YIELD AND QUALITY EVALUATION OF FRESH AND THERMALLY PROCESSED DESERT GROWN TOMATOES

by

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ABSTRACT

Two processing tomato cultivars, 'VF198' and 'VF145-21' and two fresh-market cultivars, 'Roza' and 'Pakmor' were evaluated for yield, fruit color, pH, total acidity, soluble solids, soluble solids to acid ratio and ascorbic acid content of both fresh and heat processed juice. The object of the study was to investigate the suitability of these cultivars for different purposes under Arizona conditions.

Differences noted in the above characteristics studied were mainly attributed to cultivars and the rest to thermal processing.

After thermal processing total acidity increased, pH, soluble solids, soluble solids to acid ratio and ascorbic acid dropped. These changes were within acceptable ranges compared to similar investigations.

The two processing cultivars, 'VF198' and 'VF145-21' would be acceptable for processing in Arizona. 'Roza' would be acceptable for both fresh-market and processing, but 'Pakmor' would not be acceptable for either outlet.

CHAPTER 1

INTRODUCTION

Tomatoes (Lycopersicon esculentum Mill) are among the most important vegetables produced, ranking second to potatoes in dollar value and are the leading processed vegetable in the United States (Gould, 1974).

Yield per acre of tomatoes is variable depending upon many factors which include: cultivar, environmental conditions, soil types, and cultivation and handling practices.

Tomato fruit color and composition, particularly soluble solids, acids and vitamin C are the most important quality factors for evaluation of tomatoes and tomato products.

The major portion of the soluble solids in tomatoes is reducing sugars, which are mainly glucose and fructose (Goose and Binstead, 1964). Acid in tomatoes is almost entirely citric acid. Acids and sugars are important components of flavor in tomato fruits and tomato products. In addition, acids and pH play an important role in the keeping quality of processed tomato products by inhibiting germination of spores of thermophilic organisms (Lower and Thompson, 1966). There are differences in acid content and pH values of the different tomato cultivars. These differences are

of importance in canning technology as they determine the optimum temperature and time for sterilization.

Variation in acids and soluble solids content in tomatoes and tomato products is related to many factors including cultivar, environmental and soil conditions, cultivation practices as fertilization, position on the plant, and season of development and harvest date of the fruit, processing and storage effects. Crean (1966) indicated that sugars decompose on heating in presence of acids, as in the sterilization of canned vegetables, and this is responsible for increase in total acid and drop in pH in the final processed product.

Tomatoes, tomato juice and other tomato products make a significant contribution to human nutrition because of their vitamin C content, which is in the reduced ascorbic acid form. Vitamin C content of tomatoes and their products is variable depending upon different factors which include heredity, soil and plant nutrition, cultivation and handling practices, maturity, processing and storage effects (Gould, 1974).

During heat processing of tomatoes part of the ascorbic acid is destroyed, being oxidized to dehydroascorbic acid. Retention of high levels of ascorbic acid during processing is important, and the amount retained is variable depending upon the processing method used. Temperature and

length of storage are also important factors in vitamin C retention.

The purpose of this study is to examine yield, and evaluate some of the quality characteristics of fresh and thermally processed samples of 4 tomato cultivars grown under desert conditions in Arizona at the University Agricultural Experiment Station in Mesa.

CHAPTER 2

LITERATURE REVIEW

Tomatoes are consumed in enormous quantities as fresh and canned product. A large quantity is also used in the manufacture of ketchups, chile sauce, and soups. The average American consumes over 23 pounds of processed tomatoes per year compared with a total of 54 pounds of all processed vegetables (Gould, 1974). Tomatoes are produced over a larger part of the United States. At present California is the leading state in tomato production, Ohio is the leader in the Midwest, and New Jersey in the East. During the past quarter of a century the average yield per acre ranged from 7 to 19 tons in the United States (Gould, 1974). Variation in yield per acre is related to many factors including: cultivar, environmental and soil conditions, cultivation and handling practices, and harvesting dates and methods.

Tomato is a warm-season plant reasonably resistant to heat and drought, and grows under a wide range of climatic and soil conditions. Tomato plant is not sensitive to day length and sets fruit in day lengths varying from 7-19 hours. It requires 3 to 4 months from time of seeding to produce the first ripe fruit. Tomato plant thrives best

when the weather is clear and rather dry, and the temperatures are moderate, 18.3 to 29.4°C (65 to 85°F). Plants are usually frozen at temperatures below 0°C (32°F) and the fruits do not increase in size at temperatures above 35°C (95°F). Hot drying winds cause flowers to drop (Anon, 1969).

Tomatoes are grown on many kinds of soil from sands to heavy clays. Generally a loamy soil well supplied with lime, organic matter and fertilizer is nearly ideal (Wittmeyer, Janson, and Goleman, 1958).

The quality of tomatoes and tomato products depends a great deal on fruit color and composition and on other minor factors such as fruit size which assists in sorting and grading.

Color is one of the most important quality factors associated with evaluation of food products. The consumer notices color first, this observation gives ideas about the other quality factors. In the case of tomatoes and tomato products the degree of color quality represents almost the whole measure of total quality. Therefore, assurance of high color ratings is important.

Color in tomato fruits is a result of presence of carotenes and carotenol. The carotenoid pigments, deriving their names from carotene, are polyene compounds of a yellow to red color. The major pigments in the tomato fruit are: alpha-carotene, beta-carotene, gamma-carotene, delta-carotene, lycopene and 22 xanthophylls (carotenol). The most abundant

carotenoid of tomato fruit is lycopene comprising about 83% of those pigments present (Gould, 1974).

McCollum (1955) investigating distribution of carotenes and carotenoids in tomato fruits, reported that the outer pericarp was highest in total carotenoids and the locular contents highest in carotene. These two regions of the tomato fruit resulted, respectively, in the best and poorest color.

The green color in the unripe tomato fruits is due to chlorophyll pigment. Various ways are used for objective color measurements of the tomato fruits, but Agtron Spectrophotometers developed by Magnuson Engineers and Hunter Colorimeters developed by Hunter Associates Laboratory, are the preferable instruments.

Tomato fruit color is affected by various factors which include cultivar, climatic conditions such as day temperature, cultivation practices, maturity and harvest dates. Luh, Ukai and Chung (1973) while investigating effects of day temperature on external tomato fruit color using Agtron E readings for color measurement, reported that the well colored tomatoes had readings of 48 or lower, fairly well colored tomatoes had readings ranging from 49 to 67 and those having readings above 68 were classified as "below color". They also reported that tomatoes of lower readings, i.e., more attractive tomato color, were obtained at day

temperature of 30°C (86°F) or lower. Poor color was observed in the fruits grown at 35°C (95°F) day temperature.

While investigating the effect of ripeness and harvest dates on tomato fruit color Yamaguchi et al. (1960) reported that the pink maturity of tomatoes was below color grade as the Agtron E readings ranged from 71.9 to 95.9, and the canning ripe maturity was better colored with readings ranging from 29.4 to 50.2. There were marked variations related to maturity degree and harvest dates (Yamaguchi et al., 1960).

