

EFFECT OF STAGE OF MATURITY AT HARVEST, POST-HARVEST  
STORAGE AND CULTIVAR ON SOME QUALITY  
DETERMINATIONS OF TOMATO FRUITS

by

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B.Sc. (Agriculture), Baghdad University, Baghdad  
Iraq, 1971

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A THESIS

submitted in partial fulfillment of the  
requirements for the degree

MASTER OF SCIENCE

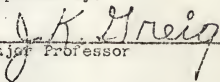
FOOD SCIENCE

DEPARTMENT OF HORTICULTURE

KANSAS STATE UNIVERSITY  
Manhattan, Kansas

1978

Approved by:

  
Major Professor

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## ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude and appreciation to Dr. J.K. Greig, Professor of Horticulture and his major professor, for his guidance and indispensable help throughout this study.

The author also wishes to express his sincere appreciation to Dr. H.L. Mitchell, Professor of Biochemistry, for his serving on his committee, assistance in chemical analysis and for unrestricted use of his laboratory equipment and materials.

He would also like to thank Dr. Jane R. Bowers, Professor and Head of the Department of Foods and Nutrition, and Jean A. Craig, graduate research assistance of the Department of Foods and Nutrition, for their assistance in chemical analysis and for use of their laboratory and materials.

Many thanks go to my wife, Nahla, for her patience, support and encouragement throughout the entire period of study. Appreciation is also due to the Iraqi Government for a scholarship which allowed this work to be accomplished.

## INTRODUCTION

The economic importance of the tomato is considerable and the demand for a high quality, widely adapted fresh tomato suitable for human consumption is increasing day by day. Interest is increasing in the major and minor constituents of the fruit which influence taste and flavor, particularly with regard to the effects of cultivar, nutrition, post harvest storage and processing.

Recently, the decreasing quality of fresh tomato fruits available in the markets has been given an extensive concern. Some investigations have been conducted to determine how quality attributes, especially those related to nutritional value, are influenced by ripening tomatoes off the vine. McCollum and Skok (45) reported that tomatoes harvested from the plants in the mature green stage and ripened in storage would have less quality compared to fruits ripened on the plant. This fact lead a number of researchers to establish more proper storage conditions for ripening and keeping quality of fresh market tomatoes.

The objectives of this study were:

1. To compare some quality determinations; pH, ascorbic acid,  $\beta$ -carotene and total sugar; of tomato fruits ripened off the vine (storage ripened) with tomatoes ripened on the vine (field ripened).
2. To determine the effect of stage of maturity at harvest upon these quality determinations.
3. To determine the effect of different cultivars on these fruit quality determinations.

## REVIEW OF LITERATURE

1. pH

Acidity has been known as one of the most important quality factors of tomato fruits, and organic acids are major components of tomato flavor. In addition, due to the importance of pH in the keeping quality of processed tomato products, many studies have been conducted that have shown that factors such as cultivar (35, 61), harvest date (32, 39), and stage of ripeness (28, 24) have a pronounced influence on pH values in tomato fruits.

Regarding the influence of sunlight exposure and post-harvest storage temperature (5, 9, 43, 54), it has been stated that sunlight exposure and post-harvest storage temperature had no detectable effect on pH. However, Lambeth et al. (32) and Lower and Thompson (35) reported that field ripened fruits had a higher pH than chamber ripened fruits.

With regard to the influence of cultivar, Hanna (24) and Orzolek and Angell (48) found that there was a difference in pH level between cultivars studied.

Lower and Thompson (35) reported that seasonal variation in pH was evident from the highly significant variance attributable to sampling dates. In addition, Orzolek and Angell (48) indicated that the range in variation in pH was inconsistent between years.

The influence of stage of ripeness on pH values was shown by Hanna (24), Janes (29), Sakiyama (50), Yamaguchi et al. (69),

and Iwahori and Lyons (28). They reported that pH is highest just after fruit set, decreases as the fruit grows, attains its lowest value at the breaker stage and increases slightly as the fruit ripens. Hanna (24) established a high degree of correlation between pH level and maturity stage. He found a trend of increase in pH with increased maturity in studies of two growing seasons.

## 2. Ascorbic Acid

Tomatoes have been recognized as a good source of ascorbic acid (vitamin C). A fresh, ripe tomato fruit supplies 10.4-44.6 mg ascorbic acid per 100 g of fresh fruit (33) with an average value of 23 mg per 100 g of fresh fruit (60). Factors that have been reported to contribute to the variations in ascorbic acid content of tomato fruits are: cultivar (19, 26, 36, 40) and environmental growing conditions (18, 22, 23, 42, 43, 49).

Some investigators have stated more than 100 percent variation between cultivars for a single season (19, 36). However, others have found less variation in ascorbic acid content between different cultivars for a single season and growing location (10, 52, 59). According to French and Abbott (19), the scorbic acid contents of 29 tomato cultivars grown at Bradenton, Florida during the 1942 season ranged from 10.8 to 27.2 mg/100 g, with a mean value of 19.5 mg/100 g.

According to Hamner et al. (22), when the same tomato cultivar was grown in different areas of United States the

ascorbic acid content could vary more than 100 percent.

'Rutgers' had a low ascorbic acid content of 8.4 mg/100 g when grown at Kingston, Rhode Island, and a high content of 19.7 mg/100 g when grown at Lafayette, Indiana. 'Marglobe' had ascorbic acid content of 14.4 mg/100 g when grown at Knoxville, Tennessee, and 30.6 mg/100 g at Wenatchee, Washington. 'Pritchard' had ascorbic acid content of 10.7 mg/100 g when grown at Kingston, Rhode Island, and 29.0 mg/100 g when grown at Fresno, California.

Regarding the seasonal trends, Scott and Kramer (51) reported that tomato fruits harvested on August 17 were significantly higher in ascorbic acid than those harvested on August 3 of the same growing season. In sampling vegetables for ascorbic acid content, Hopp and Lamden (26) found variations between harvest dates of the same growing season, and between years. French and Abbott (19) reported a considerable season to season variation for some cultivars. 'Valient' which had the highest ascorbic acid level of 27.2 mg/100 g in 1942 had only 18.5 mg/100 g in 1944. 'Grothen's Globe' had 24.5 mg/100 g in 1942 and only 14.5 mg/100 g in 1944. Yamaguchi et al. (69) indicated that ascorbic acid content was generally higher in 1958 than 1957 in 'Pearson' fruits. Orzolek and Angell (48) reported a 20% variation in ascorbic acid of all tomato cultivars studied in two successive years.

Seasonal variation of ascorbic acid in tomatoes have been given some support by the conclusions of Currence (10) and Clutter and Miller (8). The rate of tomato ripening depends on



environmental aspects which are constantly varying from day to day. This kind of development explains the variation in ascorbic acid content within any growing season.

With regard to the effect of temperature, Hamner et al. (22) grew some tomato plants at 17°C and others at 25°C in sand culture under controlled conditions. They found that the fruits from the low temperature plants were significantly lower in ascorbic acid content than those from the high temperature plants, the difference was about 16 percent of the higher value.

According to Craft and Heinze (9) after an additional 7-day period at 65 degrees F, the mature green tomatoes originally stored at 32 or 40 degrees continued to retain a significantly higher content of ascorbic acid than those stored at 50 degrees. Due to the difference in temperature, Yamaguchi et al. (69) stated that ascorbic acid content of 'Pearson' tomatoes grown in 1958 was generally higher than 1957. However, Brown and Moser (6) showed no effect of temperature upon the ascorbic acid content of ripe tomatoes.

Regarding the effect of light intensity on the ascorbic acid content of tomatoes, Hamner et al. (22), from controlled experiments with temperature, humidity, length of photo-period, and sunlight and shade, stated that light intensity just prior to harvest had the greatest influence on the ascorbic acid content of tomato fruits. McCollum (43) reported that shaded tomato fruits had less ascorbic acid content than unshaded fruits. He also reported that fruit sides with the greatest exposure to sunlight had the highest levels of ascorbic acid.

McCollum (42) in another study found that fruits shaded by the plants had significantly less ascorbic acid content than those unshaded fruits. Hassan and McCollum (25) reported that the uppermost fruits on a plant were highest in ascorbic acid content. They considered this to be due in part to better light exposure.

Wokes and Organ (68) showed that tomatoes harvested while green and ripened at room temperature in sunlight contained similar ascorbic acid content to that of field ripened fruit, but the content was appreciably lower when fruits ripened in the dark at room temperature.

Somers et al. (56) reported that the amount of light, 18 days before harvest, correlated closely to the ascorbic acid content of field grown tomatoes. Yet Somers et al. (57) believed that the close correlation observed was due to the extensive defoliation of the plants in the former study. This belief supported the finding of McCollum (42), who had previously found that tomatoes from defoliated plants were higher in ascorbic acid than those from normal plants. Brown and Moser (6) stated that greenhouse tomatoes contained only about half the ascorbic acid content of tomatoes grown simultaneously out of doors. These observations were supported in general by the findings of Wokes and Organ (68).

With regard to the effect of stage of ripeness, Jones and Nelson (30) and Clow and Marlott (7), in the early works on the ascorbic acid content of tomatoes, found an apparent increase in ascorbic acid associated with maturation of the fruits.

