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ACIDITY AND RELATED PROPERTIES OF TOMATO FRUITS AS INFLUENCED BY GENETIC, ENVIRONMENTAL, AND CULTURAL FACTORS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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ABSTRACT

The purpose of this study was to determine the influence of cultivars, fertilizer rates, ripeness levels, methods of training, shade and moisture relationships, and processing on certain quality factors of tomato fruits. The quality factors studied were pH, percent titratable acid, percent soluble solids, soluble solids-titratable acid ratio, and percent reducing sugars.

There were significant differences among cultivars for pH, titratable acidity, soluble solids, and soluble solids-titratable acid ratio. There were differences among cultivars within two harvest dates and two growing locations and a significant interaction between harvest date and location for pH and soluble solids.

There were no significant differences in quality factors due to fertilizer treatments nor was acidification of samples affected by fertilizer treatments.

Overripe fruits had a considerably higher pH, lower acid content, and higher soluble solids-titratable acid ratio than fruits analyzed when at a ripe stage of maturity. There was a significant interaction between maturity levels and harvest dates.

Four training systems did not influence fruit pH and reducing sugars but did influence titratable acidity, soluble solids, and soluble solids-titratable acid ratio. Four different fruit maturities from four training systems influenced all quality factors studied. There was no

interaction between factors studied due to system of training and stage of maturity.

Moisture levels during the growing period influenced pH, titratable acidity, soluble solids, soluble solids-titratable acid ratio, and reducing sugars. Shading plants influenced only soluble solids. There was no moisture and shade interaction for any quality factor studied.

The only difference in factors studied between tomatoes at various stages of maturity when analyzed fresh or 24 hours after canning was reducing sugar content.

Generally, in these experiments, pH and titratable acidity were related to each other but neither was related to soluble solids and reducing sugars.

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CHAPTER I

INTRODUCTION

Tomatoes are an important garden vegetable and contribute many products and nutritional benefits to human diets. Tomato fruits have certain desirable quality attributes and these, both in the raw and processed product, are closely related to the chemical composition of the fruit. The components can impart important characteristics to tomato products such as flavor and keeping quality which determine the desirability of the product. Levels of acid and sugar are important components as acidity affects both the flavor and keeping quality of the fruit while sugar is believed to affect the flavor. Acidity also influences processing time and temperature required for tomato fruits in order to prevent spoilage and possible poisoning caused by the action of certain microorganisms.

There has been some recent concern expressed about the risk of botulinal poisoning from consumption of home-canned tomatoes. Botulism is a potentially fatal poisoning produced by the bacterium Clostridium botulinum which may grow and produce toxin in canned food products that are low in acid if not previously killed by prolonged heating (42). Higher temperatures and longer than currently used processing time could be used to assure the destruction of spores of Clostridium botulinum in canned tomatoes but prolonged exposure to elevated temperatures can affect certain desirable quality factors of tomato products (30).

Low acidity can also lead to spoilage of canned tomato products by the bacterium Bacillus coagulans (12). This is known as flat-sour spoilage and a low pH (high acidity) seems to be the limiting factor for growth of this microorganism.

Research indicates certain genetic and environmental factors may influence the chemical composition of individual tomato fruits and thereby affect the quality and safety of processed tomato products.

The purpose of this study was to determine the influence of certain genetic, cultural, and environmental factors on the pH, titratable acidity, soluble solids, soluble solids-titratable acid ratio, and reducing sugar content of tomato fruits.

CHAPTER II

REVIEW OF LITERATURE

The level of the various chemical constituents found in the tomato fruit determines its quality. Cameron, cited by Lambeth et al. (27), gives the following ranges in composition of tomatoes: 4 to 6 percent soluble solids, 2 to 3 percent reducing sugar, 0.3 to 0.5 percent acid expressed as citric.

I. pH

The term, pH, is a measure of the hydrogen-ion concentration that affects and regulates many metabolic activities in foods (20). Gould (15) reports that pH is one of the most important factors affecting the sterilization times and temperature of processed tomatoes. The lower the pH, that is, the higher the amount of acidity in the food, the lower the degree of heat required for sterilization.

In terms of canning, the value of pH 4.5 is the classical division between acid and nonacid products (30). With proper sterilization, food products with a pH of 4.5 or less will be safe from the growth of such organisms as Clostridium botulinum. Desrosier and Heiligman (12) reported that increased pH levels allowed bacterial spores to cause spoilage in canned tomato juice. The spores grew only at increased pH levels. Rice and Pederson (38) found that pH was the most significant factor inhibiting the activity of Bacillus coagulans in tomato juice.

Since pH is so important to the growth of microorganisms 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 indicated a range of 3.9 to 4.8. Saywell and Cruess (43) reported a pH range from 3.8 to 4.4 for canning tomatoes. The highest pH recorded in the literature was 5.6 reported in tomatoes from Colorado (30).

The variation in pH has been associated with certain genetic and environmental factors.

Genetic Factors

Several studies have indicated considerable differences in the mean pH of cultivars (15, 24, 27, 42, 44, 46, 52). In these studies, a pH range of 3.8 to 4.8 was found among cultivars. Most authors are in agreement, however, that the usual pH range of tomatoes is from 4.0 to 4.5.