The fruit size is variable between the different tomato cultivars and within some of the same cultivars. Fruit size uniformity is preferrable as it assists in sorting for grading. If there is less size uniformity various equipment must be used for sorting as one of the unit operations in tomato processing. According to federal grade standards for fresh tomatoes fruit sizes are designated as: extra small, small, medium, large, extra large and maximum large (Peterson, 1976).

Tomato fruit weight is also variable depending upon many factors among which are: cultivar, climatic conditions, cultivation practices and harvest dates. Lower and Thompson (1966) reported that there was a significant variation in fruit weight due to cultivar and sampling dates. They reported that a consistent decrease in fruit weight occurred

in all varieties under investigation over 5 sampling dates and that the decrease for all cultivars from the first to the fifth sampling date averaged 48 grams.

Tomato fruit composition influences to a great deal the quality of tomatoes and tomato products. The major constituent of tomatoes and tomato products is water with variation of the amount depending upon the product. In the fresh fruit water is 93.5% and in the tomato juice is about 75% (Gould, 1974).

Tomatoes usually contain from 7 to 8.5% total solids, 4 to 6% is soluble solids, and about 1% is skins and seeds (Baker and Wright, 1935).

The carbohydrate portion of tomato fruit is mainly sugars. There are small amounts of polysaccharides which include pictins, arabinogalactans, xylans, arabinoxylans and cellulose (Miladi, Gould, and Clements, 1969).

The free sugars of commercial varieties of tomatoes are predominantly reducing sugars. These reducing sugars, which make up from 50 to 65% of tomato solids, are mainly glucose and fructose (Goose and Binstead, 1964). Total sugar content in fresh tomatoes is found to vary from 2.0 to 3.0% (Baker and Wright, 1935).

Factors that affect the soluble solids and sugars include cultivar, fertilizer application, soil moisture content, sunlight, harvest date, day and night temperatures and heat processing effects on tomato products.

Lee and Sayre (1946) reported that total solids content of tomatoes differs considerably between cultivars and can be modified by conditions under which plants are grown. The effective use of fertilizers, especially potash, will increase the total solids content of ripe tomatoes. They also reported that high soil moisture reduces the total solids of tomato fruits. McCollum (1946) in investigation of the effect of sunlight exposure reported that the unshaded fruits were higher in total solids and sugars than shaded fruits. He indicated that a tomato fruit functions as a photosynthetic organ even though it has no stomates or lenticels. Bisgoni and Armbruster (1976) investigating quality comparisons of 3 tomato cultivars with 3 harvest dates, reported that soluble solids content was significantly influenced by cultivar and harvest time. They also reported that harvest time significantly influenced the soluble solids-acidity ratio, and the effect of cultivar was also significant when the ratios were examined over the harvest times. These findings agreed with the investigations made by Lower and Thompson (1966). Orzolek and Angell (1975) reported that there was variation in soluble solids content of tomato fruits as a result of day and night temperatures, and radiation differences. This was confirmed by the investigations made by Luh, Ukai and Chung (1973) who reported that the percentage of soluble solids increased with periods of high

temperature and that there was a slight high Brix (soluble solids)-acid ratio observed in fruits grown at low day temperatures.

Miladi, Gould, and Clements (1969) investigating heat processing effect on tomato juice constituents reported that there was loss in the total sugar content, and that the loss went up to 19.4%. Their work confirmed the investigation done by Crean (1966) who reported that during the sterilization process of vegetables sugars decompose in the acid medium present, giving acetic, lactic, fumanic, and glycollic acids which eventually increase the total acid content and causes pH drop.

Acid in tomatoes comprise about 0.3 to 0.5% and is considered to be almost entirely citric acid. The total acid is always determined as percentage citric acid (Gould, 1974). Miladi, Gould, and Clements (1969) reported that by chromatographic analysis they had separated 8 organic acids from fresh and heat processed tomato juice. Citric acid was found to be the major acid in both fresh and processed juice. Malic acid was found to be the second major organic acid in fresh juice, whereas pyrolidone carboxylic acid was found to be the second major organic acid in the processed juice. They reported that processing of tomato juice results in an increase in total acid. They reported acetic acid increased by 32.1%, apparently due to oxidation of aldehydes and

alcohols during processing, and deamination of amino acids, such as alanine to pyruvic acid which is heat labile and decarboxylates to acetic acid. They also reported that an increase in citric and malic acids after processing was noted. These investigations confirmed the work of Scott and Walls (1947) who reported that total acidity of the fresh fruits of 11 tomato cultivars ranged from 0.273 to 0.416%, whereas total acidity of the heat processed juice was higher than that of fresh fruits, ranging from 0.376 to 0.537% in the processed juice. They indicated also that the pH values were in the same order as the total acidity readings, ranging from 4.2 to 4.5 in the fresh fruit and from 3.9 to 4.2 in the processed juice. The investigation of Crean (1966) agrees with these findings. He reported that heat sterilization of processed vegetables breaks down the carbohydrates, mainly sugars in tomatoes in the presence of the tomato organic acids. This eventually results in an increase in the total acid and a pH drop.

Among the other factors which affect the acidity of tomatoes are cultivar, harvest date, soil moisture, and fertilizer application.

Lower and Thompson (1966) in their investigation of the effect of cultivar and sampling date on total acidity and pH found that cultivars contributed the major component of variation for both total acidity and pH and that there

was highly significant variance attributable to the sampling dates.

Lee and Sayre (1946) investigated the effect of soil moisture and fertilizer application on total acid content of 16 tomato cultivars. They reported that all cultivars produced fruits containing higher total acid when grown under restricted soil moisture supply than when grown with abundant soil moisture. They reported total acid content of tomato fruits, in many cases, was found to be high at the beginning of the season, declined as the season progressed, and rose at the end of the ripening period. They suggested that this general trend can be altered by changing soil moisture conditions. They also reported that the use of potash fertilizer tends to result in higher total acid in tomato fruits, especially when large amounts of potash were applied to the soil. They indicated that nitrogen fertilizer seems to have little effect on the fruit acid content.

The acid and sugar contents of tomatoes and the ratio between them is one of the most important factors in intercultivar flavor differences.

Stevens (1972) while investigating the relationship between components contributing to quality variation among tomato lines reported that there were highly significant correlations among major components contributing to solids. He found that as the total solids increased, the proportion

of reducing sugars, the predominant organic compounds, increased.

Scott and Walls (1947) investigating the sugar-acid ratios in 11 tomato cultivars reported that the sugar content was inversely correlated with total acidity so that the calculated sugar-acid ratios showed wider variation among cultivars than either sugar content or acidity. They indicated that the sugar-acid ratios in the tomato juice ranged from 4.6 to 8.6. They found that the sugar-acid ratios of the juice were in close agreement with organoleptic ratings of blandness and acidity. Juices with high sugar-acid ratios were bland, lacked sharpness in taste and had a tendency to be "flat".

