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The Sugar-Acid Ratio of Selected Tomato Varieties

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SUMMARY

A study was made of pH, titratable acidity, soluble solids, invert sugar, and sugar-acid ratio of 11 selected tomato varieties and breeding lines. Samples for analysis consisted of both vine-ripened and chamber-ripened fruit. Varieties showing extremes for each quality factor studied were selected for taste panel studies using canned tomato juice.

As a result of the study, the following conclusions were drawn:

1. Variety and harvest date had significant effects upon pH, titratable acidity, soluble solids, invert sugar, and sugar-acid ratio of tomato fruit.

    a. The mean value for the pH of vine-ripened fruit was 4.48. Of the 11 varieties tested, Improved Garden State had the highest value (4.69) and White Queen had the lowest value (4.37).

    b. The mean value for the titratable acidity of vine-ripened fruit was 0.434 percent citric acid equivalent. Orange Jubilee, normally advertised as "non-acid," was highest of all varieties in titratable acidity (0.498) and I-417-1, a greenhouse line, was the lowest (0.361).

    c. Fruits of Orange Jubilee were also highest in soluble solids content (5.12 percent Brix); the lowest level of sugar was found in White Queen (3.60). The mean value for the percent sugar as Brix was 4.40.

    d. Orange Jubilee was highest in percent invert sugar (3.41) as well as soluble solids. The lowest invert sugar content was found in canning variety, H-1370, (2.37). The mean value for invert sugar of vine-ripened fruit was 2.93.

    e. Improved Garden State had the highest sugar-acid ratio (13.11, vine-ripened fruit) and White Queen had the lowest (8.38). The mean value for the sugar-acid ratio was 10.23.

2. Improved Garden State, a canning variety, had a high pH (4.690—seasonal mean of vine-ripened fruit), thereby increasing its chance for spoilage in canning by *Bacillus coagulans.* The other canning varieties were also in the danger zone (above pH 4.35) so far as growth of this microorganism is concerned.

3. The beefsteak-type tomatoes, Tomboy and Pink Ponderosa, normally thought of and advertised as low in acidity, tested fairly high in acid (0.471 percent and 0.459 percent respectively), compared to the other varieties included in the study.

4. The varietal rankings were nearly the same order for invert sugar as for total sugar. Therefore, a variety high in total sugar can be assumed to be high in invert sugar. Invert sugar comprised about 70 to 75 percent of the total sugar content.

5. In comparing the error mean square of chamber-ripened fruit with that of vine-ripened fruit, it was found that the chamber-ripened fruit had more homogeneity in level of the various quality factors studied than did the vine-ripened fruits.

6. The seasonal trends observed for each quality factor were:

a. The pH level of the fruit decreased as the season progressed. Therefore, a higher pH level was found at the beginning of the season than at the end of the season. This was true for all varieties whether vine-ripened or chamber-ripened.

b. The level of titratable acidity increased as the season progressed. The low titratable acidity tomatoes were found at the beginning of the season and the high values for acidity were obtained at the end of the season.

c. The seasonal trend for soluble solids was one of fairly constant sugar content from the beginning of the season to midseason, followed by a gradual decline in sugar content to the last harvest date.

d. Invert sugar followed a seasonal trend of increasing sugar content until midseason and then a fairly constant level was maintained for the remainder of the season.

e. The sugar-acid ratio of all varieties decreased as the season progressed.

7. Since total sugar content decreased from midseason to the end of the season, and invert sugar remained fairly constant during this period, there was an increasing percentage of the total sugar in the invert form as the season progressed.

8. In taste panel studies of model solutions, which had the same concentration of sugar and acid as the raw tomato juice, taste testers could detect differences between the samples by taste sensations. The concentrations for the sugar and acid were:

pH	4.28	to	4.50
Titratable acidity	.388%	to	5.0%
Sugar (Brix)	3.2 %	to	4.3%
Sugar-acid ratio	7.02	to	8.85

9. In taste panel studies of the canned tomato juice, the difference between the lowest acid line and the highest acid line could not be detected by the panel. The same results were found when comparing the highest sugar line against the lowest sugar line, and likewise for the high sugar-acid ratio variety versus the low sugar-acid ratio variety. The values for these extremes were the same as for the model solutions listed above. Apparently, other factors in the tomato juice interfere with sugar-acid ratio determination by taste.

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The Sugar-Acid Ratio of Selected Tomato Varieties

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INTRODUCTION

Individual tomato fruits contain varying concentrations of sugar and acid depending on the variety and various environmental factors. The levels of acid and sugar impart important characteristics to the fruit, both in the raw state and in the processed product. Acidity affects both the flavor and keeping quality of the fruit. High acidity reduces the processing time and temperature required to kill spoilage microorganisms. High pH of individual fruits is believed to be responsible for the increased incidence of spoilage of canned tomatoes in some parts of the United States. The level of sugar is believed to affect the flavor of the fruit. Since the levels of sugar and acid are so important, the authors have become interested in those found in fruits of selected tomato varieties.

One purpose of this study was to examine, under normal growing conditions, the sugar-acid relationship among commonly-grown, selected tomato lines and to determine whether extreme differences in sugar-acid relationships could be detected by human taste.

There is a belief, prevalent among both gardeners and consumers, that white and yellow-colored tomatoes are "anti-acid" or "non-acid." Much of the commercial advertising literature is based on this belief. Many people also believe that the beefsteak tomato is low in acid and, therefore, tastes sweeter than other varieties grown under the same conditions. These ideas have stimulated the authors to determine whether this information is actually true.

The authors were also interested in determining whether chamber-ripened fruits have more homogeneity than vine-ripened fruits with respect to sugar and acid levels.

The study covers 11 tomato varieties and breeding lines which were selected as being either high or low in sugar or acid on the basis of previous studies or on advertising claims.

REVIEW OF THE LITERATURE

The desirable quality attributes of the tomato, both in the raw state and in the processed product, are related closely to the chemical composition of the fruit. Since this composition is so important, recent research has been directed toward the objectives of studying and improving the quality characteristics of the fruit.

Bohart (9) determined that the level of the various chemical constituents found in the tomato fruit determines its quality. Cameron, in 1950, (11) gave the following ranges in composition of tomatoes: 4 to 6 percent soluble solids, 2 to 3 percent sugar as invert, and 0.3 to 0.5 percent acid expressed as citric. The sugar and acid present in the fruit are considered the most important of these constituents. Therefore, the studies have been limited mainly to pH, titratable acidity, sugar, and sugar-acid ratios.

pH

The term, pH, is a measure of the hydrogen-ion concentration, which controls and regulates many of the chemical transformations that take place in foods. The pH of the tomato fruit is very important in the tomato processing industry. Gould, in 1957 (16), reported that the pH was one of the most important factors affecting the sterilization time and temperature of tomatoes. Thompson, Hepler, Lower, and McCollum (43) found that spoilage of canned tomato products was caused by the germination of certain thermophylic bacterial spores not killed by the heating process or not held in check by an adequate level of acidity.

It has long been recognized that acid fruits are more easily sterilized than most vegetable products which are lower in acid. Cruess, in 1948 (13) also reported that the products difficult to sterilize were the ones low in acid and those containing spore-bearing bacteria. Bigelow and Cathcart (8) of the National Canners Association showed that the hydrogen-ion concentration, rather than the total acidity, is the more reliable measure of the effect of acidity on sterilization time and temperature. They also stated that hydrogen-ion concenration in most fruits is sufficient to affect the death temperatures of many microorganisms.

Since the discovery that bacteria can cause serious losses in commercial tomato packs, much work has been done to find adequate methods for controlling this spoilage. Most studies have been concerned with the factors which inhibit spore germination and growth, or factors which affect the heat resistance of the spoilage organisms.

Desrosier and Heiligman (14) reported in 1955 that increased pH levels allowed bacterial spores to cause spoilage in canned tomato juice. They found that the spores grew only at increased pH levels. Rice and Pederson (33) stated that pH produced the greatest effect on growth of *Bacillus coagulans.* They found that a pH of 4.35 or below would not support growth of many strains of *Bacillus coagulans.* Jones and Ferguson (25), in 1960, identified a type of spoilage in canned whole tomatoes and tomato juice known as "flat sour" to be a result of the development of *Bacillus coagulans.* Berry (7) reported a bacterial species named *Bacillus thermoacidurans* which caused spoilage in canned tomato juice. This organism is now believed to be the same as the one found by Rice and Pederson. Other species of bacteria have also been recognized as causing spoilage in tomato products.

Since pH is so important to the growth of these organisms and in determining the processing time and temperature, studies have been made of the pH of individual fruits. Adams (1) in a study of California tomatoes, found that individual fruits could have a pH significantly over 4.5. He reported a range from 3.9 to 4.8 for individual fruits. Saywell and Cruess (38), in a study of composition of canning tomatoes, reported a pH range from 3.8 to 4.4. Yamaguchi and Leonard, in 1960 (46), gave a range of 3.9 to 4.6 for fresh canning tomatoes. Harvey (23) reported a range of 4.148 to 4.565 in a study of 30 different tomato varieties. Smith (40) reported a range of 4.06 to 4.60. Most authors are in agreement that the usual pH range of tomatoes is from 4.0 to 4.5.

The variation in pH is caused by both genetic and environmental factors. Gould (17) postulated that with any given tomato or tomato product, the pH may vary considerably. Some of the more important factors affecting this pH level are: (1) variety, (2) moisture, (3) fertilizer, and (4) stage of maturity.

Patterson (32), as early as 1890, reported that potash-fertilized plants produced fruits with slightly less sugar and more acid. On the other hand, Bailey and Lodeman (5), in 1891, showed that fertilizer application did not give sufficient differences to warrant any conclusions as far as acidity of the fruit was concerned. In later investigations by Lee and Sayre (27), high potash applications were found to decrease the pH of the fruit. Application of nitrogen and the other essential elements seems to have had little or no significant effect.

Research findings with respect to effect of soil moisture are inconclusive and in some cases contradictory. In a study of soil moisture and its effect upon the acidity, Lee and Sayre (27) reported that restricted moisture supply produced a lower pH in the tomato fruit. Saywell and Cruess (38) ascertained that tomatoes grown in a cool and foggy climate tended to have a lower pH than those grown in a hot and dry climate.