Maclinn et al. (37) and Maclinn and Fellers (36) reported that the stage of ripeness had no effect upon the ascorbic acid content. Hamner et al. (22) reported a slight but continuing increase in the ascorbic acid concentration through the overripe stage, while LoCoco (34) reported a large increase up to the red-ripe stage with a subsequent decrease as the fruit over-ripened. These results were in agreement with the findings of Malewski and Markakis (38).

Fryer et al. (20) observed a definite rise in ascorbic acid content as the fruit ripened from mature-green to mature-red. Matthews et al. (41) reported that red ripe tomatoes had less ascorbic acid content than either green, breaker, or pink tomatoes. In earlier work Brown and Moser (6) observed higher ascorbic acid content in over-ripe than firm ripe tomatoes. In recent work Watada et al. (62) found no significant difference in ascorbic acid values between mature-green and ripe tomatoes of ten cultivars. Furthermore, Yamaguchi et al. (69) found no consistent trend in the ascorbic acid content with increasing maturity.

Regarding the effect of storage upon the ascorbic acid content, Scott and Kramer (51) reported that ascorbic acid content decreased during storage of mature-green tomatoes at 70 degrees F and ripe tomatoes at 35-50 degrees. These results supported the findings of Kays (31) who reported a remarkably uniform loss of ascorbic acid from tomatoes in storage. However, Craft and Heinze (9) found no pronounced change in the ascorbic acid content of mature green tomatoes stored at 32°,

40°, 50°, 65° and 75° F for periods up to 14 days.

Pantos and Markakis (49) reported a decline in the ascorbic acid content of two tomato cultivars with time of storage at all temperatures. Matthews et al. (41) stated that tomato fruits harvested at all stages ripened in a 70°F, unlighted, humidity controlled ripening room resulted in a slight decrease in ascorbic acid content.

In a recent report Bisogni et al. (5) reported that the reduced ascorbic acid content of field ripened tomatoes was significantly greater compared to that of room ripened tomatoes.

### 3. $\beta$ -Carotene

A fresh ripe tomato fruit weighing 100 g supplies 0.21-0.80 mg  $\beta$ -carotene (provitamin A) (33). Several workers have reported the influences of some environmental aspects, cultivars, stage of maturity and post harvest handling practices on the carotene contents of tomato fruits (15, 17, 23, 41, 44, 47, 55, 62, 66, 69).

With regard to the environmental aspects and light in particular, Duggar (16) in early studies found that light was not essential for the formation of red pigments in tomatoes during ripening. However, Smith (55) stated that exclusion of light during development and maturity of tomato fruits decreased the carotenoids content in the ripe fruits. According to Denisen (15), green tomatoes from which light had been excluded were lower in carotene than uncovered fruits. McCollum (44) reported that tomato fruits ripened at a consistent

temperature under sufficient light had a higher carotene content than those ripened in the dark at the same temperature. However, Nettles (47) ripened mature green 'Grothen's Globe' tomatoes with illumination of 10 to 450 F.C., and without illumination and observed no differences in the carotene content of the fruits as a result of treatments.

Regarding the influence of cultivars, Watada et al. (62) indicated that differences in vitamin A activity were greater among cultivars than between stage of ripeness at harvest. The vitamin A activity of 'Caro-Red', the cultivar with highest activity, was 5-11 times that of other cultivars studied. The difference between stage of maturity at harvest was only 1/4 or less of the differences observed with cultivars.

With respect to the influences of stage of maturity and postharvest handling practices, Ellis and Hamner (17) found that tomatoes picked at mature green and ripened at five different storage temperatures had lower levels of  $\beta$ -carotene than fruits picked at the pink or ripe stage. Yamaguchi et al. (69) stated that carotene content did not change significantly with ripeness or harvest date, but generally higher in 1958 than 1957. Meredith and Purcell (46) reported that  $\beta$ -carotene content of green 'Homestead' tomatoes increased in concentration through all the stages of maturity until the light red stage, then decreased. Later on, Matthews et al. (41) found that  $\beta$ -carotene content increased significantly with each increase in maturity stage. They also found that tomatoes picked at either the green, breaker, or pink stages and ripened in a

70°F, unlighted humidity controlled ripening room, did not differ significantly in  $\beta$ -carotene content from tomatoes at the ripe stage. Recently, Watada et al. (62) reported that tomatoes of nine cultivars ripened on the plant had significantly higher average  $\beta$ -carotene contents than those ripened off the plant. They also reported, however, that the increases were not always significant.  $\beta$ -carotene of all cultivars increased with ripeness of fruit at harvest.

#### 4. Total Sugars

Sugars have been known as one of the major components responsible for tomato fruit quality. Winsor and Massay (67) and Winsor et al. (66) concluded that the taste of tomato fruits is mainly dependent on the sugar and acid content. Winsor (65) stated that sugars account for some 50% of the dry matter of tomatoes. In commercial tomato cultivars the free sugars are almost entirely reducing sugars (23, 32, 66) consisting mainly of glucose and fructose present in approximately equal amounts (1, 11, 63, 64). Sucrose is present occasionally, but rarely exceeds 0.1% of the fresh weight (11, 14, 53, 63) except in fruit of some *Lycopersicon* species where it is the dominant sugar (12). Very small amounts of a ketoheptose have been reported (64).

Few studies are available regarding the factors affecting the sugars concentrations in tomato fruits. Light (43), harvest date (69), cultivars (53, 63), stage of maturity (13, 66, 69), and postharvest storage (9) have been the major factors

encountered in the literature that have influenced the sugar content in tomato fruits.

Regarding the effect of light on sugar content, McCollum (43) found in both early and late analyses of the same growing season a striking increase in sugars for the unshaded over the shaded fruits.

Regarding the effect of harvest date on sugar content, Yamaguchi et al. (69) made three harvests in the growing seasons of 1957 and 1958; early, middle, and late harvests. In both years they found that the reducing sugars were much lower in the late harvests than the early or middle harvests.

Regarding the effect of cultivars on sugar content, Simandle (53) found that there were highly significant differences in fructose content that could be related to cultivar. However, White and Alban (63) found no significant differences between cultivars in total sugar, total reducing sugar, glucose, or fructose content. On the other hand, there was a considerable variation in all determinations between samples from plots of the same cultivar and between the means of the replicates in the greenhouse.

Regarding the effect of stage of maturity on sugar content, Yamaguchi et al. (69) reported that reducing sugars of 'Pearson' tomatoes harvested three times in two growing seasons, 1957 and 1958, increased with ripeness. According to Winsor et al. (66) and Lambeth et al. (32) the content of total sugars in the expressed juices increased significantly from the mature-green to the red-ripe stage, although instances of

decrease once the fruit has begun to color have been reported (66). In recent work, Davies and Kempton (13) reported that total reducing sugars increased markedly between the mature-green and green-yellow stages with a tendency to decrease with subsequent ripening.

The only work that has been reported on the effect of postharvest storage on sugar content of tomato fruits was that of Craft and Heinze (9). They found that reducing sugars increased slightly in the mature-green 'Rutgers' tomatoes stored at 32, 40, 50, 65, and 75 degrees F for the shorter periods but decreased with longer storage.



## MATERIALS AND METHODS

A. Materials

Tomato fruits of Jetstar Hybrid and Floramerica Hybrid were grown at Ashland Horticultural Farm - Kansas State University - during the summer of 1977 using conventional cultural practices. Both cultivars were harvested at the mature-green, breaker, pink, firm ripe and overripe maturities and analyzed for pH, ascorbic acid,  $\beta$ -carotene and total sugars.

These five stages of maturities were defined as following:

1. Mature green. The stage at which tomato fruit has a completely green skin but has reached the stage where it will turn red either on or off the vine.
2. Breaker. The stage at which tomato fruit is primarily green with a tinge of yellow or pink, usually at the blossom end.
3. Pink. The stage at which tomato fruit has 50% or more pink or red skin.
4. Firm ripe. The stage at which tomato fruit is fully red colored, but still firm.
5. Over-ripe. The stage at which tomato fruit is fully red colored, but soft.

Fifteen fruits of each maturity were selected to represent three samples each of five fruits. Each sample was picked at random from the entire 15 fruits of each maturity. Fruits of each sample were quartered so that each single tomato

contributed one quarter to the determinations of all variables.

On the other hand, both cultivars were harvested at different maturities (stages), ripened in storage at 20°C and analyzed for quality determinations mentioned above when they reached the subsequent stages; this can be illustrated as followed:

1. Mature-green fruits were harvested, held in storage and analyzed for quality determinations when they reached breaker, pink, firm ripe and overripe maturities.

2. Breaker fruits were harvested, held in storage and analyzed for quality determinations when they reached pink, firm ripe and overripe maturities.

3. Pink fruits were harvested, held in storage and analyzed for quality determinations when they reached firm ripe and overripe maturities.

4. Firm ripe fruits were harvested, held in storage and analyzed for quality determinations when they reached over-ripe maturity.

In all treatments, sample portions were analyzed immediately after sampling for pH and ascorbic acid; whereas, portions for  $\beta$ -carotene and total sugars determinations were weighed (50'g), transferred to glass vials and held in a freezer at -20° C until analyzed.