Hydrogen ion concentration (pH) of food products is one of the quality-control checks that will assist in prevention of spoilage. In canning of foods, the pH value is one of the important factors affecting the sterilization times and temperatures. The lower the pH, i.e., the higher the amount of acidity in the food, the lower the degree of heat required for sterilization. Some canned foods are classified according to their pH values into non-acid, semi- or medium-acid, and acid-foods. Tomatoes are classified as acid food with pH ranging from 3.7 to 4.5, and it is usually considered that a pH of 4.5 is the dividing line between acid and non-acid foods. In a product with pH of 4.5 or

less, such as tomatoes, the growth of bacterial spores from organisms as Clostridium botulinum, which is responsible for botulism poisoning, will be inhibited after proper sterilization. In the Food and Drug Administration (FDA) Regulation on Thermal Processing of Food, the pH value is 4.6 or lower (Gould, 1974).

Gould (1974) reported that because of buffers in food products, the total acid content does not have as much as pH measurements. He reported in testing some tomato cultivars it was found that although two different cultivars had the same pH of 4.25, one had a total acid of 0.50% and the other 0.35%. He also reported the pH variation within the same product, such as tomatoes, is due to many factors as: cultivar, maturity, seasonal variations, geographical areas, handling and holding practices before processing and the processing variables.

Rice and Pederson (1954) investigated the inhibitory influence of acidic constituents of tomato juice, i.e., pH, total acidity, and buffer capacity on growth of Bacillus coagulans, the micro-organism responsible for the flat-sour spoilage in tomato juice. They indicated that the pH exerted the greatest activity and they noted that when the pH was not a variable, there was a slight inhibitory activity exhibited by a juice with the higher values for total acidity.

Soluble protein and amino acids comprise about 0.8 to 1.2%. There are 19 soluble amino acids in fresh tomato juice (Baker and Wright, 1935). They also reported that the quantity of minerals present in tomato fruit varies between 0.3 and 0.6%, and the minerals mainly found are calcium, phosphorus, iron, and potassium. Also salt (sodium chloride) varies between 0.05 and 0.1%.

Fresh tomatoes, tomato juice and other processed tomato products are nutritionally important for humans, as tomatoes and their products are good dietary sources of ascorbic acid (vitamin C). Vitamin C is necessary for normal metabolism, wound-healing, and collagen synthesis. Whole red-ripe tomatoes contain nearly all the vitamin C activity in the reduced ascorbic acid form. Ascorbic acid concentration in the tomato juice ranges from 15 to 25 mg/100 g, and in fresh ripe tomatoes is about 25 mg/100 g. Thus a small tomato can supply about 40% of the adult United States Recommended Daily Allowance (RDA) of 60 mg and about two-thirds of the RDA of 40 mg for children. Thus it is possible to meet ascorbic acid requirements in the diet from tomatoes and tomato products (Gould, 1974).

Tomatoes are also a good source of vitamin A, present in the form of carotene. Fresh ripe tomatoes and tomato juice contain 1,000 International Units (I.U.) of vitamin A/ 100 g. In addition, tomatoes provide small amounts of the

B-complex vitamins: thiamine, niacin, and riboflavin (Gould, 1974).

Factors affecting vitamin C concentration in fresh tomatoes include cultivar, soil and plant nutrition, light intensity and exposure to sunlight, harvest date, and maturity.

Maclinn and Fellers (1938) found a variation from 15 to 22 mg/100 g of different cultivars of tomatoes grown side by side on the same soil, but Currence (1939) reported that there is no significant difference between cultivars in field experiments, however he emphasized the relationship between a certain cultivar and the environmental conditions in determining ascorbic acid content.

Price, Bedford, and Lee (1976) investigated the effect of cultivar, growing season, harvest date and stage of maturity at harvest, on ascorbic acid content of 24 tomato cultivars for 3 years from 1973 to 1975. They reported that cultivars varied significantly in ascorbic acid content ranging from 23.5 to 10.7 mg/100 g. This agrees with the previous work done by Maclinn and Fellers (1938). Price, Bedford, and Lee (1976) also reported that the mean ascorbic acid content for the 3 years reported also varied significantly from a high of 18.0 mg/100 g in 1973 to 14.0 mg/100 g in 1975. They reported even within a particular growing season the ascorbic acid content of a particular cultivar

varied between harvest dates, and harvests late in the season had higher ascorbic acid concentration. They reported that the environmental conditions prior to harvests are detrimental on ascorbic acid content, and that the stage of maturity at the time of harvest also influences ascorbic acid content, with those harvested at the breaker stage and ripened under ideal conditions having the highest concentration.

Hester and Kohman (1940) indicated that there is a relationship between the ascorbic acid content of tomatoes and the soil type in different locations.

McCollum (1946) investigated the sunlight effect on ascorbic acid content of tomato fruits. He reported that due to greater exposure to sunlight, fruits from defoliated plants may be higher in ascorbic acid content than those from plants with normal foliage. This investigation is in agreement with the work done by Hamner, Bernstein and Maynard (1945).

The nutritive value of processed tomato products depends both on the initial nutrient concentration in the fresh tomatoes and on the effects of processing and storage of the finished product.

The retention of high levels of ascorbic acid during processing is important. During tomato juice processing, part of the ascorbic acid is destroyed, mainly by oxidation.

Ascorbic acid is oxidized to dehydroascorbic acid, which is further oxidized to degradation products with no vitamin C activity. The oxidation may be enzymatic or non-enzymatic, and is catalysed by copper ions. The rate of oxidation is dependent upon the dissolved oxygen, enzyme content, dissolved copper, and temperature of the juice. The longer the tomato juice is held at optimum conditions for oxidation the lower will be the retention of ascorbic acid after processing (Gould, 1974).

Clifcorn and Peterson (1947) reported an average of 63 to 70% retention of vitamin C during 3 separate plant surveys and that in some plants retention was as high as 94%. They reported that in plants where retention was high, the canning time was short (2 to 3 minutes) and the conditions increasing the oxidation rate were minimized. They also reported that the temperature to which tomato juice is heated in the presence of air is the most important factor in ascorbic acid destruction and that the rate of destruction increases with increased temperature in the presence of air. It is important that the juice be brought to the desired temperature as quickly as possible and held for only a short period at high temperature (Gould, 1974). Guerrant et al. (1945) reported that retention of ascorbic acid was greater (92%) after 15 seconds preheat before extraction at 57.2°C (135°F). Retention decreased to 54% after 35 minutes preheat at 87.8°C (190°F).

Enzymatic destruction of ascorbic acid in tomato juice is minimal, as the oxidative enzymes occur in the pulpy portion of the tomato and are destroyed or removed during extraction (Lamb, 1946).

Any unit operation which includes air into the juice will accelerate ascorbic acid oxidation. Extraction and homogenization equipment should be designed to eliminate dissolved air. Improper filling of the cans allowing an excessive headspace and low vacuums will allow air to dissolve in the juice increasing loss of ascorbic acid (Gould, 1974).

Temperature and length of storage is also important in vitamin C retention of tomato juice. Retentions decrease directly with increasing temperatures from 10°C (50°F) up to 32.2°C (90°F), and above this temperature loss of ascorbic acid increases as log function of temperature increase (Brenner, Wodicka and Dunlop, 1948). Guerrant et al. (1945) reported that 75 to 85% of the initial ascorbic acid of processed tomato juice was retained after one year at the high temperature range of 26.7 to 29.4°C (80 to 85°F), expected in warehouses in the United States. After 2 years storage at room temperature 21.1°C (70°F) and at higher temperatures of 26.7 to 29.4°C (80 to 85°F) retention of ascorbic acid was 60 to 70% or below (Brenner, Wodicka and Dunlop, 1948). Scott and Walls (1947) reported that storage of processed

tomato juice for 1 week contained from 19.0 to 23.1 mg/100 g and with an average of 20.5 mg/100 g. After 8 weeks storage at approximately 70°F the average ascorbic acid content decreased to 19.2 mg/100 g.