In 1975, because of the recent concern of botulism risk in home-canned tomatoes thought to be low in acid, the Eastern Regional Research Center of the U.S. Department of Agriculture conducted a survey of 55 cultivars for their pH and total acidity (42). All cultivars in the survey were screened by measuring the pH of 5-18 individual fruits. Although a pH range of 4.06 to 4.64 was found, these data showed that none of the cultivars had a mean pH high enough to support the growth

of Clostridium botulinum. Ace 55VF, Garden State, and Big Girl cultivars showed significant probabilities of exceeding pH 4.6.

A second important observation made was the relatively high acidity (low pH) of all tomato types usually considered by the public to be low in acidity (42). These include the cherry-type and light colored tomatoes. This substantiates previous reports that the pH of white and yellow colored tomato cultivars differs little from standard red cultivars (27, 46). The idea of certain cultivars being low in acid may have been based on taste which reflected the balance between sugar and acid rather than the acid content (42).

Newer cultivars should not be blamed for the "low acidity" problem (42). There has been only a slight change in the mean pH of cultivars introduced over the last two decades. Those cultivars introduced before 1950 which were tested at the Eastern Regional Research Center of the U.S. Department of Agriculture had a mean pH of 4.29 while those tested that were introduced between 1970 and 1976 had a mean pH of 4.38 (42).

Lower and Thompson (33) indicate that pH in a cultivar is a heritable trait.

Environmental Factors

Under the variable conditions found in the field, some workers have reported no set pattern for pH. Anderson (2) reported variability in pH between two fruits from the same plant to be as great or greater than that of fruits from different plants. One environmental factor in

which the results reported are inconclusive and sometimes contradictory is soil moisture and its relationship to pH.

Lee and Sayre (29) reported that restricted moisture supply produced a lower pH in tomato fruit. Vittum et al. (55) found that irrigation significantly increased the pH over those tomatoes not irrigated. However, Saywell and Cruess (43) ascertained that tomatoes grown in California in a cool and foggy climate tended to have a lower pH than those grown in a hot and dry climate.

Little research has been conducted on the effect of light on the pH of tomato fruits. McCollum (34) studied the exposure of fruits to light under natural conditions. He found the pH of fruits exposed to light to be significantly higher than fruits on the same plant not exposed to light. No differences in pH were found between the upper and lower sections of the fruit of both shaded and nonshaded fruit.

Boe and Salunkhe (5) studied the effects of dark, light, oxygen, and ethylene treatments on the composition of ripening detached tomato fruits. They found no differences in the pH due to any of the treatments either alone or in combination.

Seasonal trends of pH have been reported and are generally attributed to the climate. Lower and Thompson (32) found significant variation in pH over five sampling dates but obtained no consistent trend. However, Lambeth et al. (27) reported a consistent trend. For both chamber and vine ripened fruit, the pH showed a gradual decline as the season progressed. They postulated that the reason for the pH being lowered as the season progressed was lower soil moisture at the

end of the season. They also implicated increased daily mean temperatures, reasoning that as the temperatures increase there is an increased amount of sugar being respired to organic acids, thereby increasing the acidity level and lowering the pH.

Cultural Factors

Several investigators have studied pH in relation to maturation and ripening of the tomato fruit (19, 35, 39, 54, 58). All are in agreement that there is a progressive increase in pH from the turning stage to a very ripe stage in the tomato fruit. However, Rosa (39) found that in passing from the green mature to turning condition, there was a decrease in pH followed by a subsequent increase which reached a maximum in ripe fruit.

Fruits harvested at the mature green to turning stage, or any later stage, may be ripened to a fully colored fruit under adequate ripening conditions. Lambeth et al. (27) studied the pH of vine ripened fruits versus those ripened in a ripening chamber for seven days at 65° F. They found a greater range in pH for the vine ripened fruits than for chamber ripened fruits. They indicated that chamber ripened fruits may be more homogeneous in quality factors than vine ripened fruits.

Lower and Thompson (32) reported that field ripened samples were less acid and had a higher pH than chamber ripened samples for both cultivar and sampling date parameters.

Fertilization

Patterson (27), as early as 1890, reported that potash fertilized tomato plants produced fruits with slightly less sugar and lower pH. This was later substantiated by Lee and Sayre (29) who found that high potassium applications decreased the pH of the fruit.

However, other investigators have found different results. Kattan et al. (24) and Vittum et al. (55) reported that fertilization and plant nutrition had little effect on tomato fruit pH.

Processing

It has been shown by several investigators that processing has an effect upon the pH (1, 24, 25, 44). All investigators are in agreement that the average pH value of processed tomatoes is actually lower than that of raw tomatoes.

Certain variables have been studied for influence. Kattan et al. (24) found that a rather wide range of application of nitrogen, phosphorus, potassium, magnesium, and boron did not exert any significant effect on the pH between raw and canned tomato juice. Scott and Walls (44) studied the response of several cultivars on the change in pH between raw and processed tomato fruits. They found the pH to be lower after processing for all cultivars studied.