Hanna (20), in 1961, when studying the changes in pH in relation to maturity and ripening, noticed a progressive increase in pH during maturation. Yamaguchi and Leonard (46) also recognized that the pH increased with ripening. Anderson (3) reported a progressive increase in pH from the turning stage to a very ripe stage in the whole tomato fruit. Since there is a high degree of correlation between pH and maturity, any comparison in pH of tomato varieties should be made on comparable maturities.

A varietal difference in pH of the tomato fruit was ascertained by Thompson, Hepler, Lower, and McCollum (43). They listed certain varieties consistently producing fruits with a higher pH from one year to the next. This same result was also determined for varieties having a low pH. They also showed the lower pH lines as ones having a high degree of firmness.

Other workers in the field have found no set pattern for pH or the factors affecting it. Under field conditions, Anderson (3) noticed variability in pH between two fruits from the same plant to be as great or greater than that from fruits of different plants.

The pH level of the fruit also affects the flavor of the fruit both in the raw state and the final processed product. Anderson, in 1957 (3), reported that both the hydrogen-ion concentration and the total free acid in a solution or tomato product affects the degree to which the sensation of sourness is perceived. Harvey (23) determined sourness to be a function of two dependent variables: the hydrogen-ion concentration and the total acidity.

Titratable Acidity

The titratable acidity includes the potential hydrogen ions as well as the actual hydrogen-ion concentration. This is sometimes called the total acidity. The titratable acidity, as shown by Harvey (23), does affect the flavor of the tomato. The environmental factors affecting the titratable acidity are similar to those affecting pH, and the effects are somewhat similar to those of pH. Season and climate seem to be the main environmental factors controlling the titratable acidity along with the stage of maturity.

Saywell and Cruess (38) found an acid range of 0.26 to 0.81 percent citric equivalent in clear tomato juice. Scott and Walls (39) gave a range in fresh tomato fruits from 0.273 to 0.416 percent citric acid equivalent. As mentioned earlier, Cameron (11) reported a range of 0.3 to 0.5 percent citric equivalent.

In general, it can be said that when pH is low, titratable acidity is high, and when pH is high, titratable acidity is low. However, this is not always true, and some studies have shown nearly the opposite. Anderson (3) found that pH was not always lowest where the titratable acidity was highest. In several cases, he found the pH highest where the titratable acidity was highest; Bohart, in 1940 (9), also showed a high positive correlation between pH and titratable acidity.

Sando (36), in 1920, reported the organic acids in the tomato fruit to be citric, malic, formic, oxalic, succinic, and tartaric. Since then, other organic acids have been found—acetic, aconitic, lactic, and pyrrolidonecarboxylic. The latter acid was identified by Rice and Pederson (33) in canned tomato juice, but not in fresh tomato juice. In all studies, it is unanimously agreed that citric is the most prominent, while malic is present in next greatest amounts, followed by aconitic. The remaining acids comprise 0.01 percent or less, as reported by Anderson (3). Nelson (31), in 1928, determined the acid present in tomatoes to be approximately 60 percent citric and 40 percent malic.

Yamaguchi and Leonard (46) found that total acidity decreased with ripening of the fruit. Anderson (3) also noticed a progressive decline in titratable acidity from the turning stage to a very ripe stage in the whole tomato fruit. He also found the level of titratable acidity varied with the different parts of the fruit. The locular jelly had the highest, the outer pericarp the lowest, and the inner pericarp an intermediate level of titratable acidity. Bohart (9) also showed the total acidity to be higher in the free locule contents than in the flesh of the tomato. Therefore, he concluded that fruits with relatively large locules would tend to be more acid than those in which the proportion of flesh was high.

As in pH, research findings with respect to soil moisture and its effect on total acidity are inconclusive. Gorev (15), in 1959, found that less-irrigated plants had lower total acidities. Similarly, Saywell and Cruess (38) noticed that non-irrigated plants gave a lower level of total acidity when compared to irrigated plants. In their studies the average acid level found was 0.31 percent citric equivalent. Lee and Sayre (27) obtained opposite results. In a study of 16 varieties, they found higher total acidity when the tomatoes were grown under restricted moisture supply. They also found a seasonal trend with the acidity being high at the beginning of the season, followed by a gradual decline as the season progressed, and a small rise at the end of the season. They noticed this trend could be altered by changing soil moisture and temperature conditions. Saywell and Cruess (38) stated, however, that total acid content did not appear to follow any definite trend with picking date.

The level of titratable acidity, along with the hydrogen ion concentration, does determine the degree of sourness of the product. As mentioned earlier, Harvey (23) found sourness to be related to two variables, the hydrogen-ion concentration and the total acidity.

Sugars

The sugars are important organic constituents which affect the quality and flavor of the tomato, both in the raw state and in the processed product. Scott and Walls (39) gave a sugar range in fresh fruit from 2.28 to 3.57 percent. Saywell and Cruess (38) identified practically all the sugar present in the fruit as reducing sugar. They also found that a high total of solids in general is correlated with high reducing sugar content. Similarly, Scott and Walls, in 1947 (39), determined that practically all the sugar present was in the invert form. This finding was also confirmed by Cameron (11). Airan and Barnabas (2), in 1953, found the sugars present to be mainly glucose, fructose, and sucrose. They also identified raffinose in very ripe fruit.

The level of sugar depends on various genetic and environmental factors. MacGillivray and Clemente (29), in 1956, noticed a consistent decrease in percent solids as the fruits increased in size. They also found that low soil moisture increased the solids content of the fruit. Gorev (15), in 1959, reported that fruits of less-irrigated plants contained higher sugar concentrations than irrigated plants. He also reported that the mono-saccharide concentration was higher in unripe fruit than in ripe fruit.

In studying the effects of harvest date on the sugar content, Yamaguchi and Leonard (46) stated that the reducing sugar content was gradually decreased as the season progressed. They attributed this to the loss of foliage as the season advanced. Beadle, in 1937 (6), found that fruits which ripened first in the season had the highest sugar content. He also reported that premature picking resulted in a lowered sugar content even though the fruit subsequently ripened off of the vine.

The stage of maturity seems to have the greatest effect upon sugar level in the fruit. Rosa (35), in 1925, noticed that sugars increase steadily from the green mature stage to the ripe fruit. Vittum, Robison, and Marx (45), in 1962, showed that as individual fruits mature, sugars tend to increase, while the organic acids tend to decrease. Hanna (20), however, in 1961, reported that there was little or no correlation between stage of maturity and total soluble solids.

Scott and Walls (39) reported that the sugar present in a solution could be tasted since the sugar-acid ratios showed varying degrees of sharpness and blandness in taste testing of tomato juice. Harvey (23) ascertained that addition of sugar to acid solutions altered the taste even though it didn't change the hydrogen-ion concentration or the total acidity.

Sugar-Acid Ratio

Early literature on the composition of the tomato fruit shows no data on the sugar-acid ratio. Later studies, however, have included this ratio along with the sugar and acid content. Since the acidity and sugar level of the tomato fruit is so important, the sugar-acid ratio is also calculated in quality studies and correlations with quality and taste are made from it. Scott and Walls (39) found that the sugar content was inversely correlated with total acidity, so that the calculated sugar-acid ratios show wider variation among varieties than either sugar concentration or acid concentration alone. In their studies, they gave a range of 6.9 to 10.8 in the sugar-acid ratio of fresh fruit.

The sugar-acid ratios would be affected by the same factors which affect either the level of acidity or sugar alone. There is some correlation of sugar-acid ratio with maturity. Vittum, Robison, and Marx (45) reported a correlation between maturity of tomato fruits and the sugar-acid ratio of the maturing fruits. They found, as mentioned earlier, that as fruits mature, organic acids decrease while sugars tend to increase. Thus, the sugar-acid ratio should be higher in mature fruits than in immature fruits.

Quality Constituents and Their Effect Upon Taste

Little taste research has been reported upon tomato fruit and tomato products. Gould (18) reported that flavor differences indicated factors of quality which every food processor must be able to control for the successful repeat business needed in the industry. The initial raw product is the starting point in control of the flavor and taste of the final processed product.

There is some doubt as to what degree flavor can be measured. Gould (18) reported that it can be measured by using taste panel ratings and figuring LSD values. Hartman (22) determined the flavor of some chemical compounds by using electrical methods. Roessler, Warren, and Guymon (34) report that flavor differences in some samples are obvious and in other samples they are less easily detected.

Flavor was defined by Hartman (22) as the combined effect of the olfactory (odor) and gustatory (taste) sensations experienced when a food material is placed in the mouth. The commonly described taste factors registered through the taste buds are sweetness, sourness, bitterness, and saltiness. Gould (18) stated that the materials which are ordinarily responsible for the characteristic flavor of vegetables and fruits appear to be ones which are volatilized in the mouth and detected by the olfactory epithelium located in the upper part of the nasal cavity. Research has shown that these volatile constituents are alcohols, aldehydes, ketones, organic acids, and esters or other similar compounds.

There is evidence in fruits and vegetables that several different volatiles contribute to the flavor. Sandor (37) reported the presence of an appreciable amount of these volatile acids in ripe tomatoes.

Leonard, Pangborn, and Luh (28) found that with pH reduced to 3.9 and total acidity doubled, tomatoes still had a high flavor acceptability. Taste panels indicated that small additions of sucrose were necessary to offset the sourness contributed by this increased acidity.

Varietal Differences in Relation to Quality Attributes

As reported earlier by Thompson, Hepler, Lower, and McCollum (43), varietal differences do exist in sugar and acid content of the fruit. They studied 21 selected varieties and highly significant varietal differences were measured in all of the constituents of quality evaluated. They evaluated color, firmness, pH, titratable acidity, soluble solids, and holding capacity of the fruit. Commercial seed advertising catalogues also mention a varietal difference in tomatoes and much of their advertising is based upon this. Many seed companies advertise white and yellow-pigmented tomatoes as being low in acid or anti-acid and many of their small-fruited varieties as being high in sugar content. They also consider the beef-steak type tomato as being low in acid. Following are a few quotes taken from some of the latest seed catalogues:

> "The White Beauty tomato is ivory white in color and the flesh is almost paper white. White Beauty is the anti-acid tomato.
> It is extremely mild, containing less acid than other tomatoes, so can be eaten by people who have heretofore avoided tomatoes on account of the acidity."

> "Sugar tomatoes are the sweetest of all tomatoes. The fruits are small, but are so sweet they can be used for preserves."

"Ponderosa. A giant pink tomato. Meaty and tender with a mild and delicious flavor and low acid content."