Daniel and Rutherford (1936) investigating the effect of home canning and storage on the ascorbic acid content reported that both canning and storage have a significant destructive effect upon ascorbic acid and that both factors caused approximately the same % loss in whole tomatoes and juice canned in tin cans. They reported that canning and storage destroyed a greater percentage of ascorbic acid in the juice canned in glass containers (45% loss) than in juice canned in tin cans (20% loss). They related the greater loss in glass containers to the destructive effect of light on ascorbic acid content. They also indicated that ascorbic acid is stable in acid solutions devoid of oxygen, but in presence of the latter is oxidized rapidly at elevated temperatures and slowly at room temperatures.

Since tomato products are usually held in warehouses that are not refrigerated, the vitamin concentration will be less than in the fresh product or immediately after processing. To maintain vitamin levels at or above that of fresh tomatoes, fortification of tomato products has been proposed (Bauerfeind and Pinkert, 1970). Their review suggests that a minimum of 30 mg of ascorbic acid per 4 fluid oz (26 mg

per 100 ml) could easily be maintained in tomato juice. The shelf-life of tomato juice fortified with ascorbic acid is dependent not only upon temperature and length of storage, as in unfortified juice, but also upon the original ascorbic acid concentration before fortification.

CHAPTER 3

MATERIALS AND METHODS

Seeds of four commercial tomato cultivars obtained from Peto Seed Co. were sown in 4 flats on February 18, 1977. After 10 days the seedlings were transplanted into 2-inches-squared plastic pots filled with a mixture of 1/3 peat-moss, 1/3 vermiculite and 1/3 soil. The plants were grown in a greenhouse at The University Campbell Avenue Farm in Tucson.

Two of the four cultivars were processing cultivars and the other two were fresh-market cultivars. The two processing cultivars were 'VF198' and 'VF145-21'. The two fresh-market cultivars were 'Roza' and 'Pakmor'. Cultivar 'VF198' was developed by The University of California Agricultural Experiment Station. Cultivar 'Roza' was released by the USDA in cooperation with the Washington and Idaho Agricultural Experiment Stations particularly for the intermountain Western States subject to curly top virus.

The seedlings were transplanted to the field at The University of Arizona Agricultural Experiment Station at Mesa, on April 13, 1977. The design used was a randomized complete block with 10 replications. Plots were 10 plants long with 2 feet spacing between the plants in the rows and

90 inches spacing between the rows. The area of land used was 1/8 of an acre. Six hand-harvests were made throughout the 1977 season on the dates: June 24, July 1, July 12, July 21, August 1, and August 10 referred to in the text as harvests 1, 2, 3, 4, 5 and 6 respectively.

The other cultural practices such as plowing, irrigation, fertilizer application, insecticide spraying and cultivation were employed according to the standard methods practiced at Mesa Farm. Seven irrigations were made during the season on the dates: April 8, April 21, May 27, June 3, June 16, July 2, and August 6, 1977. Fertilizers were applied at three different times on April 4, April 18 and May 10, 1977. Malathion insecticide was sprayed for hornworms once at the middle of the season.

Complete data for the different characteristics under investigation was taken on 5 replicates.

Yield

At each harvest marketable fruit numbers and weights and cull fruit weights were determined. Weights were determined in kg and then expressed as metric tons per hectare (t/ha). The percentage marketable or processable values of the yield were computed. The mean fruit weight was also computed in g.

Fruit Size

Diameter and length (maximum and minimum diameters) of the fruit in millimeters (mm) were determined for each plot using a ruler and caliper. Ten fruits taken at random were used. The length to diameter ratio was calculated.

Fruit Color Measurement

A Bausch and Lomb Spectronic 20 (Rochester, New York) equipped with the reflectance attachment was used and the percentage reflectance determined at wavelength 640 nm for red color in tomatoes.

After each harvest 10 representative fruits were taken from each plot. The percentage reflectance was measured on 3 different sides of each fruit. The mean value of the readings were computed.

Preparation of the Tomato Juice for Chemical Analysis and Heat Processing

Ten to fifteen representative ripe tomato fruits from each replicate in each cultivar were washed, cut into slices and blended in a blender (Waring). The juice was extracted using screens of 0.03 inches in diameter. Fresh juice was extracted in the same way after the 6 harvests. Soluble solids and pH of the fresh juice were determined immediately after the juice extraction. A portion of the juice was kept frozen in plastic bags for later analysis for

titrable acidity and vitamin C content. These plastic bags were packed in small boxes which were kept closed for protection from air and light to minimize changes in the juice. Another portion of the juice was used for thermal processing. The juice used for processing was from the third, fourth, and fifth harvests only.

In-Can Thermal Processing of Tomato Juice

The raw juice was filled into number-two tin cans (211X400). Two cans were filled in each replicate for each cultivar. The cans, filled with the juice and with less than 10% headspace, were heated in a water bath to 87.9°C (190°F) and then closed at this temperature using a canning machine developed by Dixie Canner Equipment Co. The closed cans were transferred immediately to the autoclave to be processed under steam pressure at 120°C (248°F) for 2 minutes, and then cooled and stored in a cold room with temperature of 7.2 to 10°C (45 to 50°F) for later analysis. This method of processing used is based upon the method reported by Gould (1974).

Analytical Methods

All samples of the fresh tomato juice from the 6 harvests and the processed juice from the 3 indicated harvests were analyzed for pH, titrable acidity, soluble solids, and ascorbic acid content.

All methods of analysis used were based upon the Official Methods of Analysis of the Association of Official Analytical Chemists [A.O.A.C.] (1975).

Determination of pH

Juice pH was determined using a Coleman-Metrio-IV pH meter with a combination electrode at 25°C (77°F). Duplicate readings were made for each sample. Percentage change after processing was computed.

Titrable Acidity

The glass-electrode titration method with 0.1N NaOH to pH 8.1 was employed. Duplicate titrations were made using 10 ml aliquots of juice. The average volume of 0.1N NaOH used and the total acidity, expressed as percentage citric acid, were calculated. Percentage change after processing was computed.

Soluble Solids

A refractometer (Industrial and Mill Supply Co.) was used and the soluble solids determined as °Brix at 20°C (68°F). Duplicate readings were made for each replicate. Percentage change after processing was computed. The soluble solids-acidity ratios were computed from soluble solids and acidity data.

Ascorbic Acid

The method employed was the 2,6-dichloroindophenol method used for determination of reduced ascorbic acid. Ascorbic acid reduces oxidation-reduction indicator dye, 2,6-dichloroindophenol to colorless solution. At end point, excess unreduced dye is rose pink in acid solution persisting for about 5 seconds or longer. Vitamin C is extracted and titration performed in presence of metaphosphoric acid-acetic acid solution as extracting solution. This is to maintain proper acidity for reaction of ascorbic acid. Hundred ml aliquots of juice were added to equal volumes of of extracting solution. Ten ml aliquots of the extract were used for titration. Duplicate titrations were made for each replicate and mg ascorbic acid per 100 ml juice were calculated. Percentage retention of ascorbic acid after processing was computed.