II. TITRATABLE ACIDITY

Titratable acidity is the free weak organic acids measured by neutralizing fruit extracts with a strong base (53). Acidity is

calculated from the quantity of base necessary to reach the pH decided on for the end point of the assay. The end point is usually taken at pH 8.1 which is that for phenalphthalein, an indicator (53).

The acid in tomatoes is generally considered to be almost entirely citric, and the titratable acidity is usually expressed as percent citric acid or milliequivalents of citric acid (16). Malic acid was found to be the second most prevalent organic acid while traces of tartaric, succinic, acetic, and oxalic acids have also been found (16).

Cameron, as cited by Lambeth et al. (27), reported a range of 0.3 to 0.5 percent acid in raw tomato fruits while Scott and Walls (44) gave a range from 0.270 to 0.416 percent acid. Saywell and Cruess (43) found an acid range of 0.26 to 0.81 in clear processed tomato juice. This variability indicates that several factors may influence the amount of acid in tomato fruits.

Genetic Factors

Tomato cultivars can vary markedly in acidity (7, 17, 27, 44, 46, 52).

Sapers et al. (42) surveyed 15 "low acid" (high pH) cultivars for percent acid and found a range of 0.291 to 0.399. Since their values are in the lower range of those previously mentioned, there is indicated a genetic basis for acidity.

Stevens (50) indicates that there is a genetic potential to breed cultivars for total citric and malic acid concentrations.

Lower and Thompson (32) studied the behavior of six cultivars or strains at five sampling dates for percent acid. They reported that cultivars responded differentially over the five sampling dates with regard to percent acid but not to pH.

Generally, pH is negatively correlated with percent acid. Lower and Thompson (33) found a highly negative correlation between pH and percent acid. Stevens (51) found negative correlations between pH and percent acid among 55 lines. However, Anderson (2) found that pH was not always lowest when titratable acidity was highest. In several cases, he found the pH highest where the acidity was the highest. Stevens (50) indicates that the ratio of citrate to malate varies greatly among cultivars and because of differing disassociation constants between these two organic acids low intercultivar correlations between pH and percent acid are sometimes found.

Environmental Factors

The effects of soil moisture on the percent acid of tomato fruits are inconclusive as with pH.

Vittum et al. (55) studied the effects of irrigation versus nonirrigation on the quality aspects of tomato fruits. They found a significant difference between the percent acid of the two treatments with the highest level of acidity from the nonirrigated plants. Similarly, Lee and Sayre (29) found higher total acidity when the tomatoes were grown under restricted moisture supply. However, Gorev (14) and Saywell and Cruess (43) found that plants maintained at lower

moisture levels gave fruit with lower percent acid. Sando (41) suggests that a tomato with excessive water content may have intercellular spaces sufficiently diminished so that gas exchange is impeded. Under those conditions, a deficiency of oxygen might result in an accumulation of acid due to incomplete oxidation of carbohydrates to carbon dioxide.

Seasonal trends of percent acid in tomato fruits are not clear and consistent. Lee and Sayre (29) 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 then with a small rise at the end of the season. Lambeth et al. (27) found a gradual increase in acidity as the season progressed which corresponded with a gradual decrease in the pH. Saywell and Cruess (43) stated, however, that the acid content did not appear to follow any definite trend with harvest dates. Anderson's results (2) are in agreement.

Reports of the effects of light on percent acid in tomato fruits found in the literature are for ripening of detached fruits and are contradictory. Boe and Salunkhe (5) found a general increase in acidity during the ripening period, with a light treatment enhancing the percent acid of the ripened fruit. Shewfelt (45) reported a slight decrease in acidity during the ripening period. However, there was little difference between fruits ripened in dark and in light.

Cultural Factors

The percent acid of tomato fruits increases during growth and maturation. It reaches a maximum at the turning or breaker stage, then

decreases during ripening and senescence (35, 39, 50, 51, 57). Bradley (6) attributes the change in acidity to metabolism of citric acid during ripening while Davies and Maw (10) include changes in metabolism of both citric and malic acid.

Acidity has been found to increase in storage of fruits detached at immature stages, whereas the acidity of those detached at the turning stage decline on subsequent storage (40). This suggests that organic acids are produced within the fruits. Sakiyama and Stevens (40) indicate that carbohydrate materials which were stored before detachment may be used for synthesis of organic acids. They further indicate that organic acid accumulation in detached fruits is determined by metabolism at the time of detachment.

Fertilization

Vittum et al. (55) and Hester (22) found that a high rate of fertilization significantly increased the percent acid. High rates that increased the acid level did not, however, affect the pH (55). Where no fertilizer was used, the percent acid of tomato fruits was lowest (22).

There is a close relationship between potassium content of the fruit and acidity (6). The juices of the tomato constitute a weak acid/strong base buffer system in which the anions are mainly citrate and malate, and the cations are mainly potassium (23). Hamner and Maynard (18) indicate that any factor which increases the potassium content of the fruit will produce a corresponding increase in organic acids in

order to maintain a constant pH. Bradley (6) studied the effects of potassium, magnesium, and calcium applications on acidity and tomato yields. Potassium applications induced significant increases in acidity, but calcium and magnesium had no effect on acidity. Lee and Sayre (29) also found a higher percent of acid from increased potassium fertilization of tomatoes.