## B. Chemical Analyses

### Part I: pH

- a. Sample preparation. Five fruits of the proper stage

of maturity were washed. Then one quarter of each fruit was blended for one minute at high speed with a Waring Blender. The entire puree was analyzed for pH immediately after blending.

b. pH determination. All pH measurements were performed using a Horizon pH-meter. The pH-meter was first standardized using pH 4.00 buffer solution.

## Part II: Ascorbic Acid

The official microfluorometric method of AOAC (3) was used in the ascorbic acid determinations. Only one modification was introduced to the method; instead of using 2 g Norit A, 4 g were used.

a. Sample preparation. (1.) One quarter of five washed tomato fruits were weighed and an equal amount of extracting acid solution (3%  $\text{HPO}_3$  - 8% HOAC) was added. The mixture was blended for 30 sec. at high speed with a Waring Blender. (2.) The slurry was drawn into a wide tip pipet, and 50 g were weighed into a 100 ml. volumetric flask and diluted to volume with extracting acid solution (3%  $\text{HPO}_3$  - 8% HOAC).

b. Ascorbic acid determination. (1.) A 100 ml. sample assay solution was transferred to 250 ml. erlenmeyer flask. Four grams of Norit A (activated charcoal) were added, shaken vigorously and allowed to stand 5 minutes. (2.) The mixture was filtered through fluted filter paper. (3.) Then 5 and 10 ml. aliquots were pipetted into separate 100 ml. volumetric flasks. (4.) Approximately 75 ml. of water were added. (5.) Then 5 ml. of 50% NaOAc solution (sodium acetate) were added and

the content was diluted to volume with water.

#### Preparation of Ascorbic Acid Standard Solution

1. A 100 mg of L-ascorbic acid were weighed, transferred to 100 ml volumetric flask, and diluted to volume with extracting solution (3%  $\text{HPO}_3$  - 8% HOAc).

2. The 100 ml. standard assay solution was transferred to 250 ml. erlenmeyer flask. Four grams of Norit A (activated charcoal) were added, shaken vigorously and allowed to stand 5 minutes.

3. The mixture was filtered through fluted filter paper.

4. Then 10 ml. of this filtrate were pipetted into a 100 ml. volumetric flask and diluted to volume with extracting acid solution. The final volume contained 2  $\mu\text{g}$  ascorbic acid/ml.

5. Aliquots of 1, 3, 5, 7 and 10 ml were pipetted into separate 100 ml volumetric flasks. These dilutions were treated as were the samples (75 ml of water, 5 ml of 50% NaOAc solution were added, respectively, and the mixture was diluted to volume).

#### Preparation of Standard and Sample Blank Solutions

1. The 5 ml. aliquots of sample and standard filtrates were transferred into separate 100 ml. beakers.

2. Then 5 ml. of freshly prepared 3% Boric Acid in 50% NaOAc were added to each beaker and shaken. The pH's of both solutions were adjusted to 7.5 - 8.0 using 1 N KOH solution.

Contents were allowed to stand 15 minutes.

3. At appropriate time, both blank solutions were transferred to separate 100 ml. volumetric flasks and diluted to volume with water.

As soon as all sample, standard and blank solutions were prepared, 2 ml aliquots of each dilution were pipetted into each of 2 fluorescence reading tubes. Using automatic pipetting machine, 5 ml of freshly prepared O-phenylenediamine solution were added to all tubes. Tubes were protected from light and allowed to stand 30-35 minutes at room temperature. Fluorescence of all tubes was measured using Coleman Electronic Photofluorometer model 12C.

#### Calculation

a. Standard and sample blanks readings. Two fluorescence readings of both standard and sample blanks were averaged.

b. Plotting of standard curve. (1.) The average of standard blank readings was subtracted from the average of two readings of each standard dilution. (2.) The standard curve was established by plotting the number of micrograms of ascorbic acid of each dilution on abscissa against the fluorescence readings obtained from the fluorometer on the ordinate. Therefore a standard curve had to be plotted for each determination.

c. Calculation of ascorbic acid values in tomato samples. (1.) The average of two sample blank readings was subtracted from the average of two readings of each sample dilution.

(2.) The result obtained from (1) was placed on the standard curve. Then an imaginary line was drawn down to the abscissa and value was recorded. This value was multiplied by a dilution factor of (4) for the volumetric flask that contained 5 ml of the filtrate and by (2) for the volumetric flask that contained 10 ml of the filtrate (see page 15 determination, no. 3). (3.) Values of ascorbic acid obtained from both 5 ml and 10 ml filtrate were averaged. The final value represented the amount of ascorbic acid in mg/100 g of tomatoes.

### Part III. $\beta$ -Carotene

Analyses were made for  $\beta$ -carotene using a modified AOAC (4) method by increasing sample size to 50 grams and alcohol volumes 5 fold for extraction with blending. Instead of using 10% acetone in hexane (skellysolve), 4% acetone in skellysolve B was used to slow down elution of carotene.

Preparation of sample. (1.) One-quarter of each of five washed tomato fruits were cut into small pieces and mixed to assure a representative sample. (2.) Then 50 grams were weighed, transferred to glass vials and frozen at  $-20^{\circ}\text{C}$  until analyzed. (3.) At appropriate time, 40 ml of skellysolve B were added to the sample and the contents were warmed on a hot plate until tissues thawed. (4.) The content was transferred to a blender cup, using 20 ml of skellysolve B and about 200 ml of 95% ethyl alcohol. The purpose of alcohol was to dehydrate the tissues to allow skellysolve B to penetrate the cells and extract carotenes. (5.) The mixture was blended for

approximately 5 minutes at high speed with a Waring Blender. The slurry was filtered through filter paper in a Buchner funnel with suction, and the residue was washed with approximately 50 ml of skellysolve B. (6.) The filtrate was transferred to a 500 ml separatory funnel. Then 100 ml of water containing about 1 gram of sodium sulfate were added. Sodium sulfate was used to prevent emulsions. The mixture was allowed to stand a few seconds and the water-alcohol layer was drawn off. (7.) The water-alcohol layer was extracted twice with 50 ml portions of skellysolve B. (8.) All of the skellysolve B extracts were combined and washed twice with water to eliminate the alcohol.

Separation and determination of  $\beta$ -carotene. (1.) The washed extract was transferred to a 600 ml beaker and concentrated on a hot plate to about 30 ml. (2.) A column was prepared by placing small cotton plug inside the chromatographic tube, then loose adsorbent (MgO-supercel 1:1) was added to 15 cm depth, tube was attached to suction flask, and full vacuum of water pump was applied. Tamping rod was used to gently press adsorbent and flatten surface (packed column had to be about 10 cm deep). A 1 cm layer of anhydrous sodium sulfate was placed above adsorbent. (3.) The concentrated extract was chromatographed on a column of MgO-supercel 1:1. Supercel was used to make the mixture porous enough for  $\beta$ -carotene to elute through. Activated MgO was used as an adsorbent. (4.) The carotene was eluted using a solution of 4% acetone in skellysolve B. (5.) The eluate was collected in a 250 ml volumetric flask,

diluted to the mark with skellysolve B, and color intensity was measured photometrically at 436 nm with a Backman spectrophotometer.

Calculation. Two fundamental laws are associated with spectrophotometry; these are Lambert's and Beer's laws. By combining both laws we obtain:

$$A = \log_{10} \frac{I_0}{I} = \alpha \cdot l \cdot c.$$

where:

A = absorbance

$I_0$  = incident light intensity

I = transmitted light intensity

$\alpha$  = absorbcancy index characteristic for the solution

l = length or thickness of the medium

c = concentration of solute (carotene) in solution

If l is held constant by employing a standard cell or cuvette, the Beer-Lambert law reduces to:

$$A = \log_{10} \frac{I_0}{I} = \alpha c$$

Since value of A was known and  $\alpha = 196$  for  $\beta$ -carotene, the concentration was calculated:

$$c = \frac{A}{\alpha} = \frac{A}{196} = \text{grams of carotene/liter of solution.}$$

This was multiplied by a factor of 500 to get concentration of  $\beta$ -carotene in mg/100 grams fresh weight of tomato.

#### Part IV. Total Sugars

The official method of AOAC (2) was used in the total



sugar determinations.

Sugars extraction. (1.) Five-quarter sample portion of washed tomato fruits were cut into small pieces and mixed to assure representative sample. (2.) Fifty grams were weighed, transferred to glass vials and frozen at  $-20^{\circ}\text{C}$  until analyzed. (3.) At appropriate time, 50 ml of 95% ethyl alcohol were added and contents were warmed up on a hot plate until the tissues thawed. (4.) The contents were transferred to a blender cup, using 50 ml of 95% ethanol and sugar was extracted by blending the sample with a total of 100 ml 95% ethanol for two minutes at high speed with a Waring Blender. (5.) The slurry was filtered through a layer of supercel in a Buchner funnel, with suction. The purpose of supercel was to speed up the process of filtration. (6.) The extract was transferred to a 500 ml volumetric flask and diluted to volume with 75% ethanol.

Preparing solution for total sugars analysis. (1.) Fifty ml of tomato extract solution was transferred to a 250 ml beaker. (2.) The beaker of tomato extract solution, which contained approximately 80% alcohol was placed on a hot plate in order to evaporate the solution to a small volume. The extract was heated for about 10 to 20 minutes. (3.) Twenty-five ml of water were added and heating was continued until most of the alcohol was evaporated. (4.) After evaporation of alcohol, the solution was transferred to a 250 ml volumetric flask and diluted to volume with distilled water.