Statistical Analysis of Data

Statistical analysis of data was run by computer using SPSS program (Statistical Package for Social Sciences) at The University of Arizona. Means were separated by the Student, Newman and Keul's (SNK) multiple range test at the 5% level.

CHAPTER 4

RESULTS AND DISCUSSION

Yields and quality characteristics of the 4 tomato cultivars studied make 3 suitable for canned juice and 2 for fresh-market when grown under irrigated desert conditions in Arizona.

Yield

Percent marketable and fruit yield of cultivars 'VF198', 'VF145-21' and 'Roza' were satisfactory (Table 1) in comparison with the national average yield of 43 metric tons per hectare (19 tons per acre) for commercial tomato cultivars (Gould, 1974). 'Pakmor' yield was too low to be acceptable which was attributed to radial fruit cracking (Fig. 1) which also dropped its marketable yield 14 percent below the other cultivars. Yield reduction in 'VF145-21' was due to a solar injury of fruit (sunburn and sunscald) as most of the plants lacked adequate foliage cover for fruit protection (Fig. 1).

Higher yields were expected from the four cultivars. The high temperature during the growing season was one of the main factors resulting in yield reduction. At the temperature of 35°C (95°F) and above, there is poor or no

Table 1. Number, weight, yield and percent processable or marketable fruit of 4 tomato cultivars.

Cultivar	Number mean/plot[z]	Weight mean/plot[z] (Kg)	Yield (T/ha)	Processable or Marketable (%)
'VF198'	79.6 a[y]	7.3 a	34.5	85.7 a
'VF145-21'	80.5 a	6.7 a	31.8	86.3 a
'Roza'	67.2 a	6.7 a	32.1	84.2 a
'Pakmor'	32.3 b	5.4 a	25.8	71.5 b

[z]Means based on total fruit harvested including culls.

[y]Means in the same column followed by the same letter are not significantly different at the 5% level (Student, Newman and Keul).

a.

b.

Fig. 1. Fruit cracking and sunscald defects.

a. 'Pakmor' fruits showing radial cracking.

b. 'VF145-21' fruits inadequately covered by foliage and showing sunscald.

tomato fruit setting (Gould, 1974). At the Mesa Experiment Farm the average maximum temperature went up to 39.7°C (103.4°F) and 40.4°C (104.8°F) during June and July, 1977, respectively (Appendix A). This resulted in yield reduction as a result of poor setting of some fruits.

Yield patterns throughout the season (Fig. 2) showed that the four cultivars gave the highest yields at the third and fourth harvests. If mechanical once-over harvest was to be employed, the third week of July would have been most suitable except for 'Roza' which peaked a week earlier.

Fruit Size, Weight and Shape

Fruit sizes and weights of the four cultivars (Table 2) showed important differences which would affect their uses. Federal standards for grades for fresh tomatoes (Peterson, 1976) shown in Appendix B, classify fruit for market in sizes from extra small to extra large. All harvested fruit were sized according to the standards.

'Pakmor' fruits were of medium to large size, flattened in shape, and with some shoulder roughness and cracking (Fig. 3). 'Roza' fruits were of medium to small size, almost flattened globe or round in shape (Fig. 3), firm, with little cracking, and with a good slicing characteristic. Both cultivars were of acceptable fruit size and weight for fresh-market.

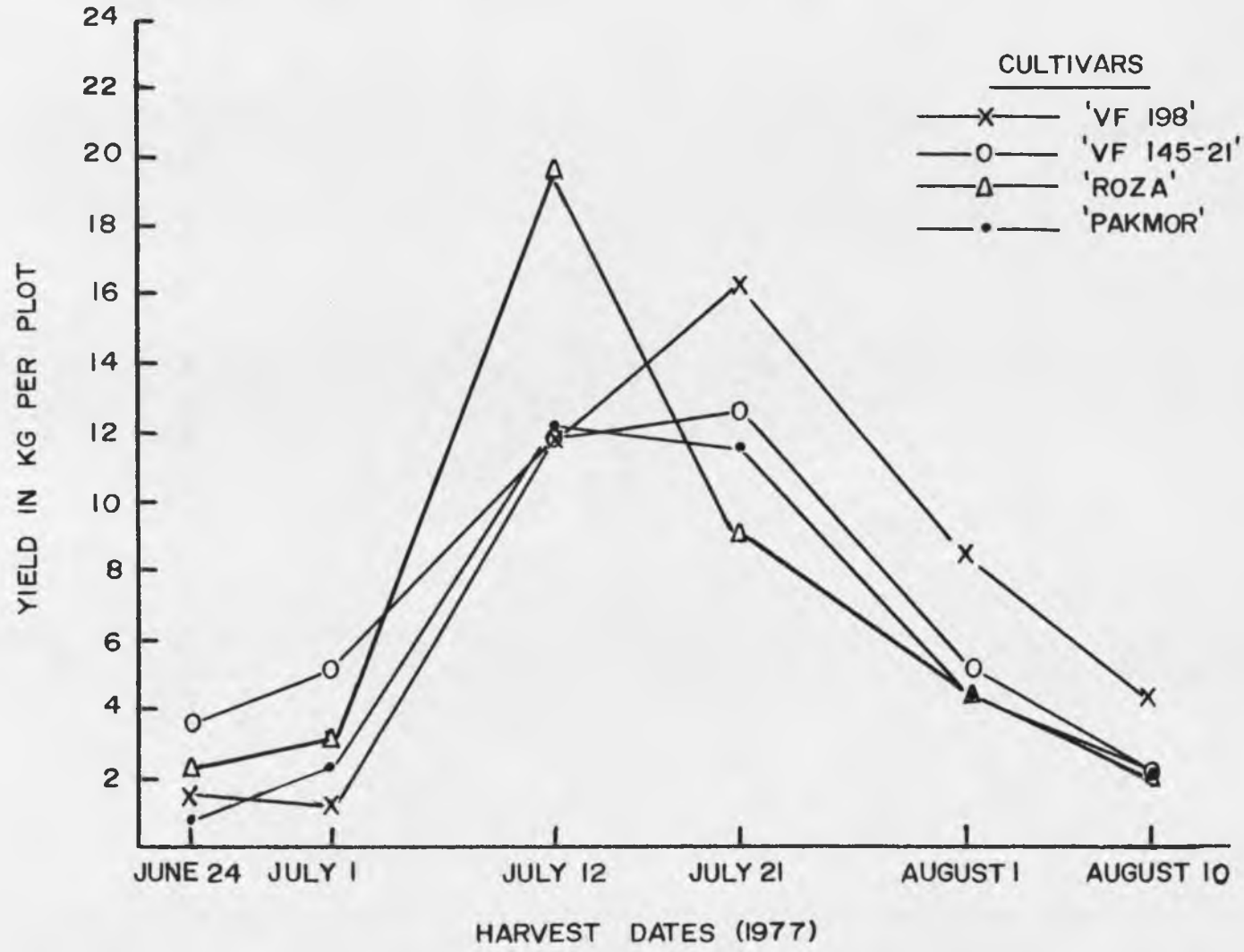

Fig. 2. Yield patterns of 4 tomato cultivars.