Nitrogen applications have been reported to increase the acidity of tomato fruit (22). Carangal et al. (8) found the form in which nitrogen is applied has an influence on acidity. They found fruits were less acid when fertilized with the ammonium than when fertilized with the nitrate form of nitrogen. No explanation was given.

Processing

Scott and Walls (44) found that percent acid in processed tomato juice was considerably higher than that of fresh fruit after one-week storage. Acidity of the juice tended to decrease slightly during storage after eight weeks. Hamdy and Gould (17) reported a decrease in pH of eight cultivars after processing, but they also found a decrease in percent citric acid after processing.

The acidification of canned tomatoes with citric acid has been suggested as a means of increasing acidity to a more desirable and safer level (1, 30, 31, 38). Lowering the pH allows the processor to more easily inactivate the spores of the organism Bacillus coagulans. Lopez and Schoenemann (31) reported that the addition of sodium and/or calcium chloride in normally used proportions depresses pH by

approximately 0.1 pH unit. They concluded that when acidification is needed for tomatoes processed in the mid-Atlantic states, addition of an acid in sufficient quantity to depress pH by another 0.2 of a pH unit is all that is necessary to prevent spoilage. Adams (1), in a study of the effect of citric acid of lye peeled tomatoes, indicates that the buffer capacity of a tomato may affect the influence of citric acid on the pH value.

III. SOLUBLE SOLIDS

Tomato fruit contains from 4 to 6 percent soluble solids (16). Sugars, important organic constituents which affect the quality and flavor of the tomato, make up the largest portion of soluble solids. Sugar content is generally given to be 2 to 3 percent (16). Scott and Walls (44) gave a sugar range of 2.37 to 3.41. Saywell and Cruess (43) found that a high total of solids in general is correlated with high reducing sugar content. Simandle et al. (46) found a significant correlation between soluble solids and glucose and fructose.

Several investigators have reported that practically all the sugar present in the tomato fruit is reducing sugar (23, 27, 43, 44). Simandle et al. (46) found glucose and fructose present in about equal amounts in tomato fruits, but sucrose was not present in large enough amounts for determination with the procedure that was used. Traces of other sugars have been reported, notably a ketopentose (57).

The level of sugar is influenced by factors similar to those influencing pH and percent acid.

Genetic Factors

Cultivars differ in percent soluble solids (19, 27, 32, 46, 51) and in percent reducing sugar (27, 44, 46). Hanna (19) indicates there is considerable variation in soluble solids within and between cultivars as some cultivars used in California have produced a higher percentage of soluble solids than other cultivars. Lower and Thompson (32) found highly significant interaction of cultivars x sampling dates for soluble solids which indicates that cultivars may vary in their composition depending on the season. Breeding programs indicate that high solids strains can be achieved (33, 51). Stevens (51) found that in a high solids selection program, the major component increased was reducing sugars.

It is interesting to note the studies involving fruit of some cultivars that are generally thought to be mild and low acid. As mentioned previously, researchers have found no difference in pH between fruit of white and yellow pigmented cultivars as compared to red cultivars. The sugar content, however, may explain why some cultivars are thought to be mild and low in acid. Lambeth et al. (27), in a study of 11 different cultivars, found that Orange Jubilee had the highest percent soluble solids and percent reducing sugar of the 11 cultivars. They indicate the high sugar level could be masking the effect of the high acid content so far as taste is concerned, thereby causing the public to believe that it is actually lower in acid.

Environmental Factors

Several investigators have noted an increase in percent solids with lower soil moisture content. Saywell and Cruess (43) reported that tomatoes from plants suffering from lack of water were higher in total solids than those from well irrigated plants. Similarly, Vittum et al. (55) found that irrigation significantly decreased the percent soluble solids of tomato fruits. The authors of both these studies indicate the solids content can be explained by the dilution effect due to more water in the fruit where moisture was plentiful. Gorev (14) found higher sugar concentration in fruits of nonirrigated plants than in fruits of irrigated plants. He also reported that the monosaccharide concentration was higher in unripe than in ripe fruit.

Changes in soluble solids and sugar content occur during the growing season. Forshey and Alban (13) reported a decrease in sugar content with each successive harvest during an autumn crop and an increase during the spring crop. Yamaguchi et al. (58) also found a decrease in both total solids and reducing sugar during harvests in September and October. Poor foliage at that time was indicated as probably responsible. Lambeth et al. (27) found that soluble solids generally declined as the season progressed but reducing sugars increased until July with little change during August. The solids contained a larger percentage of reducing sugar as the season progressed. They explained that the decreasing level of soluble solids as the season progressed was most likely due to increasing temperatures and lower leaf-to-fruit ratio. They also concluded the increase in

reducing sugars at the beginning of the season to be due to the increase in foliage during the growing part of the season.