Total sugars determination. (1.) Fifty ml of the 250 ml sugar solution were placed in a 250 ml beaker and 10 ml. of

HCl 1:1 were added. The beaker was allowed to stand overnight to hydrolyze the sucrose to glucose and fructose (invert sugars). (2.) After 18 hours at room temperature, 5 ml of 10 N NaOH (40%) were added and the contents adjusted to pH 7.0 with 1 N NaOH solution using a pH meter. (3.) The contents were then transferred to a 100 ml volumetric flask and diluted to volume with distilled water. (4.) Two ml aliquot of this solution was pipetted into a 100 ml volumetric flask and 5 ml of alkaline ferricyanide reagent were added. (5.) The flasks were immersed in a boiling water bath for 10 minutes. (6.) After heating the flasks, they were rapidly cooled in running water and contents were partially neutralized with 10 ml of  $2N-H_2SO_4$  solution. (7.) The contents of the flasks were mixed until no more gas evolved. (8.) Four ml of the arsenomolybdate solution were added. (9.) The contents of the flasks were again mixed and diluted to 100 ml and allowed to stand 30 to 60 minutes. The ferrocyanide-arsenomolybdate complex becomes stable approximately 15 minutes after its formation, but after 1 hour the absorbance decreases gradually. Therefore, all measurement had to be taken 30 to 60 minutes after the formation of the complex. (10.) A blank was treated in exactly the same way as the sample. (11.) Solutions were read with a Beckman Spectrophotometer and the absorbances were measured at 745 nm using a 1 cm cell. (12.) The absorbances were compared with a standard curve.

Calculations. The absorbance reading obtained was placed on the standard curve. Then an imaginary line was drawn down

to the abscissa and the value was recorded. This was multiplied by a dilution factor of (5000) to get milligrams total sugars per 100 grams fresh weight of tomato. The final results were expressed in percent fresh weight of tomato.

## EXPERIMENTAL RESULTS AND DISCUSSION

Part I: pHA. Jetstar

a. Field ripened. According to the data in Table 1, Jetstar tomatoes showed no consistent trend of pH changes during ripening on the vine. However, pH decreased significantly from the mature green to the breaker stage followed by a slight but not consistent increase toward the overripe stage. There was a pronounced increase in pH from the breaker to the pink stage followed by a significant decrease to the firm ripe and a slight increase toward the overripe stage. In this study the variation of pH can be attributed mainly to the varying climatic conditions such as rainfall distribution and sampling dates and in part to the use of incipient color as an indication of readiness for harvest instead of physiological age. Our results are in general agreement with those of other workers (35, 48).

b. Storage ripened. (1.) Jetstar tomatoes picked at mature green, ripened at 20°C in storage and analyzed for pH when they were in the breaker, pink, firm ripe or overripe stage consistently changed in pH during ripening (Table 1). Significant decrease occurred in pH as fruits ripened from mature green to breaker and pink followed by significant increase toward the overripe stage. These results are consistent with other reports of changes in the ripening fruit (21, 24, 28, 29, 32, 50, 69).

They found that pH is highest just after fruit set, decreases as the fruit grows, attains its lowest value at the breaker stage and increases slightly as the fruit ripens. (2.) Tomato fruits picked as breaker and ripened in storage again showed no consistent trend of changes in pH during ripening. There was a slight increase in pH as fruits ripened from the breaker to the pink stage followed by a significant decline in the firm ripe and a small increase for the overripe stage (Table 1). These results are in general agreement with those of other workers (28, 29, 66). (3.) Tomato fruits picked at the pink stage and ripened in storage showed a slight but not significant decrease in pH in the firm ripe and overripe stages during the storage period (Table 1). These observations seem to be comparable to those of Iwahori and Lyons (28) whose results have graphically shown a very small but not significant decrease in pH from the firm ripe to the overripe stage. This possibly occurred because the fruits were analyzed before they attained the appropriate stage of maturity (based on the incipient color) even though they were soft enough. Winsor et al. (66) suggested that the increase in acidity shown in some instances as the fruit becomes fully ripe could be explained by the accumulation in the walls of relatively acid juices, increasing in amount as the fruit ripens and softens. (4.) Tomato fruits picked as firm ripe and ripened in storage demonstrated a very slight but not significant increase in pH as they ripened to overripe.

Consequently, the results from all treatments have generally shown that the trend of pH changes was more consistent

in storage-ripened tomatoes than field-ripened tomatoes. This was attributed mainly to more variation in climatic conditions in the field during maturation.

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of pH values in tomatoes have been made only on comparable maturities (Table 3). The pH value of each individual stage of maturity from the vine was contrasted with the mean value of the same stage of maturity of all storage treatments. Statistically, no significant differences were observed between the pH value of field-ripened tomatoes and storage-ripened fruits. These observations agree with the reports of McCollum (43), Craft and Heinze (9), and Bisogni et al. (5). However, Lambeth et al. (32) and Lower and Thompson (35) reported that field-ripened tomatoes had higher pH values relative to chamber ripened fruits. One exception was reported that of the pink stage at which the pH was significantly higher in the field-ripened tomatoes than in the storage-ripened fruits. Based on the observations of McCollum and Skok (45), some differences would be observed in pH between room-ripened fruits and field-ripened fruits.

## B. Floramerica

a. Field ripened. According to the data in Table 2, a consistent trend in pH has been shown during ripening of fruits on the vine. The pH was highest at mature green, decreased significantly as the fruits ripened, attained its lowest value at the breaker stage and increased slightly as

the fruits ripened toward the overripe stage. Our results demonstrated agreement with those of other investigators (21, 24, 28, 29, 32, 50, 69).

b. Storage ripened. (1.) Tomato fruits picked at mature green stage ripened in the storage and analyzed for pH when they were breaker, pink, firm ripe and overripe have shown a significant decline at the breaker stage in which the pH was lowest followed by a consistent significant increase as the fruits ripened to the overripe stage (Table 2). Our results are consistent with those of other authors (21, 24, 28, 29, 32, 50, 69). (2.) Tomato fruits picked at the breaker stage and ripened in storage continued the trend of low pH at the pink stage followed by a consistent and statistically significant increase to the overripe stage (Table 2). (3.) Tomato fruits picked at pink stage and ripened in the storage showed the same consistent trend of increase in pH during ripening to the overripe stage (Table 2). (4.) Tomato fruits picked at firm ripe and ripened in the storage again increased in pH as they ripened to the overripe stages. Therefore, according to the results listed in Table 2 it was observed that there was a consistent trend of pH changes with maturation in all treatments of both field-ripened and storage-ripened tomatoes of the cultivar Floramerica. These observations indicated that pH of Floramerica tomatoes was less affected by climatic conditions than that of Jetstar tomatoes particularly for those field-ripened fruits. On the other hand, Floramerica fruits were lower in pH than Jetstar fruits at all stages of maturity.

Based on the findings of Hanna (24) and Orzolek and Angell (48) there was a difference in pH level between cultivars studied.

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of pH in Floramerica tomatoes have been made only on comparable maturities (Table 4). The pH of each individual stage of maturity from the vine was compared with the mean value of the same stage of maturity of all storage treatments. No significant differences were observed between the pH values of field-ripened and storage-ripened tomatoes. These observations are again in agreement with those of McCollum (43), Craft and Heinze (9), and Bisogni et al. (5). However, Lambeth et al. (32) and Lower and Thompson (35) reported that field-ripened tomatoes had higher pH values relative to chamber ripened fruits. One exception was observed that of the overripe stage at which the pH was significantly higher in the storage-ripened tomatoes than that of the field-ripened tomatoes. According to the observations of McCollum and Skok (45), it might be expected that some differences would be observed in pH between room-ripened and field-ripened fruits.

According to the pH data for both Jetstar and Floramerica cultivars the trend of pH changes with maturation of Floramerica has been very consistent compared to that of Jetstar particularly for field-ripened tomatoes. The variation in the pH of Jetstar tomatoes was attributed to harvest date and using the incipient color as indication for maturity instead of the physiological age.



Generally, a statistically significant decrease in pH, corresponding to the first appearance of yellow color (breaker) in the fruits was ultimately established, followed by a consistent slight increase during the subsequent ripening of Floramerica tomatoes, but no consistent trend could be shown for Jetstar tomatoes. Furthermore, the trend of pH changes of the storage-ripened tomatoes has not been exactly the same for both cultivars. It seems that the trend of pH changes for Floramerica fruits demonstrated a better repeatable consistency during ripening regardless of stage of maturity at harvest than occurred for Jetstar fruits.