Table 2. Size, shape ratio, weight and color of fruit of 4 tomato cultivars.

Cultivar	Size: Width (mm)	Shape Ratio L/W[z]	Weight (g)	Color[y] (% Reflectance)
'VF198'	54.0 c	1.24	93.0 b[x]	49.4 a
'VF145-21'	57.0 c	0.96	85.0 b	55.7 a
'Roza'	63.0 b	0.83	93.0 b	49.5 a
'Pakmor'	68.0 a	0.88	160.0 a	53.6 a

[z]Length/width fruit diameter ratio.

[y]Percent reflectance measured at 640 nm.

[x]Means in the same column followed by the same letter are not significantly different at the 5% level (Student, Newman and Keul).

a.

b.

Fig. 3. Typical shape and sections of 2 fresh-market cultivars.

a. 'Pakmor'

b. 'Roza'

Processing cultivar 'VF198' fruits were of medium size, nearly oblong in shape with a tough skin and thick walls (Fig. 4) which makes it more desirable for processed tomato products. 'VF145-21' fruits were smallest of the four cultivars, globe shaped, (Fig. 4) firm, and developed relatively few cracks which made it suitable for processing of whole tomato packs.

Fruit Color

All four cultivars showed acceptable color for both fresh-market and juice processing (Table 2). However, 'VF145-21' reflectance gave higher readings than the others because of sunburn and sunscald defects (Fig. 1) resulting from excessive exposure. Average high temperatures for June, July and August 1977 at the Mesa Experiment Farm (Appendix A) were 39.7, 40.4 and 40.1°C (103.4, 104.8 and 104.1°F) respectively which is considerably in excess of the lycopene conversion blockage limit. Foliar cover provided sufficient shade that serious discoloration did not occur.

Total Acidity and pH

Total acidity is expressed as percentage citric acid of the fresh and processed juice for the 4 cultivars (Table 3). These acidity values were acceptable for commercial cultivars as they were lying in the desirable acidity range of 0.3 to 0.5% for commercial tomato cultivars (Gould, 1974).

a.

b.

Fig. 4. Typical shape and sections of 2 processing cultivars.

a. 'VF198'

b. 'VF145-21'

Table 3. Percent total acidity and pH of fresh and processed tomato juice of 4 tomato cultivars for the entire season and processing period.

Cultivar	Sample Period[z]	Total Acidity				pH			
		Fresh	Processed	Change		Fresh	Processed	Change	
'VF198'	Entire	0.539 a[y]	-	-		4.19 d	-	-	
	Part	0.523 b	0.553 a	(+)	5.74[x]	4.20 d	4.16 e	(-)	0.95[x]
'VF145-21'	Entire	0.424 c	-	-		4.26 c	-	-	
	Part	0.407 f	0.438 def	(+)	7.62	4.26 c	4.22 d	(-)	0.94
'Roza'	Entire	0.442 c	-	-		4.40 a	-	-	
	Part	0.417 ef	0.462 cd	(+)	10.79	4.42 a	4.34 b	(-)	1.81
'Pakmor'	Entire	0.468 b	-	-		4.31 b	-	-	
	Part	0.448 de	0.487 c	(+)	8.71	4.32 b	4.27 c	(-)	1.16

[z]Entire period represents means of all 6 harvests. Part represents means of the 3rd, 4th and 5th harvests which span the primary processing period.

[y]Means in the same column followed by the same letter are not significantly different at the 5% level (Student, Newman and Keul).

[x]Percentage increase (+) or decrease (-) show the effect of processing.

He also reported that even higher values up to 0.55% were acceptable for certain processing cultivars.

The 4 cultivars showed significant differences from each other in pH values (Table 3). The test pH values all lay within the desirable pH range of 3.9 to 4.5 for commercial tomato cultivars (Gould, 1974). Gould (1974) also reported that the recommended pH value by the FDA is 4.6 or lower in the regulations for thermal processing of foods. It is evident from the results in this investigation that the pH values of the 4 cultivars were lower than the recommended value of 4.6. The processing cultivars: 'VF198' and 'VF145-21' with their low pH values of 4.19 and 4.26 respectively, closely approach the pH requirements of 4.2 or less for commercial processing (Gould, 1974). The pH values of 4.5 or less, as expected in tomatoes and tomato products, inhibit growth of bacterial spores of Clostridium botulinum responsible for botulism poisoning. In addition, the lower the pH, the more inhibition occurs for Bacillus coagulans, the microorganism responsible for flat sour spoilage in tomato juice (Rice and Pederson, 1954).

From the results it is evident that the 4 cultivars exhibited a considerable variation in total acidity and pH values. This is in agreement with the investigations made by Lower and Thompson (1966) who found that cultivars contributed the major component of variation for both total acidity and pH.

Acidity of the processed juice was up to about 11% higher than that of the fresh juice (Table 3). Values for pH of the processed juice were about 2% lower than that of fresh juice (Table 3).

It is evident from these results that heat processing contributed to increase of total acidity and pH drop of the processed tomato juice. This is in agreement with the investigations made by Miladi, Gould and Clements (1969). They reported that tomato juice processing results in an increase in total acid. They related this acid increase to the breakdown and conversion of some soluble solids as sugars to acids, and also the deamination of some amino acids to acetic acid during processing, and eventually increasing total acid content. In agreement with these findings Crean (1966) found that thermal processing of vegetables breaks down carbohydrates, mainly sugars, resulting in an increase in total acidity and a pH drop. Scott and Walls (1947) also reported that total acidity of fresh fruits of 11 cultivars ranged from 0.273 to 0.416%, whereas acidity of the heat processed juice was higher ranging from 0.376 to 0.537%. They also indicated that the pH values ranged from 4.2 to to 4.5 in fresh juice and from 3.9 to 4.2 in the processed juice.

Soluble Solids and Soluble Solids-Acid Ratios

The soluble solids and the acid contents of tomatoes and the ratio between them is one of the most important factors in flavor differences between the different cultivars. Soluble solids and soluble solids-acid ratios in both fresh and processed juice are shown in Table 4. In processed juice the soluble solids content was about 4% lower than that of the fresh juice (Table 4). The soluble solids values reported were acceptable compared with the desirable soluble solids content of 4 to 6% in the commercial tomato cultivars (Gould, 1974). The variation was noticeable among the 4 cultivars and this is in agreement with the findings of Lee and Sayre (1946) who reported that the solids content of tomatoes differed considerably between cultivars. The decrease in soluble solids after processing was related to the breakdown of sugars, which contributed 50 to 65% of tomato solids (Goose and Binstead, 1964), and other carbohydrates during the heat processing of tomato juice and resulted in the total acid increase and a pH drop (Crean, 1966). This is in agreement with investigations made by Miladi, Gould and Clements (1969). They found that after processing there was a loss in total sugar content which went up to 19.4% in some cases.

