

Sites, J. W., *Proc. Fla. State Hortic. Soc.* **57**, 122 (1944).

Sites, J. W., *Proc. Fla. State Hortic. Soc.* **60**, 55 (1947).

Sites, J. W., Reitz, H. J., *Proc. Am. Soc. Hortic Sci.* **56**, 103 (1951).

Smith, P. F., in "Proc. First Int. Citrus Symp.", Chapman, H. D., Ed., University of California, Riverside, 1969, p 1559.

Smith, P. F., Rasmussen, G. K., *Proc. Fla. State Hortic. Soc.* **73**, 42 (1960).

Smith, P. F., Rasmussen, G. K., *Proc. Fla. State Hortic. Soc.* **74**, 32 (1961).

Smoot, J. M., Nagy, S., *J. Agric. Food Chem.*, in press (1979).

Swisher, H. E., Swisher, L. H., in "Citrus Science and Technology", Vol. 2, Nagy, S., Shaw, P. E., Veldhuis, M. K., Ed., Avi Publishing Co., Westport, CT, 1977, p 253.

Szent-Gyorgyi, A., *Biochem. J.* **22**, 1387 (1928).

Ting, S. V., in "Citrus Science and Technology", Vol. 2, Nagy, S., Shaw, P. E., Veldhuis, M. K., Ed., Avi Publishing Co., Westport, CT, 1977, p 401.

Wagner, J. R., Ives, M., Stron, F. M., Elvehjem, C. A., *Food Res.* **10**, 469 (1945).

Waletzko, P., Labuza, T. P., *J. Food Sci.* **41**, 1338 (1976).

Waugh, W. A., King, C. G., *J. Biol. Chem.* **97**, 325 (1932).

Webber, J. H., in "The Citrus Industry", Webber, J. H., Batchelor, L. D., Ed., University of California Press, Berkeley, 1943, p 475.

Winston, J. R., Miller, E. V., *Food Res.* **13**, 456 (1948).

Zilva, S. S., *Biochem. J.* **22**, 689 (1927).

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