## Part II: Ascorbic Acid

### A. Jetstar

a. Field ripened. Results of ascorbic acid determination of field-ripened tomatoes picked at different stages of maturity are given in Table 1. The data showed no consistent trend in the ascorbic acid content of field-ripened tomatoes during the five stages of maturity studied. However, tomatoes exhibited a tendency of slight but not statistically significant increase in the ascorbic acid content as they ripened from the mature green to the pink stage followed by a significant decrease to the firm ripe and a considerably significant increase to the overripe stage. These observations are in general agreement with those of Brown and Moser (6) and Hamner et al. (22) who reported a small but continuing increase in ascorbic acid content through the overmature stage. Our results also agree to an extent

with those of Matthews et al. (41) who found that fruit harvested at the red ripe stage were lower in ascorbic acid content than either those harvested at the green, breaker, or pink stages. Because no consistent trend in ascorbic acid changes was established, Maclinn et al. (37), Maclinn and Fellers (36) and Yamaguchi et al. (69) reported that the stage of maturity had no effect on the ascorbic acid concentration. While the general trend of our results agrees with the conclusions of Brown and Moser (6), Hamner et al. (22) and Matthews et al. (41), the amount of the difference in ascorbic acid contents was variable. These variations could possibly be caused by the varying environmental conditions of field ripening such as temperature, rainfall, and illumination as indicated by McCollum (42, 43), Hamner et al. (22) and Bisogni et al. (5).

b. Storage ripened. (1.) Tomato fruits picked at mature green and ripened in storage showed a significant decrease in ascorbic acid content as fruits ripened to the breaker stage during the first part of storage period. Scott and Kramer (51) and Craft and Heinze (9) found similar observations in their studies. This decrease was followed by inconsistent sequence of changes in the ascorbic acid contents of subsequent ripening (Table 1). Furthermore, there were no significant differences in ascorbic acid contents among all maturities. Since the storage conditions were constant during the whole period of storage, we would not expect them to account for the variation that occurred. The most likely factor accounting for this

variation was that all three replicates of each maturity did not ripen at the same time since some fruits ripened faster than others. Each replication was analyzed at the proper stage of maturity based on incipient color development.

(2.) Tomato fruits picked at breaker stage and ripened in storage again showed no consistent trend of ascorbic acid changes during ripening (Table 1). There was a slight increase to the pink stage followed by a slight decrease to the firm ripe and a highly significant increase to the overripe stage. This trend of increase in ascorbic acid is almost similar to the field-ripened fruits. Tomatoes demonstrated the same tendency of increase in ascorbic acid up to the overripe stage which had the highest mean ascorbic acid for the entire storage period and greatest retention during storage. These observations are in agreement with the report of Scott and Kramer (51). The factors accounting for the variations in ascorbic acid content could possibly be the same as those attributed to the variation in tomatoes picked at mature green stage (item 1).

(3.) Tomato fruits picked at the pink stage and ripened in the storage showed a slight but not significant decrease as they ripened to the overripe stage (Table 1). These results supported the observations of Kays (31), Scott and Kramer (51), and Pantos and Markakis (49).

(4.) Tomatoes picked at firm ripe stage and ripened in the storage increased significantly in ascorbic acid as they ripened to the overripe stage (Table 1). These results again agree with those of Brown and Moser (6) and Hamner et al. (22).

Accordingly, Jetstar fruits exhibited the highest ascorbic acid concentration at the overripe stage in both field ripened and storage ripened with one exception. Overripe fruits obtained from the storage ripened of mature green fruits in which the ascorbic acid concentration was the lowest. Based on the results (Table 1) it was observed that tomatoes harvested at the mature green stage and ripened in the storage at 20°C showed the lowest mean ascorbic acid value for the entire storage period. While tomatoes harvested at the breaker stage in particular and pink and firm ripe in general showed the highest mean ascorbic acid value for the entire storage period, and had the greatest retention during storage. Our results are in general agreement with the report of Scott and Kramer (51).

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of ascorbic acid concentrations in Jetstar tomatoes have been made only on comparable maturities (Table 3). The ascorbic acid concentration of each individual maturity from the vine was contrasted with the mean value of the same maturity of all storage treatments. The ascorbic acid content of field-ripened tomatoes was significantly greater than storage-ripened fruits with one exception. Fruits from the firm ripe stage were slightly lower in ascorbic acid than the storage-ripened fruits. Based on the results of Bisogni et al. (5), room ripened fruits could have equal amounts of ascorbic acid as of field ripened fruits. This variation could be possibly due to the varying environmental conditions of field ripening such as temperature, rainfall and illumination as

shown in the reports of McCollum (42, 43), Hamner et al. (22) and Bisogni et al. (5). However, it was noted that the ascorbic acid content of the storage ripened fruits was appreciably lower than that of vine-ripened tomatoes at the time of harvest (51). Therefore, our results are more consistent with those of Kays (31), Scott and Kramer (51), Pantos and Markakis (49) and Bisogni et al. (5). Craft and Heinze (9), however, found no pronounced change in the ascorbic acid content of mature green tomatoes stored at different temperatures for periods up to 14 days.

It has been shown that light had the greatest influence on the ascorbic acid content of tomato fruits (22, 42, 43, 56, 68). Besides light, an increased amount of an ascorbic acid precursor such as glucose (27) in the field ripened tomatoes could possibly cause the difference. McCollum and Skok (45), on the other hand, stated that phytosynthates were translocated from the leaves to the fruits until coloration occurred and that glucose applied to the leaves was translocated to the fruits until the turning stage.

## B. Floramerica

a. Field ripened. Results of ascorbic acid determinations of Floramerica field-ripened tomatoes picked at different stages of maturity are given in Table 2. Results showed a slight but not significant decrease from the mature green to the pink stage followed by a slight but not significant increase to the overripe stage. This general trend represents the tendency of

tomato fruits to show no actual change in the ascorbic acid content with ripening since no significant differences were observed among any stages of maturity. These observations agree with the works of Maclinn et al. (37) and Maclinn and Fellers (36). Again the varying environmental conditions could possibly have been responsible for the variations which occurred as discussed in the works of McCollum (42, 43), Hamner et al. (22) and Bisogni et al. (5).

b. Storage ripened. (1.) Tomatoes harvested at mature green and ripened in storage showed a significant decrease in ascorbic acid as the fruits reached the breaker stage during the first part of storage period followed by a slight but not significant increase during ripening through the firm ripe stage and significantly declined when they were overripe. This sequence of changes in ascorbic acid content is comparable to results of Scott and Kramer (51) and Craft and Heinze (9) who found an appreciable loss of ascorbic acid during the first part of storage period followed by an apparant increase associated with coloration of the fruits during the subsequent ripening. (2.) Tomatoes harvested at breaker stage and ripened in storage showed the same sequence of changes as in item 1. A decline in ascorbic acid content was observed as the fruits reached the pink stage during the first part of storage period followed by a significant increase up to the overripe stage. (3.) Tomatoes harvested at pink stage and ripened in storage showed a consistent slight but not significant increase in the ascorbic acid content up to the overripe stage. (4.) Tomatoes

picked firm ripe and ripened in storage showed no significant difference in ascorbic acid content as fruits reached the overripe stage.

According to the data in Table 2, Floramerica tomatoes exhibited the highest ascorbic acid concentration at the overripe stage in both field-ripened and storage ripened with one exception. Overripe tomatoes obtained from the storage of mature green fruits at which the ascorbic acid concentration was the lowest. Generally, tomatoes harvested at mature green rather than breaker, pink or firm ripe and ripened in the storage showed the highest loss of ascorbic acid during the entire period of storage and had the least retention during storage. These results are in general agreement with those of Scott and Kramer (51) and Pantos and Markakis (49).

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of ascorbic acid concentrations in Floramerica tomatoes have been made only on comparable maturities (Table 4). The ascorbic acid concentration of each individual maturity from the vine was contrasted with the mean value of the same maturity of all storage treatments. For all maturities, the ascorbic acid content of field ripened tomatoes was greater compared to that of storage-ripened fruits. However, the difference was not statistically significant for either the pink or the firm ripe stages. The general trend of our results agrees with those of Kays (31), Scott and Kramer (51), Pantos and Markakis (49), and Bisognia et al. (5). The reasons that could possibly account for the difference have

been mentioned earlier (in item c-Jetstar).

According to the results of ascorbic acid for both Jetstar and Floramerica cultivars no consistent trend of changes in the ascorbic acid concentrations was established during the field ripening of either cultivar. However, Jetstar tomatoes showed a tendency of a slight increase in ascorbic acid during ripening up to the overripe stage. While no actual change in the ascorbic acid concentration were shown during the field ripening of Floramerica tomatoes, the varying environmental conditions such as temperature, rainfall and illumination have been the most important factors responsible for the variation in ascorbic acid content of field-ripened tomatoes. On the other hand there was an appreciable loss in ascorbic acid content during the storage ripening of both cultivars particularly when the fruits were harvested at mature green stage. However, tomatoes picked at either breaker, pink or firm ripe stages showed no significant loss in ascorbic acid during the entire storage period.

### Part III: $\beta$ -Carotene

#### A. Jetstar

a. Field ripened. Results of the  $\beta$ -carotene analyses of Jetstar tomato fruits harvested at mature green, breaker, pink, firm ripe and overripe stages are given in Table 1. A consistent trend of changes in the  $\beta$ -carotene content has been shown during the ripening of tomatoes on the plant.  $\beta$ -carotene increased significantly in concentration through all stages of



maturity until the firm ripe stage, then decreased in the overripe stage. Our results are in agreement with those of other workers (17, 41, 46, 62). Yamaguchi et al. (69), however, stated that carotene content did not change significantly with ripeness or harvest date.

b. Storage ripened. Results of the  $\beta$ -carotene analyses of Jetstar tomato fruit harvested at mature green, breaker, pink and firm ripe stages and ripened at 20°C in storage to the subsequent stages of maturity are given in Table 1.