These same beliefs persist in the minds of the public today, probably as a result of advertising and word-of-mouth transmission. Research has been conducted in some of the areas mentioned above. Bohart (9) reported that the acidity was higher in the locule contents of the fruit than in the flesh and he concluded that fruits with relatively large locules would tend to be more acid than those in which the proportion of flesh was high. Thompson (44) studied and compared the quality constituents of normal and high pigment tomatoes. He found no measurable differences between the processed products of normal and high-pigmented tomatoes with regard to pH, total acidity, total sugars, and total solids.

MATERIALS AND METHODS

Eleven varieties and breeding lines of tomatoes were selected for this study. They were selected to include the varieties usually advertised as low-acid, certain high-acid lines, and several commercial canning varieties. Two greenhouse lines were included as checks or controls because their quality factors had previously been determined by the Horticulture Department laboratories. The varieties used and the purposes for including them in this study are listed in Table 1. The stake numbers are given to identify the varieties with samples of the sliced fruit in Figure 1.

TABLE 1 - VARIETIES AND PURPOSE IN STUDY OF TOMATO QUALITY FACTORS

Variety + Stake Number	Purpose
Oxheart - 50	beefsteak type
Pink Ponderosa - 51	pink variety and "low-acid"*
White Queen - 52	white variety and "anti-acid"*
Orange Jubilee - 53	orange variety and "non-acid"*
Tomboy - 54	pink beefsteak, quality unknown
Improved Garden State - 55	commercial canning variety (control)
K-135 - 56	commercial canning variety
H-1370 - 57	commercial canning variety
K-146 - 58	commercial canning variety
I-417-1 - 59	greenhouse (low acid and sugar)
I-418-3 - 60	greenhouse (control)

* As advertised by commercial seed companies.

The authors thought that these 11 selected varieties and breeding lines would give the maximum range for acid and sugar present among common cultivated varieties of *Lycopersicon esculentum.*

Cultural Practices

On March 26, 1962, seeds of the varieties were seeded in vermiculite in flats. They remained in the flats until the first pair of true leaves appeared. The plants were then potted-off into 3-inch peat pots. They remained in the greenhouse until April 25, at which time they were removed to cold frames to harden them for the field planting. On May 14, they were transplanted to the experimental field plots at the New Franklin Horticulture Research Farm. They were set in individual rows, seven plants per row for each variety. The rows were seven feet apart and the plants were two feet apart within the row.

The statistical design used was a completely randomized block with five replications for each variety.

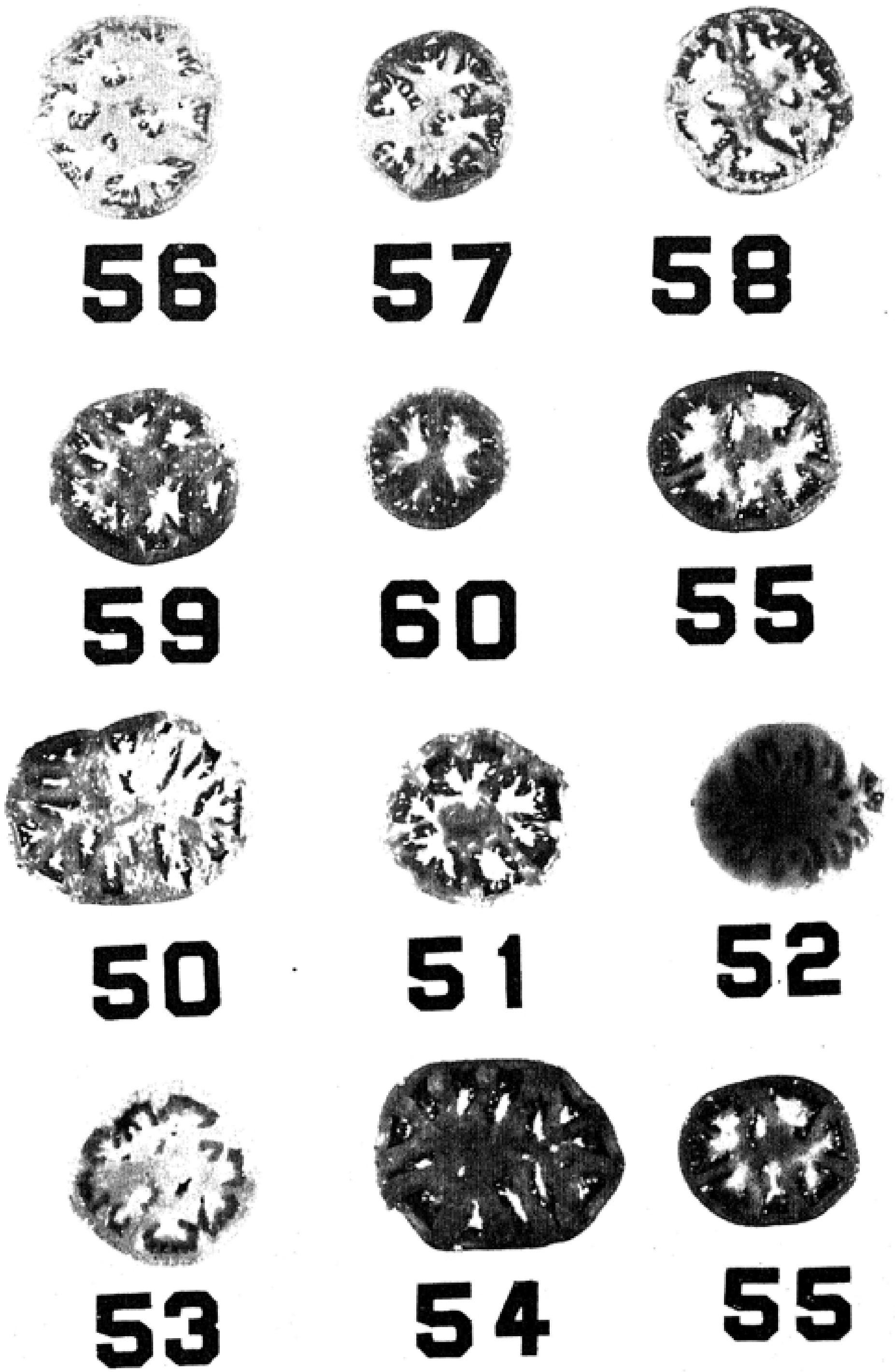


Fig. 1—Composite photograph of sliced fruits of tomato varieties and breeding lines included in the study.

The soil in the field was wilt-free and fairly uniform from one end of the field to the other end. The soil on which the crop was grown gave the following soil test (Missouri procedures) before fertilization.

Organic matter	1.6 percent
Phosphorus	130.0 pounds per acre
Exchangeable Potassium	365.0 pounds per acre
Exchangeable Calcium	3650.0 pounds per acre
Exchangeable Hydrogen	1.7 meq./100 g. soil
pH	5.7

Adequate fertilizers were added to maintain vigorous growth and heavy fruiting. A plow-down application of 300 pounds per acre of 12-12-12 and 250 pounds per acre of 0-56-0 was made, followed by several side dressings of Ammo-Phos (11-48-0) and ammonium nitrate (33-0-0) after flowering started. Limestone was also plowed down, at a rate of 2 tons per acre, before the crop was transplanted.

There was some rainfall throughout most of the growing season (Table 28). This rainfall was supplemented with irrigation water applied by sprinklers at various times during the season. A total of approximately 10 inches of irrigation water was added (Table 2).

TABLE 2 - SIDE-DRESSINGS, IRRIGATION, AND SPRAYING PROGRAM FOR TOMATO VARIETIES IN QUALITY STUDY

Treatment	Amount	Date
Fertilization		
11-48-0	25 lbs. N/acre	June 8, 1962
Ammonium Nitrate	25 lbs. N/acre	July 6, 1962
Ammonium Nitrate	25 lbs. N/acre	Aug. 2, 1962
Irrigation	(after)	
Sprinklers	1½ in. (transplant)	May 14, 1962
Sprinklers	2 in.	June 21, 1962
Sprinklers	1½ in.	July 3, 1962
Sprinklers	2 in.	July 17, 1962
Sprinklers	1½ in.	Aug. 3, 1962
Sprinklers	1½ in.	Aug. 17, 1962
Spraying		
Dieldrin	2#/100 gal.	May 9, 1962
Zineb and Sevin	2# each/100 gal.	May 29, 1962
Zineb, Sevin, Marlate	2# each/100 gal.	June 6, 1962
Zineb, Methoxychlor	2# each/100 gal.	June 19, 1962
Zineb, Sevin, Malathion	2# each/100 gal.	July 6, 1962
Zineb, Sevin	2# each/100 gal.	July 31, 1962

For insect and disease control, the plants were sprayed about every 10 days during the growing season with an insecticide-fungicide mixture. Table 2 gives the side-dressings, irrigation, and spraying program for the crop for the entire season.

The fruits were picked from the individual varieties by plot and kept separate for each plot. Weights of the fruit were kept on each variety to campare the varieties for yield and number of fruit per plant with data on other varieties in a separate study.

Methods for Preparing Sample

One dozen fruits from each variety were selected from comparable positions on the plants in a row. They were also selected for uniformity in size and shape and color typical of the variety. These samples were then taken to the Horticulture Laboratories for analysis. Since stage of maturity has a significant effect upon the levels of the quality constituents of the tomato, as found by McCollum (30), it is important that fruits of equal maturity be selected.

It is difficult to measure maturity in tomato fruits between varieties and between fruits of the same variety. McCollum (30) stated that maturity cannot be determined by age, size, color, or any other apparent characteristic. He recommended the time of incipient coloring as a good indication of equal maturities. Samples harvested at this incipient coloring or so-called "turning stage" should be ripened at a constant temperature of about 20°C. for a period of time. This period of time varies from seven to 14 days as suggested by other workers in the field (3) (43). Thompson, Hepler, Lower, and McCollum (43) suggested picking the samples at the "turning stage" and placing them in an air conditioned ripening chamber maintained at a temperature of 65°F. Therefore, in this study, an analysis of quality factors was also made on chamber-ripened fruits picked at the same stage of incipient coloring.

The picking dates are shown in Table 3, along with the data as to whether fruits for that date were vine-ripened or chamber-ripened.