McCollum (34) found that exposure of fruits to sunlight can affect the solids and reducing sugar content of ripe tomato fruits. Exposed fruits had higher total solids and reducing sugars than shaded fruit when harvested on September 7. However, the fruit harvested on September 22 did not differ in solids and sugar content. This was probably due to loss of foliage and the impossibility of determining how long shaded fruits had been exposed.

Cultural Factors

The stage of maturity seems to have the greatest effect upon the sugar and soluble solids level of fruit. Rosa (39) noticed that both soluble solids and reducing sugar content increase steadily from the green mature stage to the ripe fruit. Yamaguchi et al. (58) found that reducing sugars increase from the pink stage on up to the soft ripe stage of maturity. Massey et al. (35) report the soluble solids increase from the green to ripe stage of maturity. Vittum et al. (55) observed that as individual fruits mature, organic acids tend to decrease while sugars tend to increase. However, Hanna (19) reported that there was little or no correlation between stage of maturity and total soluble solids.

Several investigators have studied the sugar content of vine-ripened versus chamber-ripened fruit. Lambeth et al. (27), Lower and Thompson (32), and Rosa (39) are in agreement that vine-ripened fruit

have a higher sugar content throughout the season than chamber-ripened fruits. Sando (41), however, reports that artificially-ripened tomatoes have the same sugar content as vine-ripened fruits. Rosa (39) concludes that there is evidently a movement of substances from the plant into the fruit throughout the ripening process so vine-ripened fruits should contain more sugar.

Fertilization

Reports on the influence of fertilization of tomato plants on the solids and sugar content are somewhat contradictory. Kattan et al. (24) reported the quality constituents of tomatoes, including sugar, were not related to any fertility factors. A rather wide range of application of nitrogen, potassium, phosphorus, magnesium, and boron failed to exert any influence on sugar content of tomato fruits. However, other investigators have found significance of fertilization on sugar content. Hester (22) found that nitrogen and potassium applications increased the amount of sugars over those fruits from plants receiving no fertilizer. This was true for some analyses used but not for all. He also found that applications of 500 pounds per acre of 5-10-10 analyses fertilizer greatly increased the sugar content over those fruits from plants receiving no fertilizer. Vittum et al. (55) applied extra complete fertilizer to high fertility plots for two years and found significant increases in percent soluble solids both years. It has been reported that potash has a tendency to produce a fruit with slightly less sugar (37). The influence of fertility level may be related to foliage production by the tomato plant.

Processing

Skoh (47) studied the quality of vine-ripened versus artifically-ripened tomatoes after they had been processed. The differences between total sugars of juice made from field-ripened and room-ripened tomatoes were not significant. Kattan et al. (24) studied the quality components of fruits from different cultivars and breeding lines before and after processing. They found an increase in the soluble solids content after processing. This was true for all cultivars, although they differed in their soluble solids content. Scott and Walls (44) found the sugar content of fresh fruit and freshly prepared juice about the same but also found that sugar content of juice decreased slightly during a storage of eight weeks. Kattan et al. (25) reported a similar decrease in soluble solids during storage of canned tomato juice.

IV. SUGAR-ACID RATIO

The level of sugar or soluble solids and acidity in tomato fruits is important in determining the flavor of tomato products. The sugar-acid ratios can show varying degrees of sharpness and blandness in taste of tomato products (44). Simandle et al. (46) found a significant positive correlation of flavor with soluble solids-titratable acid ratio.

There is a wide range of sugar-acid ratios reported. Some researchers give the reducing sugar-acid ratio while others use the soluble solids-acid ratio. In both cases, the sugar-acid ratios would

likely be affected by the same factors which affect either the level of acidity or sugar alone.

Genetic Factors

Scott and Walls (44) reported in general the sugar content was inversely correlated with acidity so that calculated sugar-acid ratios show wider variation among cultivars than either sugar content or acidity. They gave sugar-acid ratios from 6.9 to 10.8 in a study of 11 cultivars. Vittum et al. (55) gave a soluble solids-acid ratio of 14.4 to 19.7 while Simandle et al. (46) gave a soluble solids-acid ratio of 10.5 to 14.3 for different cultivars. Lambeth et al. (27) gave a range of 7.3 to 13.1. Lower and Thompson (32) found a major component of the variation in the sugar-acid ratio is attributed to differences among cultivars. They concluded that large quantitative differences in titratable acidity account for most of the differences in the ratios.

Environmental Factors

The effects of moisture or fertilization on the sugar-acid ratio are dependent on the effect of sugar and acid content. Vittum et al. (55) found irrigation did not change the sugar-acid ratio since it decreased both percent acid and percent soluble solids. They also found that extra fertilizer applied to high fertility plots significantly reduced the soluble solids-acid ratio.

The sugar-acid ratio has been shown to decline as the season progresses (22, 27). This would be expected since it has been shown

that soluble solids decrease and percent acid increases as the season progresses.

There is some correlation of sugar-acid ratio with maturity of tomato fruit. Vittum et al. (55) indicate that as individual fruits mature, organic acids tend to decrease while sugars tend to increase, thus the sugar-acid ratio should be higher in mature fruits. Dennison (11) indicates the sugar-acid ratio of ripened fruit will be about twice that of mature-green fruits.