1. Tomatoes picked at mature green have generally shown a consistent trend of changes in  $\beta$ -carotene concentration during ripening.  $\beta$ -carotene significantly increased in concentration from the mature green through the subsequent stages of maturity up to the overripe stage. The general trend of our results agrees with that of other authors (17, 41, 46, 62).

2. Tomatoes picked at the breaker stage showed a highly consistent trend of changes in  $\beta$ -carotene concentration during ripening. It was observed that  $\beta$ -carotene concentration significantly increased through all stages of maturity up to the overripe stage. These observations again agree with those of other investigators (17, 41, 46, 62).

3. Tomatoes picked at the pink stage showed no significant difference in  $\beta$ -carotene concentration as they ripened from the pink to the overripe stage, although there was a very slight increase during ripening.

4. Tomatoes picked at firm ripe exhibited the same concentration of  $\beta$ -carotene at both the firm ripe and the overripe stages.

Based on our results just explained, the trend of changes in  $\beta$ -carotene concentration was very consistent for both field ripened and storage-ripened tomatoes of the Jetstar cultivar.  $\beta$ -carotene increased through all stages of maturity and exhibited its highest value at the firm ripe stage for the field-ripened tomatoes and at the overripe stage for the storage-ripened tomatoes. However, no direct evidence is available to support our result that  $\beta$ -carotene of ripened tomatoes may increase in concentration up to the overripe stage. According to Meredith and Purcell (46), it has been suggested that changes in the concentration of  $\beta$ -carotene may be explained by assuming that the rate of synthesis is constant and independent of the precursor concentration while the rate of destruction increases with maturity. Conversely, the rate of ring closure may decrease in the late stages of maturity while the rate of destruction is constant.

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of  $\beta$ -carotene contents in tomatoes have been made only on comparable maturities (Table 3). The  $\beta$ -carotene content of each individual stage of maturity from the vine was contrasted with the mean value of the same stage of maturity of all storage treatments. Generally no statistically significant differences were reported between the  $\beta$ -carotene concentrations of field-ripened tomatoes and storage-ripened tomatoes at most stages of maturity with one exception. Overripe tomatoes from storage had significantly higher  $\beta$ -carotene content than that from field. The general trend of our results

agrees with the observations of other workers (16, 41, 47). These workers found that light exposure had no significant effect on the  $\beta$ -carotene content of tomatoes and no significant difference in  $\beta$ -carotene was reported between tomatoes ripened on the plant and those ripened off the plant. However, Denisen (15), McCollum (44), and Watada et al. (62), due to the effect of light, reported that tomato fruits ripened on the plant had significantly higher  $\beta$ -carotene concentrations than those ripened off the vine.

#### B. Floramerica

a. Field ripened. Results of the  $\beta$ -carotene analyses of Floramerica tomato fruits harvested at mature green, breaker, pink, firm ripe and overripe stages are given in Table 2. A consistent sequence of changes in  $\beta$ -carotene content has been shown with ripening of Floramerica tomatoes on the vine.  $\beta$ -carotene showed a definite increase in concentration with maturation up to the overripe stage. The sequence of our results is in general agreement with other reports (17, 41, 46, 62). Yamaguchi et al. (69), however, reported that carotene content did not change significantly with ripeness or harvest date.

b. Storage ripened. Results of the  $\beta$ -carotene analyses of Floramerica tomato fruits harvested at mature green, breaker, pink and firm stages and ripened at 20°C in storage to the subsequent stages of maturity are listed in Table 2.

1. Tomatoes picked at mature green stage have shown a

significant increase in  $\beta$ -carotene concentration during ripening until the firm ripe stage followed by a very slight decrease in the overripe stage. These observations are again in agreement with the works of other investigators (17, 41, 46, 62).

2. Tomatoes harvested at the breaker stage increased significantly in  $\beta$ -carotene concentration during the subsequent ripening up to the overripe stage. Similar results were reported by Ellis and Hamner (17), Meredith and Purcell (46), Matthews et al. (41), and Watada et al. (62).

3. Tomatoes harvested at the pink stage again increased significantly in  $\beta$ -carotene concentration during the subsequent ripening up to the overripe stage.

4. Tomatoes harvested at firm ripe showed no significant difference in the  $\beta$ -carotene concentration as they ripened to the overripe stage.

Floramerica tomatoes showed a consistent sequence of changes in  $\beta$ -carotene content for all field-ripened and storage-ripened treatments. Tomato fruits showed a definite increase in  $\beta$ -carotene concentration through all stages of maturity and exhibited their highest value at the overripe stage for the field-ripened tomatoes as well as the storage-ripened tomatoes except for those tomatoes picked at the mature green which had their highest value at the firm ripe stage.

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of  $\beta$ -carotene contents in tomatoes have been made only on comparable maturities (Table 4). The

$\beta$ -carotene content of each individual stage of maturity from the vine was contrasted with the mean value of the same stage of maturity of all storage treatments. No significant differences were observed between the  $\beta$ -carotene concentrations of field-ripened tomatoes and storage-ripened tomatoes except for that of the pink stage of harvest of the storage-ripened fruits which showed significantly higher  $\beta$ -carotene concentration than that of the field-ripened. The general sequence of our results agrees with that of other investigators (16, 41, 47). These investigators found that light exposure had no effect on the  $\beta$ -carotene content of field-ripened tomatoes and no significant difference was observed between tomatoes ripened on the plant and those ripened off the plant. However, Denisen (15), McCollum (44) and Watada et al. (62), due to the effect of light, observed that tomatoes ripened on the plant had significantly higher  $\beta$ -carotene content than those ripened off the plant.

The  $\beta$ -carotene data for both cultivars, Jetstar and Floramerica (Tables 1, 2, 3, and 4), showed significant increase in the concentrations of  $\beta$ -carotene through all stages of ripeness and exhibited their highest values at the overripe stage. However, field-ripened tomatoes of the Jetstar cultivar had their highest value at the firm ripe stage. Jetstar fruits contained higher  $\beta$ -carotene content than Floramerica fruits as we compared the highest value of 0.46 mg/100 gm fresh weight for Jetstar with the highest value of 0.32 mg/100 gm fresh weight for Floramerica.

No significant differences in the  $\beta$ -carotene content were reported between the field-ripened tomatoes and storage-ripened tomatoes for either cultivar. Tomatoes picked at either mature green, breaker, pink or firm ripe stages showed a similar  $\beta$ -carotene concentrations and a great retention for the entire storage period. It was obvious that although the differences were not significant in most stages of maturity,  $\beta$ -carotene concentration of storage-ripened fruits was slightly higher than that of field-ripened fruits. This could possibly be due to higher field than storage temperatures in which it might be expected to depress the synthesis of both lycopene and  $\beta$ -carotene as long as the two pigments are derived by a common synthetic pathway and have the same precursor. In this regard, our observations are in agreement with the results of Tomes et al. (58), who reported that in tomato cultivars possessing the dominant gene B, on both storage and field-ripened fruits, synthesis of both lycopene and  $\beta$ -carotene was inhibited at temperatures above  $31^{\circ}\text{C}$ . This indicates a common synthetic sequence and suggests that in B-strains lycopene might be the precursor for  $\beta$ -carotene or, if not, that lycopene and  $\beta$ -carotene are obtained from the same precursor. In addition, the temperature of the ripening room was consistent at  $20^{\circ}\text{C}$  during the entire storage period. This temperature has been found over the years to be the most favorable for ripening tomatoes artificially and developing their desired pigments. Therefore, we would not expect this temperature to depress the synthesis of lycopene and  $\beta$ -carotene in storage

especially since light is not necessary for the synthesis of these carotenoids.

#### Part IV: Total Sugar

##### A. Jetstar

a. Field ripened. Results of the total sugar analyses of field-ripened Jetstar tomatoes harvested at mature green, breaker, pink, firm ripe and overripe stages are listed in Table 1. The total sugar concentration significantly increased as tomato fruits ripened from the mature green to the overripe stage at which the value was the highest. However, a pronounced decline in total sugar was noted as fruits ripened from the mature green to the breaker stage at which the value was the lowest. The increase was statistically significant between the pink, firm ripe and overripe stages. The general pattern of our results is in agreement with that of other investigators (13, 32, 66, 69). These investigators have previously reported that the content of total sugars in the expressed juices increased significantly from the mature green to the red-ripe stage, although Winsor et al. (66) reported some instances of decrease once the fruits had begun to color.

b. Storage ripened. Results of the total sugar analyses of tomatoes harvested at mature green, breaker, pink and firm ripe stages and ripened at 20°C in storage to the subsequent stages of maturity are given in Table 1.

1. Tomatoes picked at mature green showed a statistically significant decrease in the content of total sugar as fruits

ripened from the mature green to the breaker stage. With further ripening, tomatoes exhibited almost a constant total sugar value during the pink and firm ripe stages followed by a highly significant decline when fruits reached the overripe stage. This pattern of changes in the total sugar concentration during the storage ripening of mature green tomatoes is in general agreement with that of Craft and Heinze (9), who reported that reducing sugars increased slightly in the mature green 'Rutgers' tomatoes stored at different temperatures for the shorter periods but decreased with longer storage periods.