TABLE 3 - PICKING DATES AND RIPENING PROCESS FOR TOMATO VARIETIES IN QUALITY STUDY OF 1962

Date	Ripening Process
July 16, 1962	vine
July 20, 1962	chamber
July 23, 1962	vine
July 26, 1962	chamber
Aug. 2, 1962	chamber
Aug. 6, 1962	chamber
Aug. 29, 1962	vine
Aug. 29, 1962	chamber
Sept. 4, 1962	vine

The vine-ripened fruits were brought into the laboratory and the analyses were run on the following day. The chamber-ripened fruits were put into ripening chambers set at 65°F. and left there for seven days before they were analyzed.

Procedure for Analyzing Sample

Four uniformly-ripened fruits were selected from the 12 fruits previously picked of each variety. These four fruits were cut into quarters and two quarters from each fruit were chosen. These quarters were blended in a Waring Blendor for 2 minutes and the slurry was then filtered through paper towels. Paper towels were found to work better than filter paper. A special filter stand was built to hold several plastic funnels, so several samples could be filtered at the same time (Figure 2). This facilitated the process, as filtering was the most time consuming part of the testing procedure.

Ten ml. of filtered juice were added to 40 ml. of distilled water in a beaker. Readings for pH were made from this sample on a Beckman Zeromatic pH meter. The titratable acidity was also measured from this sample by using 0.1201 N NaOH and titrating to an end-point of 8.1 (Figure 3). Total titratable acidity was expressed as percent citric acid equivalent.

The total of soluble solids of the fruit was measured on a precision, laboratory model Abbe' refractometer with a refractive index scale. One drop of the filtered juice was used for this determination. Corrections were made for temperature according to the thermometer on the refractometer. The results were reported as percent Brix as taken fom tables in A.O.A.C. (4). The remainder of the filtered juice was put into small bottles, labeled, and stored at 15°F. This sample was thawed and used for analysis of invert sugar during the fall of 1962. The sugar-acid ratios for the varieties were calculated by dividing the percent sugar as Brix by the percent citric acid equivalent.

The method used for determination of invert sugar was the Lane-Eynon General Volumetric Method as described in A.O.A.C. (4). This method gives the invert sugar as mg. per 100 ml. of solution. The invert sugar was then reported as a percent of the total fruit composition. The invert sugar analysis had no replication as a composite sample of the five previously selected samples was used for the invert sugar analysis.

Statistical Analysis of Data

These data were analyzed by the analysis of variance method using the facilities of the University computor service. Significant differences were computed between picking date, variety, replication, and the interactions. The analysis of variance was first run on the total of all picking dates. Following this, the four vine-ripened dates were selected. An analysis was run for them and for the five chamber-ripened dates. The means were then ranked and significant differences shown by Duncan's "New Multiple Range Test" (21). This test, as explained by Steele and Torrie (42), gives the shortest significant range for data having several means and provides a test for comparing any variety mean with any other variety mean. The same holds true for comparing the date means among themselves or the interaction means among themselves. As explained by Steele and Torrie (42), this test has considerable advantage over the commonly used LSD tests and greater accuracy.

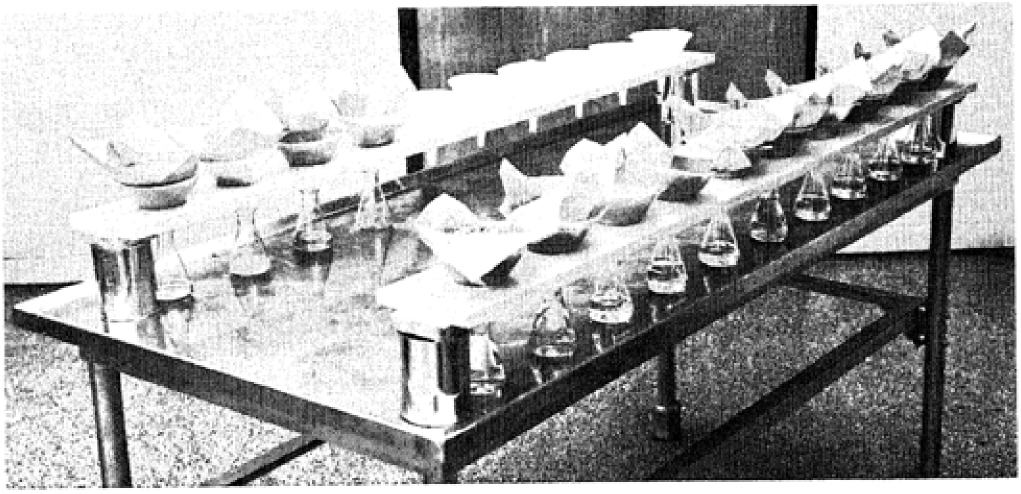


Fig. 2—Equipment and setup used for filtering of samples for analysis.

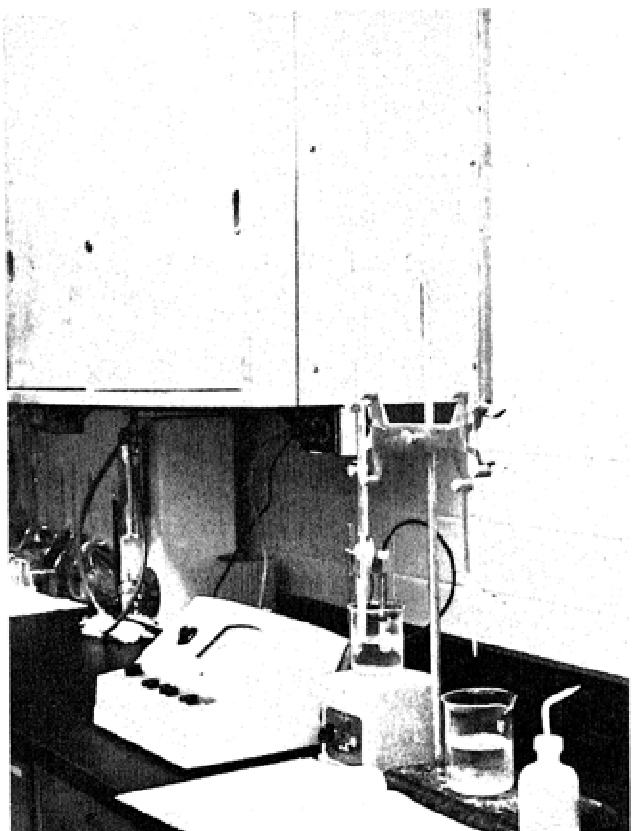


Fig. 3—Titrating apparatus and pH meter used for measuring acidity.

Procedure for Taste Testing

On August 29, juice was extracted from ripe fruit of all varieties and canned by a boiling water bath process, holding cans at 212°F. for 35 minutes. These cans of juice were stored and were used for taste panel testing in the spring of 1963.

The varieties, showing extremes for the quality factors studied the previous summer and fall, were chosen as samples to be used in the taste panel studies. Before the actual juice was used for taste testing, model solutions were prepared by using citric and malic acids in a 60:40 ratio in distilled water and adding sucrose to get the proper sugar concentration. These solutions were made to compare with the concentrations of the extremes in pH, titratable acidity, sugar, and sugar-acid ratio found in tomato juice. The solutions were given to taste panels to determine if taste differences could be detected among them. The triangle taste test, as explained by Roessler, Warren, and Guynon (34), was used.

Three samples were given to the panel members; two of the samples were alike, the third was different. The samples were given to the panel members in a three-fourths ounce portion cup. Cups were coded at random on the bottom. Each taste panel consisted of 15 members. The results were recorded as number of panel members detecting a difference. This number was applied to tables of significance for the triangle taste test, as given by Roessler, Warren, and Guynon (34). The tomato juice was filtered before it was given to the panel members to remove the color. This eliminated possible bias due to color of the juice. Taste panel results were recorded in the manner described for the model systems.

The taste panel members consisted of randomly selected personnel from the Agriculture Building of the University of Missouri. Panel members ranged from students to retired professors. Both males and females were included to reduce influence of sex on preference.

RESULTS AND DISCUSSION

Seasonal Varietal Variation in Quality Factors

Chamber-Ripened Tomatoes. There were five picking dates throughout the season in which the tomato fruits were chamber-ripened. Table 4 gives the analysis of variance for the pH values of the fruit.

TABLE 4 - ANALYSIS OF VARIANCE OF pH FOR CHAMBER-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	4	.0773	23.42**
Variety	10	.1390	42.12**
Date x Variety	40	.0052	1.57
Error	220	.0033	
Total	274		

** Significant at the .01 level.

The variation due to replication in the analysis of variance was small for all the quality factors in this study; therefore, it was included in the error term in all cases. As seen in Table 4, the pH differed significantly for variety and picking date. The means of the varieties and significant differences are shown in Table 5 along with the shortest significant ranges.

TABLE 5 - RANKED VARIETAL MEANS FOR pH READINGS OF CHAMBER-RIPENED FRUIT

Variety	Mean	Shortest Significant Ranges[1]
I-417-1	4.54	a
Imp. Garden State	4.52	ab
Oxheart	4.50	abc
K-146	4.47	bcd
H-1370	4.47	bcde
K-135	4.47	bcdef
Orange Jubilee	4.39	f
Tomboy	4.37	f
I-418-3	4.36	f
White Queen	4.36	f
Pink Ponderosa	4.34	f
MEAN	4.44	

[1] Means with the same letter are not different from each other at the .01 level of significance.

The range in pH was from 4.34 to 4.54. This range falls in the ranges which were found by other workers and reported in the review of literature. Although this appears to be a small range, one must remember that pH is on a logarithmic scale, meaning that a pH of 4.0 is ten times more acid than a pH of 5.0. The varieties appear to fall into two groups. A high pH group was composed mainly of canning varieties and extended down to a pH of 4.47. From the canner's viewpoint, the canning varieties had a pH that would be undesirable as many of the spoilage microorganisms can thrive at such high pH levels. White Queen, which is supposedly low-acid, was the second most acid variety, considering pH level alone. The low pH group included primarily the pink and white varieties.

Titratable Acidity of Chamber-Ripened Tomatoes. The analysis of variance for the titratable acidity was computed on the ml. of .1201 N NaOH required to bring the pH to an end-point of 8.1. This value was converted to percent citric acid equivalent.

There were significant differences in titratable acidity due to date and to variety (Table 6). The date x variety interaction also showed a small significance. Table 7 ranks the varieties according to their means and gives the shortest significant ranges for titratable acidity among the varieties.