The higher the soluble solids-acid ratio, the more bland or flat and less sharp is tomato juice (Scott and Walls,

Table 4. Percent soluble solids, soluble solids to acid ratio of fresh and processed juice of 4 tomato cultivars for the entire season and the processing period.

Cultivar	Sample Period[z]	Soluble Solids			Soluble Solids/Acid Ratio		
		Fresh	Processed	Change	Fresh	Processed	Change
'VF198'	Entire	5.86 a[y]	-	-	10.94 c	-	-
	Part	5.79 ab	5.59 ab	(-) 3.5[x]	11.12 cd	10.13 d	(-) 8.90
'VF145-21'	Entire	4.77 c	-	-	11.35 bc	-	-
	Part	4.93 c	4.79 c	(-) 2.8	12.19 b	11.00 cd	(-) 9.76
'Roza'	Entire	5.92 a	-	-	13.53 a	-	-
	Part	5.86 a	5.77 ab	(-) 1.5	14.17 a	12.57 b	(-) 11.29
'Pakmor'	Entire	5.49 b	-	-	11.85 b	-	-
	Part	5.61 ab	5.48 b	(-) 2.3	12.58 b	11.30 c	(-) 10.17

[z]Entire period represents means of all 6 harvests. Part represents means of the 3rd, 4th and 5th harvests which span the primary processing period.

[y]Means in the same column followed by the same letter are not significantly different at the 5% level (Student, Newman and Keul).

[x]Percentage decrease (-) shows the effect of processing.

1947). After processing the soluble solids-acid ratios decreased in the 4 cultivars (Table 4) as a result of the increase in the total acid content of the juice.

In this investigation cultivars 'VF198' and 'VF145-21' had acceptable ratios in both fresh and processed juices which make them suitable for juice manufacture. 'Roza' and 'Pakmor', however, had higher ratios in both fresh and processed juices which make them less acceptable for juice manufacture.

Ascorbic Acid

The 4 cultivars showed variation in ascorbic acid (vitamin C) contents in the fresh juice and the amounts retained after the heat processing of the juice (Table 5).

Ascorbic acid contents of 'Roza' and 'VF145-21' were acceptable for tomato juice manufacture as a minimum of 20 mg/100g is desirable in processing of the juice as reported by Gould (1974). He also reported that ascorbic acid content in tomato juice of commercial cultivars generally ranges from 15 to 25 mg/100 g and in this investigation 'Roza' and 'VF145-21' cultivars had values of ascorbic acid which lie in this range. Ascorbic acid level in 'Pakmor' and 'VF198' was not sufficiently high for juice manufacture. The early work made by Maclinn and Fellers (1938) is also in agreement with the results of this investigation. They found a variation from 15 to 22 mg/100 g of different tomato

Table 5. Content and percent retention of ascorbic acid in fresh and processed juice of 4 tomato cultivars.

Cultivar	Sample Period	Ascorbic Acid Fresh (mg/100 ml)	Ascorbic Acid Processed (mg/100 ml)	Retention (%)
'VF198'	Entire	11.33 c[z]	-	-
	Part	10.93 c	8.01 d	73.3
'VF145-21'	Entire	19.54 a	-	-
	Part	19.08 a	14.35 b	75.2
'Roza'	Entire	19.49 a	-	-
	Part	19.85 a	14.19 b	71.5
'Pakmor'	Entire	13.67 b	-	-
	Part	14.45 b	9.50 cd	65.7

[z]Means in the same column followed by the same letter are not significantly different at the 5% level (Student, Newman and Keul).

cultivars grown under the same conditions. However, Currence (1939) reported that there was no significant difference between cultivars in field experiments.

In this investigation the 4 cultivars varied in ascorbic acid content during the growing season depending upon the harvest dates (Fig. 5). There was a slight increase in ascorbic acid content in the 4 cultivars at the end of the season, mainly at the fifth harvest date. This is in agreement with the investigations made by Price, Bedford and Lee (1976). They reported that within a particular growing season the ascorbic acid content of particular cultivars varied between harvest dates, and harvests late in the season had higher ascorbic acid concentration. They also indicated that the environmental conditions prior to harvests are detrimental on ascorbic acid content. Investigating the effect of sunlight and high temperature may result in higher ascorbic acid content. In our investigation the increase in ascorbic acid content at the late season is explained in the light of these early findings. The average maximum temperatures went up to 40.4°C (104.8°F) and 40.1°C (104.1°F) during the harvest months of July and August, 1977, respectively (Appendix A). This can be the reason for ascorbic acid content increase. McCollum (1946) also reported that fruits from defoliated tomato plants exposed to sunlight may be of higher ascorbic acid content than fruits from plants with