2. Tomatoes picked at the breaker stage increased markedly in the total sugar content as they reached the pink and the firm ripe stages then decreased with the subsequent ripening to the overripe stage. This sequence of changes in storage is again in agreement with the results of Craft and Heinze (9).

3. Tomatoes picked at the pink stage showed a statistically significant decline in the total sugar content as fruits ripened subsequently to the firm ripe and overripe stages.

4. Tomatoes picked at the firm ripe stage decreased in total sugar contents as fruits ripened to the overripe stage, even though the decrease was not statistically significant.

The total sugar analyses listed in Table 1 indicates that the total sugar content increased progressively during ripening from the mature green stage to the overripe stage in field-ripened fruits, although an instance of a decrease once the fruits reached the breaker stage was reported. The changes in the total sugar concentration during ripening appear to be more



influenced by the fructose than by the glucose content (13). It has been shown that glucose concentrations in immature, preclimateric fruit were approximately twice those of fructose. By the time the fruit became mature green, however, glucose and fructose were present in almost equal amounts and there was no further significant change with subsequent ripening. In addition, these changes may be explained by the presence of invertase which has been demonstrated in tomato fruits and which increases in activity during ripening of the fruits (13). However, small quantities of sugars appear to be formed within the fruit from the metabolism of the major fruit acids (13) and there is some evidence that photosynthesis occurs in tomato fruits, at least during the stages of ripening before the disappearance of chlorophyll. Furthermore, catabolism of hexoses occurs during ripening, particularly via the oxidative monophosphate pathway (13).

Regarding the storage ripening, tomatoes harvested at the mature green stage showed the least retention of total sugar for the entire storage period. While tomatoes harvested at the breaker stage had the greatest retention of total sugar during storage in contrast to those harvested at either mature green, pink or firm ripe. Tomatoes of most storage treatments exhibited their highest value of total sugar at the firm ripe stage and their lowest value at the overripe stage.

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of total sugar concentrations in Jetstar tomatoes have been made only on comparable maturities

(Table 3). The total sugar content of each individual stage of maturity from the vine was contrasted with the mean value of the same stage of maturity of all storage treatments. The total sugar concentration of field-ripened fruits was significantly higher in contrast to that of storage-ripened fruits at most stages of maturity with one exception, that of the breaker stage which was markedly lower than that of the storage-ripened fruits. The greatest difference in the total sugar concentration was observed at the overripe stage. The general pattern of our results is in agreement with that of other workers (9, 43). Due to the effect of sunlight exposure, McCollum (43) found a striking increase in reducing sugars for the unshaded tomatoes over the shaded fruits.

## B. Floramerica

a. Field ripened. Results of the total sugars analyses of field-ripened Floramerica tomatoes picked at various stages of maturity are given in Table 2. Tomatoes demonstrated a constant level but not consistent of total sugar concentration as they ripened from the mature green stage to the pink stage. With further ripening, total sugar content significantly increased as fruits reached the firm ripe stage with a tendency to decrease very slightly with subsequent ripening to the overripe stage. The sequence of our results is in general agreement with the reports of other authors (13, 32, 66, 69).

b. Storage ripened. Data of the total sugar analyses of Floramerica tomatoes harvested at mature green, breaker, pink

and firm ripe and ripened at 20°C in storage to the subsequent stages of maturity are given in Table 2.

1. Tomatoes picked at mature green showed a slight but not significant increase in total sugar concentration as they ripened to the breaker stage then significantly increased to the pink stage at which the highest concentration of total sugar was observed. With further ripening, total sugars tended to decrease markedly to the firm ripe and significantly to the overripe stage at which the lowest concentration of total sugar was reported. Our results are consistent with those of Craft and Heinze (9).

2. Tomatoes picked at the breaker stage showed a highly significant increase in total sugar concentration as they ripened to the pink stage at which the highest level of total sugar was found followed by significant decreases during ripening to the firm ripe and the overripe stages, respectively. Tomatoes exhibited their lowest total sugar value at the overripe stage. The trend of changes is again in agreement with that of Craft and Heinze (9).

3. Tomatoes picked at the pink stage showed a significant increase in total sugars as they reached the firm ripe stage with a tendency to decrease with subsequent ripening to the overripe stage. These results are comparable to those of Craft and Heinze (9).

4. Tomatoes picked at firm ripe stage showed no change in the total sugar concentration as they ripened to the overripe stage.

Total sugar content increased with ripening for Floramerica fruits. The explanation of the changes in sugars was mentioned earlier in the discussion of Jetstar results.

c. Comparison between field-ripened and storage-ripened tomatoes. All comparisons of total sugar concentrations in Floramerica tomatoes have been made only on comparable maturities (Table 4). The total sugar content of each individual stage of maturity from the vine was contrasted with the mean value of the same stage of maturity of all storage treatments. Generally, no significant difference was observed in the total sugar concentration between field-ripened tomatoes and storage-ripened tomatoes. However, field overripened tomatoes had significantly higher sugar content than storage-ripened fruits. On the other hand, the concentration of total sugar at the pink stage was significantly lower in the field-ripened fruits than in storage-ripened fruits.

Based on the data of total sugar concentration (Tables 1, 2, 3, and 4) of both Jetstar and Floramerica cultivars, the total sugar content increased progressively during ripening from the mature green stage to firm ripe stage, although instances of a decrease once the fruits have begun to color have been observed for both cultivars particularly for those field-ripened tomatoes. Field-ripened tomatoes exhibited their highest values of total sugar at the overripe stage for Jetstar fruits and at the firm ripe stage for the Floramerica fruits. Storage-ripened tomatoes, on the other hand, exhibited their highest values at the firm ripe stage for Jetstar and at the

pink stage for Floramerica. The total sugar concentration of Jetstar tomatoes was appreciably affected when fruits ripened in storage compared to Floramerica tomatoes. Field-ripened Jetstar tomatoes contained more total sugar than Floramerica fruits. On the other hand, storage-ripened Floramerica tomatoes contained more total sugar than Jetstar fruits. Therefore, Floramerica tomatoes exhibited higher retention of total sugar during ripening in storage than Jetstar tomatoes. However, both cultivars retained the highest total sugar values when tomatoes were picked at the breaker stage and ripened to the subsequent stages of maturity in storage. Therefore, the breaker stage seems to be the most favorable stage at which tomatoes have to be picked and ripened artificially in the storage from the standpoint of keeping quality for fresh human consumption.

## SUMMARY AND CONCLUSION

This study was designed to determine the effects of stage of maturity at harvest, post-harvest storage and cultivar upon some quality determinations; pH, ascorbic acid,  $\beta$ -carotene and total sugar; of two tomato cultivars, Jetstar Hybrid and Floramerica Hybrid.

### Part I: pH

It was concluded that the trend of pH changes with maturation of Floramerica tomatoes was very consistent compared to Jetstar tomatoes for field-ripened and storage-ripened fruits.

For both cultivars, generally a statistically significant decrease in pH, corresponding to the first appearance of yellow color (breaker) in the fruits was established, followed by a slight increase during the subsequent ripening to the overripe stage.

Generally, no significant differences were observed between the pH values of field-ripened and storage-ripened tomatoes for either Jetstar or Floramerica cultivars.

The pH value of the Floramerica fruits was lower than that of Jetstar fruits at all stages of maturity and for both field-ripened and storage-ripened fruits.

### Part II: Ascorbic Acid

No consistent trend in ascorbic acid concentrations was

established during the field ripening of either cultivar and the storage ripening of Jetstar fruits.

Jetstar tomatoes showed a tendency of an increase in ascorbic acid concentration during ripening both on and off the plant, while no actual changes in the ascorbic acid concentration were observed during ripening of Floramerica tomatoes.

Generally, the ascorbic acid concentration of field-ripened tomatoes was significantly higher than storage-ripened fruits for both cultivars. Tomato fruits of both cultivars harvested at the mature green stage and ripened in storage exhibited the least retention of ascorbic acid during the storage period. No significant losses in the ascorbic acid concentrations, however, were found in tomato fruits picked at either the breaker, pink, or firm ripe stages during subsequent ripening in storage.

The ascorbic acid concentration of Jetstar tomatoes was slightly higher than Floramerica for most stages of maturity.

### Part III: $\beta$ -Carotene

The sequence of changes in  $\beta$ -carotene concentrations was consistent for both field-ripened and storage ripened tomato fruits of the Jetstar and Floramerica cultivars.

Jetstar and Floramerica fruits showed significant increase in the concentration of  $\beta$ -carotene through all stages of ripeness and exhibited their highest values at the overripe stage with one exception. Field-ripened Jetstar fruits had their highest value at the firm ripe stage.

No significant differences in the  $\beta$ -carotene content were

observed between the field-ripened tomatoes and storage ripened tomatoes for either cultivar. Tomato fruits picked at mature green, breaker, pink or firm ripe stages demonstrated a great retention in  $\beta$ -carotene concentration for the entire storage period.

Jetstar tomatoes contained higher  $\beta$ -carotene content than the Floramerica tomatoes.

#### Part IV: Total Sugar

Based on the results of both Jetstar and Floramerica cultivars, it was generally concluded that the total sugar content increased subsequently during ripening from the mature green stage to the firm ripe stage, although an instance of a decrease once the fruits reached the breaker stage was reported. This observation was more pronounced for the Jetstar cultivar than for Floramerica fruits.