TABLE 6 - ANALYSIS OF VARIANCE FOR TITRATABLE ACIDITY IN CHAMBER-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	4	15.28	45.69**
Variety	10	9.71	29.06**
Date x Variety	40	.79	2.36
Error	220	.33	
Total	274		

** Significant at the .01 level.

TABLE 7 - RANKED VARIETAL MEANS FOR TITRATABLE ACIDITY OF CHAMBER-RIPENED FRUIT

Variety	Mean (% citric acid)	Shortest Significant Ranges[1]
Orange Jubilee	.544	a
I-418-3	.491	ab
Pink Ponderosa	.485	bc
K-146	.470	bcd
K-135	.464	bcde
Tomboy	.464	bcdef
White Queen	.455	bcdefg
Imp. Garden State	.442	bcdefg
H-1370	.440	bcdefg
Oxheart	.416	g
I-417-1	.354	
MEAN	.456	

[1] Means with the same letter are not different from each other at the .01 level of significance.

The range in percent citric acid was from 0.354 to 0.544 percent. This level of acid is in close agreement with that obtained by Scott and Walls (39) and also with the reportings of Cameron (11). The Orange Jubilee variety, normally advertised as being low in acid, was found to have the highest level of acidity. The greenhouse line, I-417-1, was the lowest in acidity. This confirmed earlier findings for this line. The population had a distinct high and low variety, with the other nine varieties tending to be more closely grouped together and showing less difference among them.

Soluble Solids of Chamber-Ripened Tomatoes. The soluble solids, as mentioned earlier, are mainly sugars (20) (39). The data show the soluble solids as percent sugar on the Brix scale. The analysis of variance, Table 8, was run on the corrected refractometer readings and then the values obtained were converted back to percent sugar.

The date of picking the fruit had a very significant effect; and the variety effect was significant. There was also a significant interaction of date x

TABLE 8 - ANALYSIS OF VARIANCE FOR SOLUBLE SOLIDS IN CHAMBER-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	4	.0408	136.00**
Variety	10	.0062	20.66**
Date x Variety	40	.0009	3.00**
Error	220	.0003	
Total	274		

** Significant at the .01 level.

variety. The date x variety interaction showed that not all varieties vary the same in level of sugar from one picking date to the next. Therefore, some varieties appear to increase or decrease more than others in sugar level from one harvest date to the next. Table 9 ranks the varietal means for soluble solids and gives their shortest significant ranges.

TABLE 9 - RANKED VARIETAL MEANS FOR SOLUBLE SOLIDS OF CHAMBER-RIPENED FRUIT

Variety	Mean (% Brix)	Shortest Significant Ranges[1]
Orange Jubilee	4.52	
Imp. Garden State	3.94	
I-418-3	3.78	a
K-146	3.74	ab
K-135	3.74	abc
Oxheart	3.74	abcd
Pink Ponderosa	3.72	bcd
Tomboy	3.62	
I-417-1	3.38	
White Queen	3.30	
H-1370	3.12	
MEAN	3.69	

[1] Means with the same letter are not different from each other at the .01 level of significance.

The range for soluble solids was from 3.12 to 4.52 percent Brix. This concentration is in the same range of 4 to 6 percent soluble solids given by Cameron (11) in his study of tomato composition. The Orange Jubilee variety had the highest level of sugar in the fruit; the canning variety, H-1370, was the lowest in sugar content. This low sugar content would be highly undesirable for a canning type tomato especially if catsup, puree or paste were to be made. A high soluble solid sugar content is advantageous for these products. The other canning varieties ranked high in sugar level as expected for this type of tomato.

The Orange Jubilee variety was high in both sugar and acid. The high sugar level could be masking the effect of the high acid content so far as taste is concerned and thereby causing the public to believe that it is actually low in acid, as inferred by the advertising.

Invert Sugar of Chamber-Ripened Tomatoes. As mentioned earlier, the invert sugar determinations were not replicated and the analysis of variance was determined only on the date and variety (Table 10).

TABLE 10 - ANALYSIS OF VARIANCE FOR INVERT SUGAR IN CHAMBER-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	4	.1390	5.673**
Variety	10	.3091	12.616**
Error	40	.0245	
Total	54		

** Significant at the .01 level.

Variety shows more variation than does date in the analysis of invert sugar, although both have significant effects upon the level of invert sugar in the fruit (Table 11).

TABLE 11 - RANKED VARIETAL MEANS FOR INVERT SUGAR OF CHAMBER-RIPENED FRUIT

Variety	Mean (%)	Shortest Significant Ranges[1]
Orange Jubilee	3.32	
I-418-3	3.10	a
Tomboy	2.96	ab
Pink Ponderosa	2.93	abc
I-417-1	2.91	bcd
K-135	2.88	bcde
Imp. Garden State	2.88	bcdef
K-146	2.79	bcdefg
Oxheart	2.78	bcdefgh
White Queen	2.65	gh
H-1370	2.39	
MEAN	2.87	

[1] Means with the same letter are not different from each other at the .01 level of significance.

The range for invert sugar was from 2.39 to 3.32 percent. This range is in close agreement with the reports of Cameron (11). The Orange Jubilee variety had the highest amount of invert sugar as would be expected since it had the highest amount of soluble solids. The canning line, H-1370, which was low in soluble solids, was also low in invert sugar. Most of the other varieties fell into or near the position they held for soluble solids. The invert sugar analysis also showed that the total amount of soluble solids was approximately 74 to 77 percent invert sugar.

Sugar Acid Ratio of Chamber Ripened Tomatoes. The sugar-acid ratio was calculated by dividing the percent acid into the percent sugar as Brix.

In the sugar-acid ratio analysis given in Table 12, both date and variety show significant effects. This would be expected since environment has such an important effect upon the sugar and acid level of the fruit as mentioned earlier in the literature. Therefore, the sugar-acid ratio, which is dependent on both of these, would be highly affected by the environment preceding a picking date.

TABLE 12 - ANALYSIS OF VARIANCE OF SUGAR-ACID RATIOS FOR CHAMBER-RIPENED FRUIT

Source if Variation	D.F.	M.S.	F value
Date	4	217.63	147.81**
Variety	10	13.65	9.27**
Date x Variety	40	3.12	2.12
Error	220	1.47	
Total	274		

As shown in Table 13, the range in sugar-acid ratios was from 7.28 to 9.66. This range is in agreement with the studies of Scott and Walls (39) who found a range of 6.9 to 10.8 in the fresh fruit. The greenhouse line, I-417-1, had the highest sugar-acid ratio since it was the lowest in acid level and near the middle of the population in sugar level. The canning variety, H-1370, was the lowest in

TABLE 13 - RANKED VARIETAL MEANS FOR SUGAR-ACID RATIO OF CHAMBER-RIPENED FRUIT

Variety	Mean	Shortest Significant Ranges[1]
I-417-1	9.66	a
Improved Garden State	9.23	ab
Oxheart	8.99	abc
Orange Jubilee	8.43	abcd
K-135	8.28	bcd
K-146	7.93	bcd
Tomboy	7.90	bcd
I-418-3	7.81	cd
Pink Ponderosa	7.74	cd
White Queen	7.44	cd
H-1370	7.28	d
MEAN	8.25	

[1] Means with the same letter are not different from each other at the .01 level of significance.

sugar-acid ratio since it was the lowest in sugar level and near the average of the population in acid content.

In studying the sugar-acid ratio, less significant difference was found when comparing varieties than when comparing harvest dates.

pH of Vine-Ripened Tomatoes. The analyses of variance for the quality factors were run in the same manner for the vine-ripened fruit and the chamber-ripened fruit. The vine-ripened fruit was harvested on only four picking dates.

The variability in pH of fruits that were vine-ripened was due mostly to variability in picking date (Table 14). The difference between varieties and their pH readings was also significant; but to a less degree than was the picking date. This was just the opposite effect of that found with the chamber-ripened fruit where variety showed the greatest effect. This would be expected since the more uniform ripening occurring in the chamber would eliminate most of the variability due to environmental factors. In Table 14, the interaction of date x variety was not significant.

TABLE 14 - ANALYSIS OF VARIANCE OF pH FOR VINE-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	3	.4238	66.21**
Variety	10	.2209	34.51**
Date x Variety	30	.0110	1.71
Error	176	.0064	
Total	219		

** Significant at the .01 level.

Among the varieties tested, Improved Garden State showed the highest pH and the white variety, White Queen, had the lowest pH (Table 15). The pH

TABLE 15 - RANKED VARIETAL MEANS OF pH READINGS FOR VINE-RIPENED FRUIT

Variety	Means	Shortest Significant Ranges[1]
Improved Garden State	4.69	
Oxheart	4.59	a
I-417-1	4.56	ab
H-1370	4.54	abc
K-135	4.50	abcd
K-146	4.49	bcde
Orange Jubilee	4.43	def
Pink Ponderosa	4.41	def
I-418-3	4.38	f
Tomboy	4.37	f
White Queen	4.37	f
MEAN	4.48	

[1] Means with the same letter are not different from each other at the .01 level of significance.

range was from 4.37 to 4.69. Many of the varieties showed a pH at which the bacteria, *Bacillus coagulans*, could cause spoilage in canned tomato products. Most of the commercial canning varieties fell in the high pH range—a characteristic which would be undesirable from the canner's viewpoint.

Titratable Acidity of Vine-Ripened Tomatoes. The analysis of variance for the titratable acidity given in Table 16 was computed on the number of milliliters of NaOH required to reach the end-point of 8.1. Values were converted back to the percent citric acid equivalent.

TABLE 16 - ANALYSIS OF VARIANCE FOR TITRATABLE ACIDITY OF VINE-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	3	18.5484	44.26**
Variety	10	5.7706	13.77**
Date x Variety	30	.8534	2.03
Error	176	.4190	
Total	219		

** Significant at the .01 level.

Date of harvest seemed to have the most significant effect upon the titratable acidity. However, the variety variation was also significant. The date x variety interaction was not significant at the 0.01 level. Table 17 ranks the means for each variety and the shortest significant ranges.

TABLE 17 - RANKED VARIETAL MEANS FOR TITRATABLE ACIDITY OF VINE-RIPENED FRUIT

Variety	Mean (% acid)	Shortest Significant Ranges[1]
Orange Jubilee	.498	a
Tomboy	.471	ab
I-418-3	.461	abc
Pink Ponderosa	.459	abcd
K-146	.458	abcde
K-135	.443	bcdef
White Queen	.434	bcdefg
H-1370	.413	cdefgh
Oxheart	.399	fgh
Improved Garden State	.380	gh
I-417-1	.361	h
MEAN	.434	

[1] Means with the same letter are not different from each other at the .01 level of significance.