Several investigators report a greater sugar-acid ratio for vine-ripened fruits than for those ripened artificially (27, 32, 41). This reflects the combination of higher solids and lower acidity in vine-ripened fruit. Sando (41) observes that artificially-ripened fruit are different in taste which he attributes to the lack of one constituent (soluble solids) and an excess of another (acid).

Processing

Scott and Walls (44) reported that processing decreased the sugar-acid ratio of 11 cultivars. This would be expected since processing generally increases the acidity of tomato products.

CHAPTER III

MATERIALS AND METHODS

I. GENERAL PROCEDURES

This study was conducted during the summer and fall of 1976. There are five experiments combined in this study. These include the effects on certain quality factors of tomato fruits of different cultivars, soil fertilization rates, maturity levels, training systems, moisture stress, shade, and processing.

Tomatoes were grown at the West Tennessee Experiment Station, Jackson; Plateau Experiment Station, Crossville; and Main Experiment Station, Knoxville. This study utilized fruits from tomatoes at these stations grown primarily for cultivar evaluation and fertilizer trials.

Tomatoes were grown on a Dexter loam and a Memphis loam at Jackson, a Hartsells loam at Crossville, and an Etowah silt loam at Knoxville. All tomatoes were grown and cultured according to University of Tennessee recommendations (9).

Fruits were harvested for analysis and were in various stages of maturity according to the experiment. All fruit that were not analyzed immediately were ripened in the dark in paper bags at 21.1° C in the laboratory.

The following are definitions of terms used in this study describing the degrees of tomato maturity as given by Ware and McCollum (56):

1. Turning. About one-fourth of the surface at the blossom end shows pink.

2. Firm ripe. The fruit is nearly all red color but the flesh is firm.

3. Ripe or canning ripe. The fruit is all red and the flesh is still firm.

4. Soft ripe. The fruit is fully colored and the flesh is soft.

Illustrations of these definitions are shown in Figure 1.

Procedures used in each experiment, sample preparation, and analytical methods, are discussed below.

II. CULTIVAR EXPERIMENT

Fourteen cultivars of tomatoes, grown at Knoxville and Jackson, were analyzed for pH, percent titratable acid, percent soluble solids, and soluble solids-titratable acid ratio. The cultivars with their plant type (fruiting habit) are listed below with I indicating indeterminate and D indicating determinate.

1.	Better Boy	I
2.	Big Boy	I
3.	Big Girl	I
4.	Big Set	D
5.	Big Seven	I
6.	Early Big	D
7.	Manapal	I
8.	Oh Boy	I
9.	Red King	D
10.	Royal Flush	D
11.	Setmore	D
12.	Ultra Boy	I
13.	Ultra Girl	I
14.	Walter	D

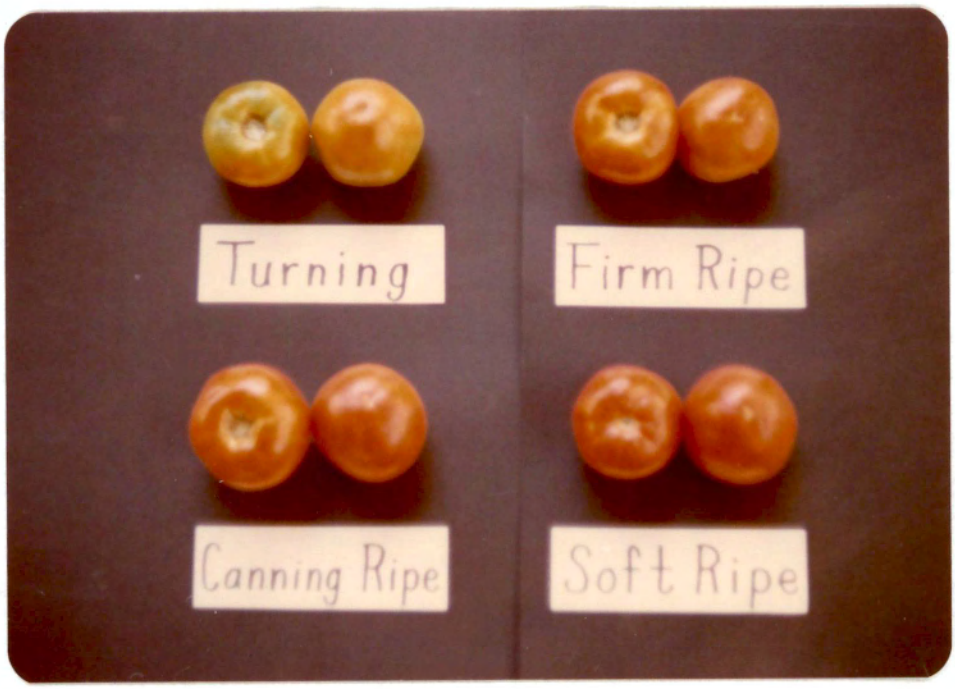


Figure 1. Illustration of different stages of maturity of tomato fruits as defined on page 23.

The cultivars were grown in a randomized complete block design with four replications. The determinate cultivars (D) were each staked and trained to the Florida Weave System, and the indeterminate cultivars (I) were each staked and pruned to two stems (9).