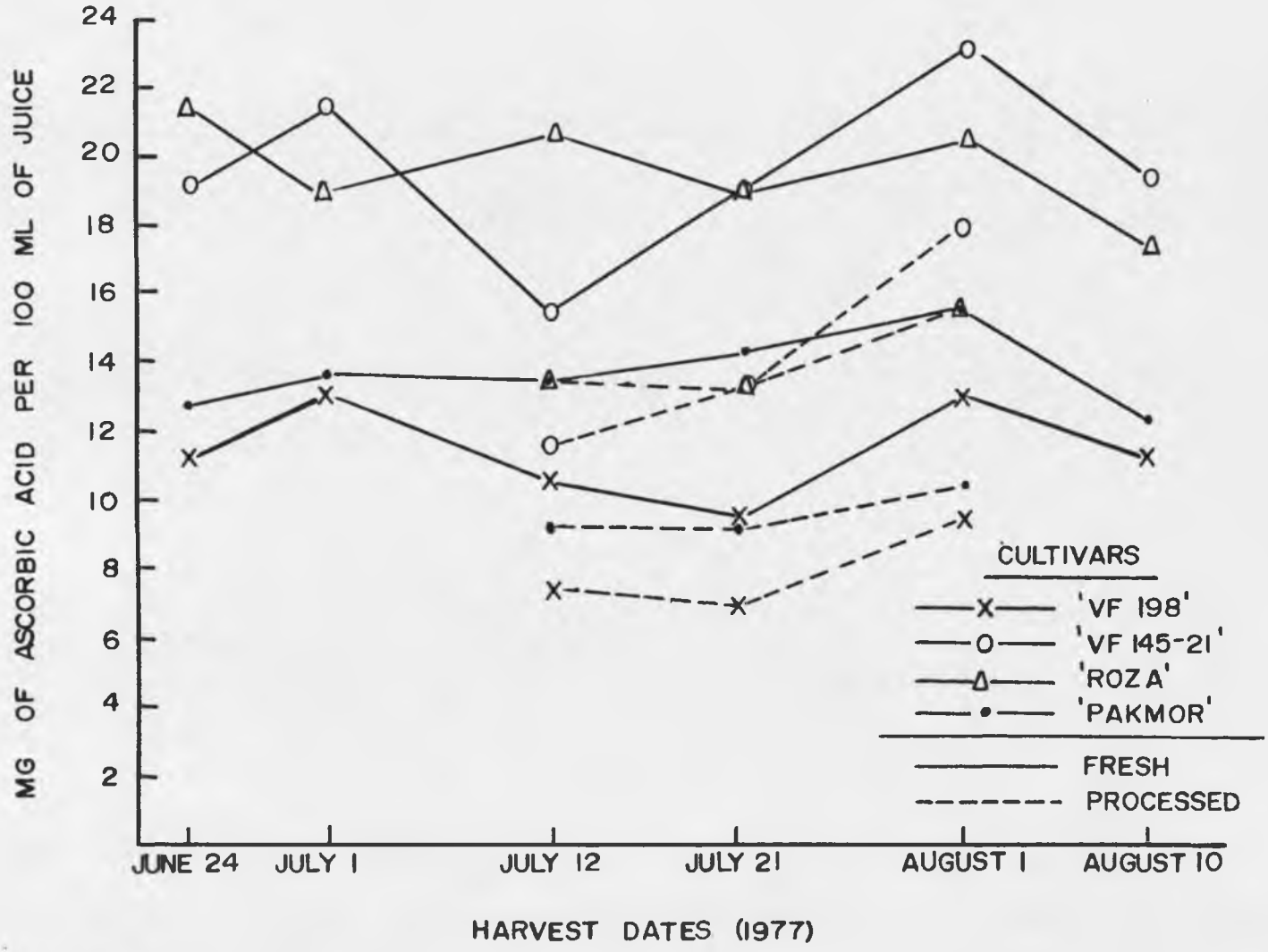

Fig. 5. Patterns of ascorbic acid content of 4 tomato cultivars affected by season and processing.

normal foliage. This is related to the significant high ascorbic acid value of 'VF145-21' where most of the fruits were exposed to sunlight due to lack of adequate cover by the plant vines.

The retention of high levels of ascorbic acid in processed tomato juice is important. Retention depends both on the initial concentration in the fresh juice and on the effects of processing and storage of the finished product. The decrease of ascorbic acid content after processing is due to the destruction and oxidation of part of the ascorbic acid to dehydroascorbic which is further oxidized to degradation products with no vitamin C activity (Gould, 1974).

In this investigation ascorbic acid retention ranged from 65 to 75% among the 4 cultivars (Table 5), while Clifcorn and Peterson (1947) reported an average of 63 to 70%. They reported that the retention was high where shorter canning time (2 to 3 minutes) were used and conditions increasing oxidation rate minimized.

Brenner, Wodicka and Dunlop (1948) investigating the effect of storage temperature on vitamin C retention of processed juice reported that retentions decrease directly with increasing temperatures from 10 to 32.2°C (50 to 90°F). In our investigation the processed juice was kept in the cold room with temperature of 7.2 to 10°C (45 to 50°F) to minimize changes in the juice. Usually, tomato juice and other

products are held in warehouses with expected temperatures of 26.7 to 29.2°C (80 to 85°F) (Guerrant et al., 1945) and the vitamin C content will be less than in fresh product or immediately after processing. To maintain vitamin levels at or above that of fresh tomatoes, fortification of tomato juice and other tomato products could be employed (Bauerfeind and Pinkert, 1970). They suggested that a minimum of 26 mg/100 ml could easily be maintained in tomato juice by fortification.

CHAPTER 5

CONCLUSIONS

In this study the results for the different characteristics investigated in desert grown tomatoes show that:

1) The 4 cultivars under study contributed the major component of variation for most of the characteristics.

2) The overall average yield and the average yield for each cultivar, with the exception of cultivar 'Pakmor', were satisfactory compared with the average yield for the commercial cultivars grown throughout the United States.

3) Color and constituents of the tomato fruit such as the acid, pH, soluble solids and ascorbic acid had the greatest influence as quality factors of the fresh and processed juice.

Cultivar 'VF198' and 'Roza' fruits showed better red color than the other 2 cultivars. Cultivar 'VF145-21' fruits showed the poorest red which was related to inadequate plant foliage cover exposing the fruits to sunshine and high temperatures.

From a processing standpoint for desirable characteristics, cultivars 'VF198' and 'VF145-21' showed satisfactory values of total acidity, pH, soluble solids and vitamin C, with the exception of 'VF198' low vitamin C content.

'Roza' a fresh-market cultivar showed a significant high content of vitamin C and soluble solids and minimally acceptable values of acid content and pH. These characteristics make this cultivar acceptable for juice manufacture.

4) The effect of thermal processing on soluble solids, total acidity, pH and ascorbic acid content of the tomato juice was evident in the 4 cultivars.

In the processed juice, soluble solids decreased and eventually resulted in an increase in total acid and a pH drop. Ascorbic acid content decreased after processing due to oxidation to dehydroascorbic acid, but the amount retained was satisfactory in all cultivars with the exception of 'Pakmor'. These changes were within acceptable limits compared with investigations made on the effect of heat processing on tomato juice.

APPENDIX A

TEMPERATURE RECORDS AT THE UNIVERSITY OF ARIZONA MESA EXPERIMENT FARM FROM APRIL TO AUGUST 1977

Month	Average Maximum °F	Average Minimum °F	Average °F	Highest °F	Date	Lowest °F	Date
April 1977	84.8	53.0	68.9	96	27	35	3
May 1977	86.7	56.4	71.6	102	31	48	18
June 1977	103.4	70.9	87.2	113	30	63	12
July 1977	104.8	78.8	91.8	110	1	72	24
August 1977	104.1	78.2	91.2	110	21	72	29

From Climatological Data Vol. 81 Numbers 4, 5, 6, 7 and 8. National Oceanic and Atmospheric Administration. Environmental Data Service. National Climatic Centre, Asheville, N.C.

APPENDIX B

UNITED STATES STANDARDS FOR GRADES OF FRESH TOMATOES

UNITED STATES STANDARDS FOR GRADES OF FRESH TOMATOES

EFFECTIVE DECEMBER 1, 1973
AS AMENDED NOVEMBER 29, 1973, FEBRUARY 1, 1975,
AND APRIL 15, 1976

U.S. DEPARTMENT OF AGRICULTURE, AGRICULTURAL MARKETING SERVICE, WASHINGTON, D.C.

—SIZE—

§ 51.1859 Size.

(a) The size of tomatoes packed in any type container, when specified according to the size designations set forth in Table I, shall be within the ranges of diameters specified for the respective designations.

(1) In determining compliance with the size designations the measurement for minimum diameter shall be the largest diameter of the tomato measured at right angles to a line from the stem end to the blossom end. The measurement for maximum diameter shall be the smallest dimension of the tomato determined by passing the tomato through a round opening in any position.

TABLE I

Size Designations	Inches		Millimeters	
	Minimum diameter[1]	Maximum diameter[2]	Minimum diameter[1]	Maximum diameter[2]
EXTRA SMALL	1-28/32	2-4/32	48	54
SMALL	2-4/32	2-9/32	54	58
MEDIUM	2-9/32	2-17/32	58	64
LARGE	2-17/32	2-28/32	64	73
EXTRA LARGE	2-28/32	3-15/32	73	88
MAXIMUM LARGE	3-15/32		88	

[1] Will not pass through a round opening of the designated diameter when tomato is placed with the greatest transverse diameter across the opening.

[2] Will pass through a round opening of the designated diameter in any position.

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