The orange variety, Orange Jubilee, which is commonly advertised as non-acid, had the highest level of acidity. The greenhouse line, I-417-1, had the lowest level of acidity, as determined previously. The White Queen variety, which is advertised as anti-acid, was fairly high in acidity, being above the average of the population in this respect. The range in titratable acidity for the 11 varieties was from 0.361 to 0.498 percent citric acid equivalent. The canning varieties tend to be near the middle of the population in titratable acidity.

Soluble Solids of Vine-Ripened Tomatoes. Table 18 gives the analysis of variance for the soluble solids content of vine-ripened fruit. The analysis was run on the corrected refractometer readings and converted to percent sugar as taken from the Brix scale.

TABLE 18 - ANALYSIS OF VARIANCE FOR SOLUBLE SOLIDS OF VINE-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	3	.0623	62.30**
Variety	10	.0078	7.80**
Date x Variety	30	.0009	.90
Error	176	.0010	
Total	219		

** Significant at the .01 level.

Both date and variety showed a significant effect upon soluble solids. The date x variety interaction was not significant at the 0.01 level of significance.

Table 19 gives the ranking of the means for soluble solids by variety and the shortest significant ranges.

TABLE 19 - RANKED VARIETAL MEANS FOR SOLUBLE SOLIDS OF VINE-RIPENED FRUIT

Variety	Mean (% Brix)	Shortest Significant Ranges[1]
Orange Jubilee	5.12	
Improved Garden State	4.77	
K-135	4.60	a
I-418-3	4.57	ab
Oxheart	4.55	ab
Pink Ponderosa	4.50	ab
Tomboy	4.42	b
K-146	4.42	b
I-417-1	4.10	
H-1370	3.85	
White Queen	3.60	
MEAN	4.40	

[1] Means with the same letter are not different from each other at the .01 level of significance.

As found with the chamber-ripened fruit, Orange Jubilee was highest in sugar content. The White Queen variety was the lowest in sugar content of the vine-ripened fruit. Two of the canning varieties, K-146 and H-1370, are fairly low in soluble solids content and this is undesirable for this type of tomato. The beefsteak tomatoes are all adjacent at the middle of the population, possibly indicating a relationship between size and soluble solids. The population shows fairly wide extremes in soluble solids with most of the varieties clustered toward the center and near the average.

Invert Sugar of Vine-Ripened Tomatoes. The analysis of variance results for invert sugar of vine-ripened fruit are shown in Table 20.

TABLE 20 - ANALYSIS OF VARIANCE FOR INVERT SUGAR OF VINE-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	3	.1010	2.39
Variety	10	.2948	7.00**
Error	30	.0421	
Total	43		

** Significant at the .01 level.

Invert sugar did not vary significantly with harvest date. However, Table 20 shows that variety had a significant effect upon invert sugar. In both cases, the calculated F values were fairly low. This also occurred in the analysis for the chamber-ripened fruit. Variations among fruits with respect to level of invert sugar seem associated with some factors other than date of picking.

Table 21 shows that the Orange Jubilee variety was highest in invert sugar as well as soluble solids or sugar as percent Brix. Invert sugar has a high degree

TABLE 21 - RANKED VARIETAL MEANS FOR INVERT SUGAR OF VINE-RIPENED FRUIT

Variety	Mean (%)	Shortest Significant Ranges[1]
Orange Jubilee	3.41	
I-418-3	3.17	a
Improved Garden State	3.11	ab
Tomboy	3.04	abc
K-135	2.96	abcd
Pink Ponderosa	2.95	abcd
I-417-1	2.92	bcd
K-146	2.82	cd
White Queen	2.79	cd
Oxheart	2.77	d
H-1370	2.37	
MEAN	2.93	

[1] Means with the same letter are not different from each other at the .01 level of significance.

of sweetness and, therefore, one would expect that Orange Jubilee would taste very sweet. The canning variety, H-1370, was lowest in invert sugar, and the second lowest in soluble solids. As with the chamber-ripened fruit, data on vine-ripened fruit showed that the soluble solids were approximately 70 to 75 percent invert sugar.

Sugar-Acid Ratio of Vine-Ripened Tomatoes. The sugar-acid ratio was again calculated by dividing the percent sugar as Brix by the percent acid as citric.

Table 22 shows that date of harvest had a highly significant effect upon the sugar-acid ratios of the vine-ripened fruit as was also found with the chamber-ripened fruit. This is because the date affected greatly the sugar level and the acid level, thereby being doubly effective upon the sugar-acid ratio. Varieties also showed a significant difference among themselves. The date x variety interaction was not significant.

TABLE 22 - ANALYSIS OF VARIANCE FOR SUGAR-ACID RATIO OF VINE-RIPENED FRUIT

Source of Variation	D.F.	M.S.	F value
Date	3	344.4559	169.54**
Variety	10	30.6812	15.10**
Date x Variety	30	4.3729	2.15
Error	176	2.0316	
Total	219		

** Significant at the .01 level.

In the varietal ranking (Table 23), the canning variety, Improved Garden State, had the highest sugar-acid ratio. Of the varieties tested, it had the second

TABLE 23 - RANKED VARIETAL MEANS FOR SUGAR-ACID RATIO OF VINE-RIPENED FRUIT

Variety	Mean	Shortest Significant Ranges[1]
Improved Garden State	13.11	a
Oxheart	11.94	ab
I-417-1	11.55	bc
K-135	10.65	bcd
Orange Jubilee	10.32	bcde
I-418-3	10.14	cdef
Pink Ponderosa	10.00	cdef
H-1370	9.87	cdef
K-146	9.82	cdef
Tomboy	9.54	def
White Queen	8.38	f
MEAN	10.23	

[1] Means with the same letter are not different from each other at the .01 level of significance.

highest level of sugar and the second lowest level of acid. The White Queen variety had the lowest sugar-acid ratio as it was the lowest in sugar while the acid level was near the average for the varieties tested. Orange Jubilee, which was the highest in sugar and the highest in acidity, was near the average in sugar-acid ratio.

The sugar-acid ratios were higher for the vine-ripened fruit than they were for the chamber-ripened fruit. This is because vine-ripening increased the soluble solids of the fruit over that of chamber-ripening, while the acid levels of fruits of these two ripening processes were the converse. The chamber-ripened fruit had the highest level of acid. This difference in sugar-acid ratio between the two ripening processes is likely associated with different rates in the respiratory breakdown of sugars and organic acids in the fruits.

Effects of Vine-Ripening Versus Chamber-Ripening

Since the stage of maturity has such a marked effect upon the quality factors, (30), (43), and since this maturity cannot be determined by size, age, or color of the fruit, this study included both vine-ripened and chamber-ripened fruit. The chamber-ripened fruit would be expected to be more uniform due to the samples being ripened under a more uniform environment.

The error mean squared (24) is a measure of dispersion of a population and is an average value for the squares of the deviations as explained by Huntsberger (24). Therefore, a larger error mean squared would indicate a population with larger deviations from the mean than would a small error mean squared. This principle will be used in this study to determine which population has more homogeneity—vine-ripened fruits or chamber-ripened fruits. Table 24 gives the error mean squares for each of the quality factors for both chamber-ripened and vine-ripened fruit.

TABLE 24 - ERROR MEAN SQUARE VALUE FOR QUALITY FACTORS OF VINE-RIPENED AND CHAMBER-RIPENED FRUITS

Quality Factor	Vine-Ripened	Chamber-Ripened
pH	.0064	.0033
Titratable Acidity	.4190	.3344
Soluble Solids	.0010	.0003
Invert Sugar	.0421	.0245
Sugar-Acid Ratio	2.0316	1.4723

In all cases for each quality factor studied, the chamber-ripened fruit had a smaller error mean square value, indicating a smaller dispersion from the mean than for the vine-ripened fruit. Therefore, the chamber-ripened fruit can be said to be more homogeneous than the vine-ripened fruit. This should be taken into consideration when studies or evaluations are to be made on the quality factors of tomato fruits. Table 25 gives the ranges for the quality factors from both vine-ripened and chamber-ripened fruits.

TABLE 25 - RANGES FOR QUALITY FACTORS OF VINE-RIPENED AND CHAMBER-RIPENED FRUITS

Quality Factor	Vine-Ripened	Chamber-Ripened
pH	4.37 -- 4.69	4.34 -- 4.54
Titratable Acidity	.361 -- .498	.354 -- .544
Soluble Solids	3.60 -- 5.12	3.12 -- 4.52
Invert Sugar	2.37 -- 3.41	2.39 -- 3.32
Sugar-Acid Ratio	8.38 -- 13.11	7.28 -- 9.66

In all cases except titratable acidity, the range spread is greater for the vine-ripened fruit than for the chamber-ripened fruit. This would indicate that chamber-ripened fruits are more homogeneous in quality factors than are the vine-ripened fruits. The levels for all of the quality factors appear to be higher in the vine-ripened fruit as compared to the chamber-ripened fruit. This finding could account for the poor flavor of most "shipped in" tomatoes which were picked immature and ripened off of the vine. Vine-ripened fruits not only accumulate more sugar but have a lower acid level; these are traits considered by most authorities to contribute to improved flavor.

Seasonal Trends in the Quality Factors of Tomatoes

As mentioned in the Review of Literature, season does have an effect upon the quality factors of tomatoes. Figures 4, 5, 6, 7, and 8 show the seasonal trends in the various quality factors for both the chamber-ripened and vine-ripened fruits.

pH. Figure 4 shows the seasonal trends for pH of chamber-ripened and vine-ripened fruit. The vine-ripened fruit tended to have a higher pH level than the chamber-ripened fruit. The vine-ripened fruit's pH was high at the beginning of the season and gradually decreased as the season progressed. The seasonal trends of pH appear to be in close agreement with the titratable acidity trends observed in Figure 5. The pH showed a gradual decline as the season progressed and the titratable acidity showed a gradual increase. This would be expected since fruits with a high pH generally have a low level of acidity and vice versa.