Samples were collected for analysis at two periods, early harvest and late harvest. The early harvest at Knoxville was from July 12 to 15 and at Jackson on July 15. Late harvest at Knoxville was on July 29 and at Jackson on August 2. U.S. No. 1 grade tomatoes with a range of maturity from turning to firm ripe were collected for analysis. Three tomatoes of similar maturity were sampled for each experimental unit and were analyzed when ripe.

III. FERTILIZATION EXPERIMENT

In this experiment, tomatoes were grown at Jackson, Crossville, and Knoxville under seven levels of fertilization. Fruits were analyzed for pH, percent titratable acid, percent soluble solids, soluble solids-titratable acid ratio, and the amount of 0.5 percent solution of citric acid required to lower the pH of each sample 0.1, 0.2, and/or 0.3 pH units. It has been indicated that minerals such as potassium may influence the buffering system of tomatoes (6).

The fertilizer treatments are shown in Table 1.

The experimental design was a randomized complete block with four replications. The cultivar used was Big Seven and plants were trained by staking and pruning to two stems.

TABLE 1

FERTILIZER TREATMENTS OF TOMATOES ON WHICH QUALITY FACTORS WERE STUDIED

Rate (kg/ha)			
At Planting			Sidedress
N	P_2O_5	K_2O	N
0	0	0	0
33.6	0	0	33.6
33.6	67.3	67.3	33.6
33.6	67.3	134.6	33.6
33.6	134.6	67.3	33.6
33.6	134.6	134.6	33.6
100.9	134.6	134.6	33.6

Fruit was harvested once at each location. Harvest at Jackson was July 16, at Knoxville, July 29, and at Crossville, August 2. All three dates were considered midseason harvests. The methods of collecting and handling samples were the same as those used in the cultivar experiment.

IV. RIPENESS EXPERIMENT

This experiment was conducted in conjunction with the cultivar study to determine the effects of two ripeness levels on certain quality factors of tomatoes. This study was done only with tomatoes grown at Knoxville. Three additional fruits per experimental unit of each of three cultivars, Better Boy, Big Seven, and Walter, were harvested at both the early and late harvests along with those fruits harvested for the cultivar experiment. These fruits were kept for 25 days after each harvest date and then analyzed for the same quality

factors as in the cultivar experiment. These fruits were all U.S. Grade No. 1.

An additional salvage harvest of fruits of the cultivars Better Boy, Big Seven, and Walter, was made on August 23. This harvest consisted of field run ungraded fruit. Three fruits of each cultivar per experimental unit were analyzed for the previously mentioned quality factors when at a ripe stage of maturity and three or more fruits of each cultivar were analyzed 25 days after harvest.

All the fruits of this experiment analyzed 25 days after harvest are designated as overripe and are compared to those fruits analyzed as ripe at each harvest date. Most of the fruit kept for 25 days was harvested in the turning stage.

The cultivar effects were combined in the analyses.

V. TRAINING SYSTEMS EXPERIMENT

Four methods of training tomato plants in the field were studied for effects of pH, percent titratable acid, percent soluble solids, soluble solids-titratable acid ratio, and percent reducing sugar on tomato fruits. The training methods consisted of plants (1) staked and pruned to two stems, (2) staked, unpruned, and tied by the Florida Weave Method, (3) grown in wire cages, unpruned, and (4) unpruned, ground grown with no support.

The cultivar Better Boy was used in a randomized complete block design with six replications. Rows were spaced six feet apart instead

of the usually recommended spacing of four feet to reduce shading of those plants receiving no support.

Fruit was harvested August 27 and September 14 in four stages of maturity; turning, firm ripe, canning ripe, and soft ripe. The stages of maturity are shown in Figure 1 (pg. 24). Three sound tomatoes of similar maturity were sampled for each experimental unit.

Those fruits harvested in the turning stage were ripened to the canning ripe stage before analysis. Fruits from all other maturity classes were analyzed immediately after harvest.

VI. MOISTURE AND SHADE EXPERIMENT

This study was designed to determine the effects of either moisture stress or shaded plants and possible interactions on certain quality factors of tomato fruits. The same quality factors studied in the training system experiment were studied. In addition in this study, the weight of each fruit analyzed was recorded. This was to determine if there was any correlation between weight of fruit and quality factor studied. This study was conducted during the fall of 1976 in a greenhouse.

Plants of the cultivar Floradel were set in 25.4 centimeter diameter plastic pots on August 18. The potting medium consisted of twelve parts loam soil, one part perlite, one part peat moss, with 0-46-0 and 6-12-12 analyses fertilizers added.

The experimental design was a factorial arrangement of treatments in a randomized complete block with four replications. Two levels of

illumination, shaded and nonshaded plants and two levels of moisture supply, no moisture stress and moisture stress were the treatments. A total of 48 plants were used with each experimental unit consisting of three plants.