The total sugar concentration of field-ripened Jetstar tomatoes was significantly higher than in the storage-ripened fruits. However, this observation was not true for the Floramerica cultivar. Tomato fruits of both cultivars harvested at the breaker stage exhibited the highest retention of total sugar when ripened in storage compared to other stages of maturity.

These results indicate that Jetstar tomato fruits generally contained a higher total sugar content than Floramerica fruits.



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## APPENDIX

Table 1. Mean effect of ripening treatment and stage of maturity on pH, ascorbic acid,  $\beta$ -carotene and total sugar of tomato fruits of Jetstar Hybrid.

Treatment	pH	Ascorbic Acid mg/100 g fresh weight	$\beta$ -Carotene mg/100 g fresh weight	Total Sugar % fresh weight
1 - mature green from vine <sup>a</sup>	4.53	22.57	0.16	3.34
2 - Breaker from vine <sup>a</sup>	4.33	22.20	0.18	2.65
3 - Pink from vine <sup>a</sup>	4.44	23.40	0.35	3.35
4 - Firm ripe from vine <sup>a</sup>	4.30	20.57	0.43	3.54
5 - Overripe from vine <sup>a</sup>	4.35	27.77	0.31	3.98
6 - Breaker from mature green (storage) <sup>b</sup>	4.35	19.23	0.26	3.04
7 - Pink from mature green (storage) <sup>b</sup>	4.25	18.73	0.39	3.07
8 - Firm ripe from mature green (storage) <sup>b</sup>	4.26	19.80	0.34	3.06
9 - Overripe from mature green (storage) <sup>b</sup>	4.34	18.37	0.45	2.46
10- Pink from breaker (storage) <sup>b</sup>	4.37	23.07	0.32	3.16
11- Firm ripe from breaker (storage) <sup>b</sup>	4.27	21.30	0.35	3.20
12- Overripe from breaker (storage) <sup>b</sup>	4.30	25.47	0.46	2.98
13- Firm ripe from pink (storage) <sup>b</sup>	4.38	22.13	0.36	3.00
14- Overripe from pink (storage) <sup>b</sup>	4.32	22.10	0.38	2.80
15- Overripe from ripe (storage) <sup>b</sup>	4.32	23.83	0.43	3.28
ISD (.05)	0.07	2.61	0.10	0.28

<sup>a</sup>Field ripening treatments.

<sup>b</sup>Storage ripening treatments.

Table 2. Mean effect of ripening treatment and stage of maturity on pH, ascorbic acid,  $\beta$ -carotene and total sugar of tomato fruits of Floramerica Hybrid.

Treatment	pH	Ascorbic Acid mg/100 g fresh weight	$\beta$ -Carotene mg/100 g fresh weight	Total Sugar % fresh weight
1 - Mature green from vine <sup>a</sup>	4.52	22.50	0.05	2.98
2 - Breaker from vine <sup>a</sup>	4.14	22.33	0.17	3.09
3 - Pink from vine <sup>a</sup>	4.15	20.57	0.14	2.94
4 - Firm ripe from vine <sup>a</sup>	4.23	21.37	0.26	3.25
5 - Over ripe from vine <sup>a</sup>	4.21	23.27	0.32	3.20
6 - Breaker from mature green (storage) <sup>b</sup>	4.19	17.27	0.22	3.08
7 - Pink from mature green (storage) <sup>b</sup>	4.24	19.37	0.25	3.37
8 - Firm ripe from mature green (storage) <sup>b</sup>	4.22	19.43	0.26	3.20
9 - Over ripe from mature green (storage) <sup>b</sup>	4.34	15.80	0.24	2.74
10- Pink from breaker (storage) <sup>b</sup>	4.14	18.17	0.22	3.43
11- Firm ripe from breaker (storage) <sup>b</sup>	4.19	21.67	0.29	2.99
12- Over ripe from breaker (storage) <sup>b</sup>	4.24	22.10	0.31	2.73
13- Firm ripe from pink (storage) <sup>b</sup>	4.25	21.20	0.25	3.30
14- Over ripe from pink (storage) <sup>b</sup>	4.32	22.80	0.28	3.25
15- Over ripe from firm ripe (storage) <sup>b</sup>	4.30	21.93	0.27	3.24
LSD (.05)	0.08	2.70	0.07	0.23

<sup>a</sup>Field ripening treatments.

<sup>b</sup>Storage ripening treatments.

Table 3. Comparison in quality determinations between storage-ripened and field-ripened tomato fruits of Jetstar Hybrid.

Treatment	pH	Ascorbic Acid mg/100 g fresh weight		β-Carotene mg/100 g fresh weight		Total Sugars % fresh weight		
		Mean value from all storage treatments	Mean value from vine	Mean value from all storage treatments	Mean value from vine	Mean value from all storage treatments	Mean value from vine	Mean value from all storage treatments
Breaker	4.33	4.35	22.20	19.23	0.18	0.26	2.65	3.04
Pink	4.44	4.31	23.40	20.90	0.35	0.35	3.35	3.12
Firm Ripe	4.30	4.30	20.57	21.08	0.43	0.35	3.54	3.09
Over Ripe	4.35	4.32	27.77	22.44	0.31	0.43	3.98	2.88
LSD (.05)	0.07		2.61			0.10		0.28

Table 4. Comparison in quality determinations between storage-ripened and field-ripened tomato fruits of Floramerica Hybrid.

Treatment	pH		Ascorbic Acid mg/100 g fresh weight		β-Carotene mg/100 g fresh weight		Total Sugars % fresh weight	
	Mean value from vine	Mean value from all storage treatments	Mean value from vine	Mean value from all storage treatments	Mean value from vine	Mean value from all storage treatments	Mean value from vine	Mean value from all storage treatments
Breaker	4.14	4.19	22.33	17.27	0.17	0.22	3.09	3.08
Pink	4.15	4.19	20.57	18.77	0.14	0.23	2.94	3.40
Firm Ripe	4.23	4.22	21.37	20.77	0.26	0.27	3.25	3.16
Over Ripe	4.21	4.30	23.27	20.66	0.32	0.27	3.20	2.99
LSD (.05)		0.08		2.70		0.07		0.23

## VITA

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EFFECT OF STAGE OF MATURITY AT HARVEST, POST-HARVEST  
STORAGE AND CULTIVAR ON SOME QUALITY  
DETERMINATIONS OF TOMATO FRUITS

by

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Iraq, 1971

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AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the  
requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

DEPARTMENT OF HORTICULTURE

KANSAS STATE UNIVERSITY  
Manhattan, Kansas

1978

Two fresh market or home garden tomato cultivars, Jetstar Hybrid and Floramerica Hybrid, were analyzed for four quality determinations: pH, ascorbic acid,  $\beta$ -carotene and total sugar; at different maturities from the mature green to the overripe stage during the growing season of 1977. Effects of stage of maturity, post harvest storage and cultivar upon the quality determinations were studied. Fruits were also harvested at the mature green, breaker, pink and firm ripe stages and ripened to subsequent stages of maturity up to the overripe stage at 20°C for the storage ripened treatments. Comparisons in quality determinations between storage ripened and field ripened tomato fruits were also studied.

The trend of pH changes with maturation of Floramerica tomatoes was more consistent than for Jetstar tomatoes. The pH significantly decreased in the breaker stage then slightly increased through subsequent ripening to the overripe stage. No significant differences were reported between the pH values of field-ripened and storage-ripened tomatoes for either cultivar. The pH of Floramerica fruits was lower than that of Jetstar fruits.

No consistent trend in ascorbic acid concentrations was established for field ripened or storage-ripened treatments. Jetstar fruits showed a slight increase in ascorbic acid content during ripening both on and off the plant. No actual changes in ascorbic acid content occurred during ripening of Floramerica fruits. Field-ripened fruits had significantly higher ascorbic acid content compared to storage-ripened fruits. Mature green fruits exhibited the least retention of ascorbic acid during



storage. Breaker, pink and firm ripe fruits showed no significant losses in ascorbic acid during storage. Jetstar tomatoes had a slightly higher ascorbic acid content than Floramerica tomatoes.

A consistent sequence of changes in  $\beta$ -carotene concentration was established during ripening. Fruits of both cultivars showed a significant increase in  $\beta$ -carotene concentration with ripening and had their highest value at the overripe stage. No significant differences in the  $\beta$ -carotene content were reported between field-ripened and storage-ripened fruits. Jetstar tomatoes contained higher  $\beta$ -carotene content than Floramerica tomatoes.

Generally, total sugar content increased progressively during ripening up to the firm ripe stage, although an instance of decrease once the fruits reached the breaker stage was reported. Field-ripened Jetstar fruits had significantly higher total sugar content than storage-ripened fruits. However, no significant difference was observed between field-ripened Floramerica fruits and storage-ripened fruits. Breaker fruits exhibited the highest retention of total sugar during storage compared to other stages of maturity.

Field-ripened tomato fruits were judged as better in overall quality determinations than storage-ripened fruits.

Field firm ripened or overripened fruits were judged as superior to storage-overripened fruits as inferior in overall quality determinations except for  $\beta$ -carotene content which was similar.

Jetstar tomatoes were judged to be better in overall quality determinations than Floramerica tomatoes.