One possible reason for the pH being lower as the season progresses is that of lower soil moisture. As mentioned earlier, Lee and Sayre (27) found a lower pH level in the fruit with a restricted soil moisture supply. In the current study, the soil moisture supply to the tomatoes was lower from about July 15 until the end of the season (Tables 2 and 26). Another explanation is that of increased daily mean temperatures (Table 27). As the temperature increases there is an increased amount of sugars being respired to organic acids, thereby increasing the acidity level.

Titratable Acidity. The seasonal trends for titratable acidity are shown in Figure 5. The trends for both the chamber-ripened fruit and the vine-ripened fruit are very similar. The chamber-ripened fruits have a higher level of titratable

FIGURE 4.

SEASONAL TRENDS OF pH FOR CHAMBER-RIPENED AND VINE-RIPENED FRUIT

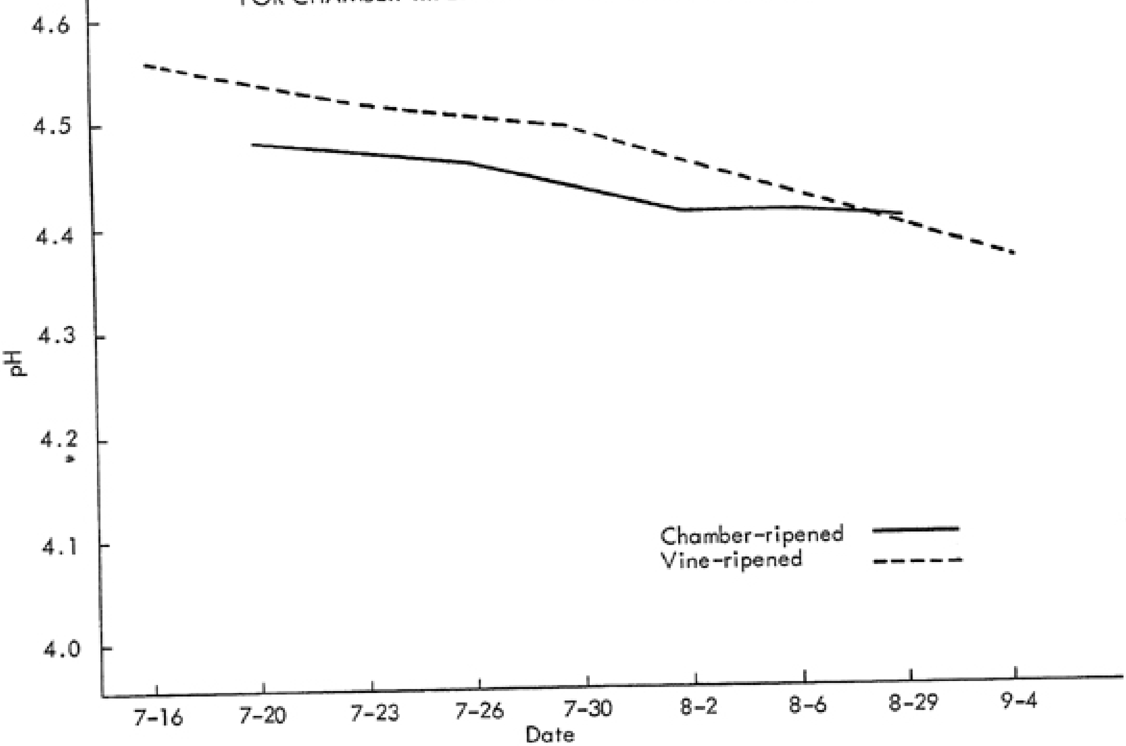


FIGURE 5.

SEASONAL TRENDS OF TITRATABLE ACIDITY FOR CHAMBER-RIPENED AND VINE-RIPENED FRUIT

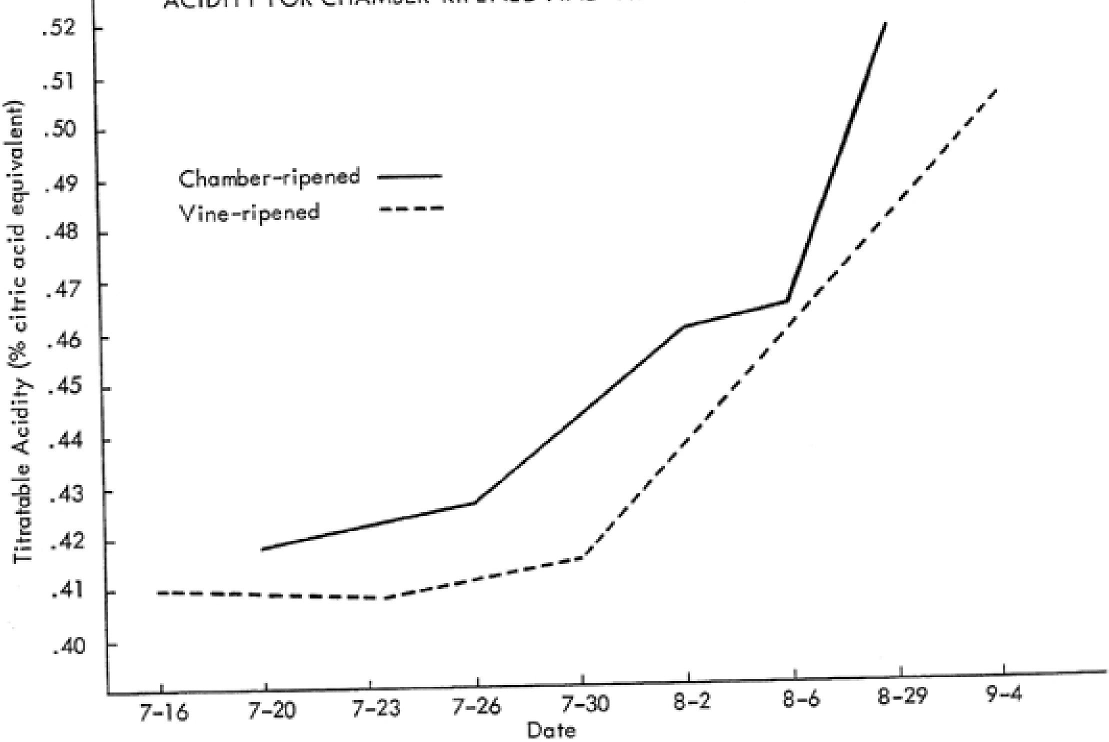


TABLE 26 - TOTAL RAINFALL FOR TWO-WEEK PERIODS DURING THE GROWING SEASON OF 1962*

Month and Period	Amount (Inches)
May	
1-15	.72
15-31	2.58
June	
1-15	1.52
15-30	.00
July	
1-15	1.60
15-31	.59
August	
1-15	1.52
15-31	.72
September	
1-15	2.89

* As recorded at New Franklin Horticulture Research Farm.

TABLE 27 - MEAN TEMPERATURES FOR TWO-WEEK PERIODS DURING THE GROWING SEASON OF 1962*

Month and Dates	Maximum (°F)	Minimum (°F)	Dry-Bulb**
May			
1-15	82.4	58.0	76.2
15-31	86.1	63.0	82.1
June			
1-15	79.6	59.8	74.9
15-30	88.4	64.0	83.6
July			
1-15	90.8	69.5	86.6
15-31	87.6	62.4	82.7
August			
1-15	89.1	63.2	85.7
15-31	93.8	65.3	87.9
September			
1-15	81.1	60.4	76.0

* As recorded at New Franklin Horticulture Research Farm.

** Reading taken at 5:00 p.m. daily.

TABLE 28 - TASTE PANEL RESULTS OF MODEL SOLUTIONS

Quality Factor and Range	Tasters Detecting Differences	
	Obtained	Required[1]
pH		
4.00 --- 4.40	14	10
4.00 --- 4.20	13	10
4.20 --- 4.40	7	10
4.28 --- 4.50*	12	10
Titratable Acidity		
.300 --- .600	14	10
.388 --- .510*	13	10
Sugar (Brix)		
3.0 --- 4.5	15	10
3.5 --- 4.0	7	10
3.2 --- 4.3*	13	10
Sugar-acid Ratio		
6.00 --- 10.00	15	10
7.02 --- 8.85*	7	10

* Indicates same extremes as found in raw tomato juice.

[1] Number of correct answers to establish results significant to the .01 level with fifteen panel members (34).

TABLE 29 - TASTE PANEL RESULTS FOR EXTREMES IN QUALITY FACTORS OF ACTUAL TOMATO JUICE

Quality Factor and Range	Tasters Detecting Differences	
	Obtained	Required[1]
pH		
4.28 --- 4.50	7	10
Titratable Acidity		
.388 --- .510	6	10
Sugar (Brix)		
3.2 --- 4.3	8	10
Sugar-Acid Ratio		
7.02 --- 8.85	7	10

[1] Number of correct answers to establish results significant at the .01 level with fifteen panel members (34).

acidity throughout the entire season. The seasonal trends, in general, are in agreement with the findings of Lee and Sayre (27). However, they found a much higher level of titratable acidity at the beginning of the season and also a steeper decline until midseason. The reason for the general increase in acidity is possibly the same as for the decrease in pH—lower soil moisture supply. Also, as mentioned under pH, the temperature increase could cause an increase in acid level.

Soluble Solids. Figure 6 shows the seasonal trends observed for soluble solids or percent sugar as Brix. The chamber-ripened fruits had a high level of sugar on the first picking date and this level gradually declined as the season progressed, reaching a low at the end of the season. In the vine-ripened fruit, there was an increase in sugar content as the season progressed and then the sugar level fell rapidly from midseason until the end of the season. The vine-ripened fruit had a higher sugar content than the chamber-ripened fruit throughout the whole season. These seasonal trends for soluble solids are in agreement with the work of Beadle (6) who also found that the first fruit of the season shows the highest sugar content.

The decreasing sugar level as the season progressed is most likely due to increasing temperatures and lower leaf-to-fruit ratio.

Invert Sugar. The seasonal trends for invert sugar are shown in Figure 7. The chamber-ripened fruits again, like total sugars, had a higher level of invert sugar than the vine-ripened fruits. The trends for invert sugar, however, were just the opposite of those observed for total sugars. In chamber-ripened fruits, there was a general increase in invert sugar as the season progressed and a small decline at the end of the season. In the vine-ripened fruits, the invert sugar gradually increased as the season progressed and then remained stable from mid-season until the end of the season. Figure 6 shows that soluble solids gradually decreased as the season progressed and Figure 7 shows that invert sugar generally increased as the season progressed. Therefore, the total sugar contained a larger percentage of invert sugar as the season progressed.

Further studies should be made of the harvest date and its effect upon total sugar and invert sugar content. This study is in conflict with the findings of Yamaguchi and Leonard (46) who found that invert sugar gradually decreased through the season. They attributed the loss to the low amount of foliage on the plant during midseason and hot weather. This could well be the reason for the slight decrease in invert sugar after midseason in this study. Since foliage is a possible control of the level of invert sugar, the increase at the beginning of the season can be explained by the increase in foliage during the growing part of the season.

FIGURE 6.

SEASONAL TRENDS OF SOLUBLE
SOLIDS FOR CHAMBER-RIPENED AND VINE-RIPENED FRUIT

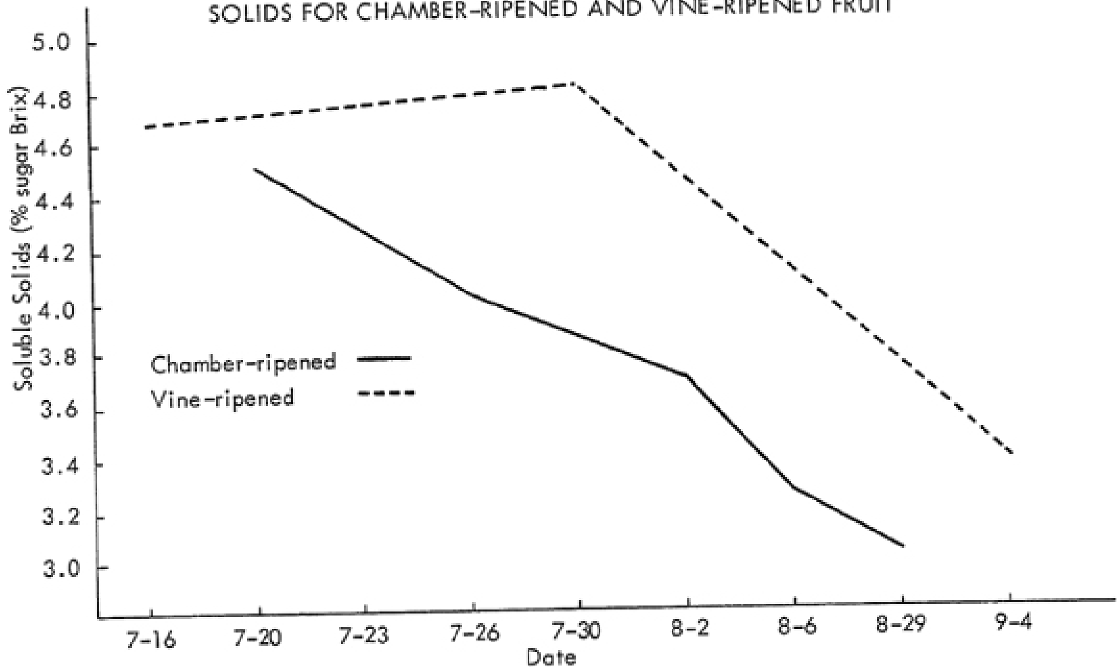


FIGURE 7.

SEASONAL TRENDS OF INVERT
SUGAR FOR CHAMBER-RIPENED AND VINE-RIPENED FRUIT

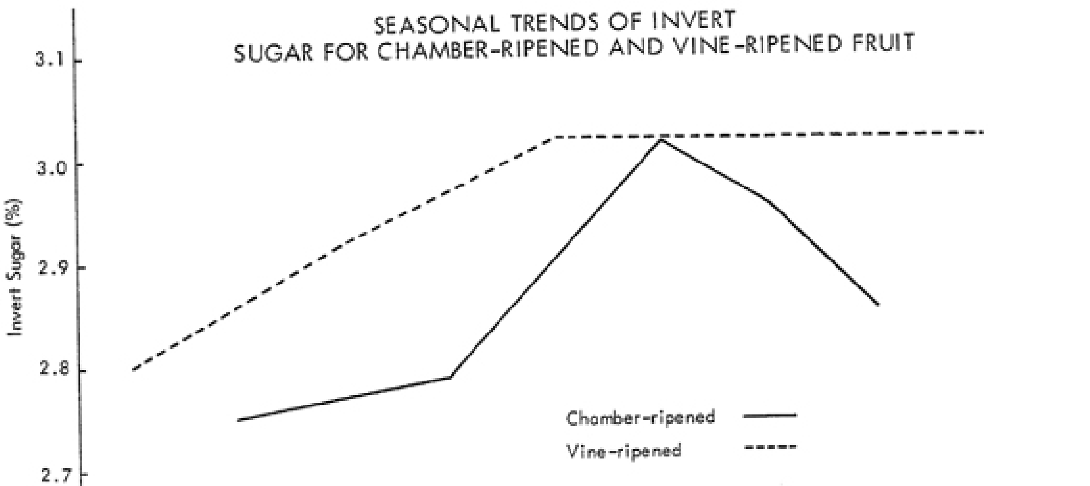
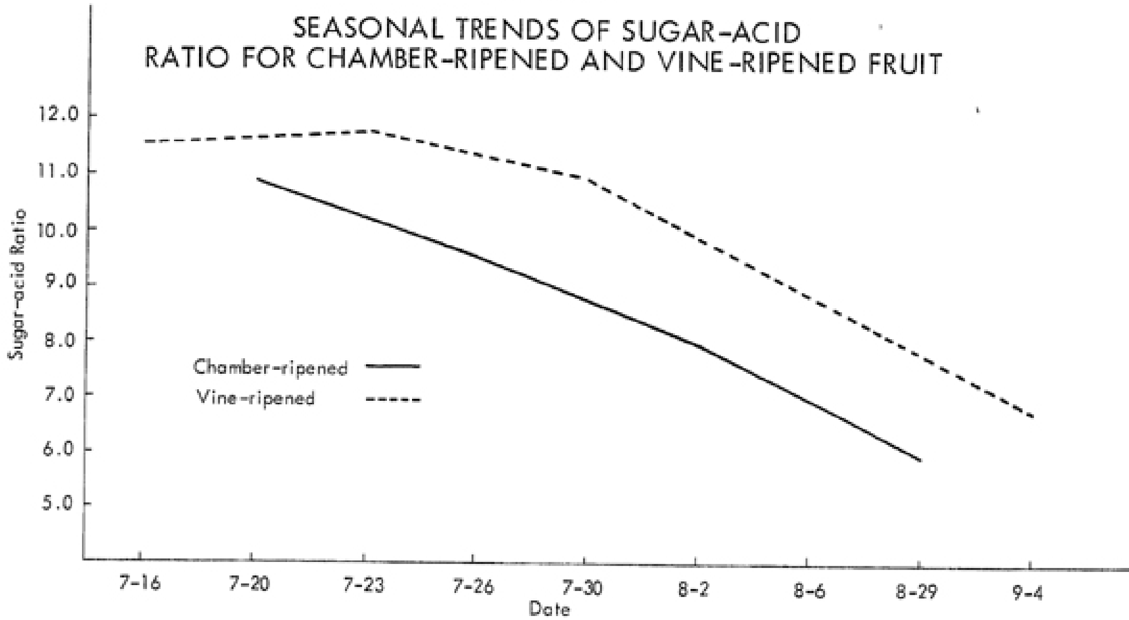


FIGURE 8.

SEASONAL TRENDS OF SUGAR-ACID RATIO FOR CHAMBER-RIPENED AND VINE-RIPENED FRUIT



Sugar-Acid Ratio. The seasonal trends for sugar-acid ratios are shown in Figure 8. The vine-ripened fruits had a higher ratio of sugar to acid than the chamber-ripened fruits. The seasonal trend for the chamber-ripened fruits was one of declining sugar-acid ratio as the season progressed. This would be expected since it was shown earlier that the sugars decreased as the season progressed and the level of acid increased. The vine-ripened fruit shows a trend nearly the same as chamber-ripened fruit, only there is a small increase in sugar-acid ratio from the first picking date to the second picking date, followed by a decline to the end of the season.

Taste Panel Results

Because of the great controversy over levels of the various constituents of the tomato and how these constituents and their level can alter taste, some taste panel studies of tomato juice were included in this investigation. The juice was tested for extreme value of pH, titratable acidity, soluble solids, invert sugar, and sugar-acid ratio. In the 11 varieties studied, the extreme ranges for these constituents were:

pH	4.280	4.500
Titratable acidity	0.388	0.510
Sugar (Brix)	3.200	4.300
Invert sugar	2.190	3.540
Sugar-acid ratio	8.850	7.020

These extremes were for the August 29 picking date, at which time the samples were collected for canning of juice to be used in taste panel studies. These extremes were the means of four readings of each quality factor for the variety for that picking date. Tomatoes of the 11 varieties were made into juice, canned, and stored for later use in taste studies.

Before the tomato varieties were tested, model solutions were sampled by panel members. These were made of citric and malic acid in a 60-40 ratio; sucrose was added to get the proper concentrations of sugar and acid as in the actual juice. These results appear in Table 28. The sugar and invert sugar were combined in the taste tests and extremes for total sugar only were used.

From Table 28 there is evidence that human taste sensation can detect differences in the model solutions which have the same concentration as the extremes found in the 11 tomato varieties studied. The sugar-acid ratio is the only exception and with the extremes of 8.85 to 7.02, the panel members could not detect a significant difference between the samples. This was a rather small range for sugar-acid ratio, even though it represented the extremes for the picking date. One would expect extreme sugar acid ratios to be detected easily by taste panels. For example, a high sugar-acid ratio indicates high sugar and low-acid content, thereby causing a sweet taste. Conversely, a low sugar-acid ratio indicates a low sugar and high acid level thereby causing a sour taste.

Table 29 gives the panel results for the juice samples, showing the extreme levels. These samples were tested the same as the model solutions. The results in Table 27 clearly indicate that the taste sensation of this panel generally could not distinguish differences in tomato varieties within the extreme values for acidity and sugar that were obtained in this study. These data would support the contention that many of the beliefs regarding distinctive taste differences among tomato varieties are unfounded.

There are apparently other factors in tomato juice which prevent detecting these differences since significant results were obtained with the same pH, titratable acidity, and sugar level in model systems. These other factors may mask the effect of the sugar-acid ratio and hence the sweetness or sourness as it affects taste.

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