Shade Method

Half the plants were covered with a frame as shown in Figure 2. This is a wooden frame covered with a double thickness of nylon tobacco seed bed cloth. Plants were covered on September 23. To determine the degree of light reduction, a Weston Model 756 light meter was used periodically throughout the study. A consistent difference of approximately 2000 foot candles was observed between shaded and nonshaded plants. Incident light in the greenhouse was checked periodically at solar noon and varied from 4500 to 7500 foot candles during the period of this study.

Moisture Method

Each plant was watered by an automatic watering system of plastic leader tubes. Half the plants were subjected to moisture stress by periodically removing leaders from those pots and allowing those plants to wilt. The plants were watered only enough to maintain a visual degree of wilt. Half the plants were watered regularly to prevent any sign of stress. These were kept at a moisture tension of 0.2 to 0.4 atmospheres.

Fruits were harvested from each plant when ripe and analyzed immediately. Eight fruits from each experimental unit of three plants provided the data used in this study.



Figure 2. Nylon covered frames used for shading experimental units consisting of three tomato plants.

VII. PROCESSING EXPERIMENT

Additional fruits from those plants of the training system experiment that were staked and pruned to two stems were canned and analyzed for the same quality factors as in the training experiment. The objective was to determine the effect of canning temperature and time on whole fruits and compare this with those fruits analyzed fresh.

Tomato fruits were harvested in the same four stages of maturity as used in the training system experiment. Fruits harvested in firm ripe, canning ripe, and soft ripe stages of maturity were canned immediately after harvest while those harvested in the turning stage were canned when ripened to the canning ripe stage.

Samples were canned with slight modification from usual home canning recommendations (21, 26). Three fruits of similar maturity from each experimental unit were quartered with quarters randomly selected and placed in 0.27 liter (one pint) jars. The noncored and unpeeled samples were cold packed and canned under 0.352 kg/sq cm (five psi) of pressure for 15 minutes.

The samples were analyzed 24 hours after canning.

VIII. SAMPLE PREPARATION FOR ANALYTICAL PROCEDURES

Tomatoes were quartered and blended into puree with a food blender. Where large tomatoes were used, two quarters randomly selected from each fruit were blended, whereas all sections of smaller fruit were blended.

Duplicate samples were analyzed from each experimental unit for all experiments except the greenhouse shade-moisture experiment where one sample was analyzed for each individual fruit because of small fruit sizes.

IX. ANALYTICAL PROCEDURES

pH

A Fisher Model 210 pH meter was used for all pH readings. Electrodes were immersed in approximately 60 grams of tomato puree kept continuously agitated by a magnetic stirrer. A buffer with pH 4.00 was used to standardize the pH meter.

Titratable Acidity

The percent acid was obtained on the same sample used for pH determination. Using a Lamotte automatic burette, the sample was titrated with 0.1 N NaOH to a pH 8.1 end point. The titratable acidity was expressed as percent citric acid using the following formula (16):

$$\text{Percent titratable acid} = \frac{V \times N \times \text{Meq. wt.} \times 100}{Y}$$

where V = Volume in ml. of NaOH titrated

N = Normality of NaOH

Meq. wt. = Milliequivalents of acid, 0.064 for citric acid

Y = Weight of the sample.

Soluble Solids

Percent soluble solids was determined directly with a hand refractometer. One to two drops of juice were obtained by squeezing puree through either bleached muslin cloth or filtering through Whatman No. 40 filter paper.

Soluble Solids-Titratable Acid Ratio

The following formula was used to obtain this parameter:

$$\frac{\text{Percent soluble solids}}{\text{Percent titratable acid}}$$

Acidification of Samples

A 0.5 percent solution of citric acid was titrated from a 50 ml burette into approximately 60 g samples of puree made from tomatoes grown in the fertilization experiment. The pH meter electrodes were immersed in the puree, and the burette was monitored for each volume of citric acid solution needed to lower the pH of the puree 0.1, 0.2, and/or 0.3 pH units.

The duplicate samples used were in addition to those samples used for pH and titratable acidity analysis.

Reducing Sugars

Filtered juice was analyzed for reducing sugar by the Nelson-Somogyi colorimetric method (36, 49).

Puree was filtered through bleached muslin, and juice was frozen immediately at 0° C for later analysis. At the time of analysis the

frozen juice was thawed and filtered through Whatman No. 40 filter paper. One ml of juice was pipetted into a 250 ml volumetric flask and brought to volume. Sugar content was determined on 2 ml aliquots from the volumetric flask except in the greenhouse shade and moisture study where high soluble solids readings were obtained. In this case, a 1 ml aliquot from the volumetric flask was used. The aliquot from the volumetric flask was pipetted into a test tube and 2 ml of copper reagent were added. The tubes were covered with marbles and placed in a boiling water bath for 15 minutes. After cooling, 2 ml of arsenomolybdate reagent were mixed with the contents of the tubes. Twenty ml of water were then added to each tube, and then read at 510 nm in a Spectronic 20 colorimeter. Standards were prepared daily along with samples. The results were expressed as percent reducing sugar on a fresh weight basis.

X. STATISTICAL ANALYSIS

The analysis of variance method was used to analyze the data (48). When significant differences at the .05 level due to treatment were detected, Duncan's New Multiple Range Test was used to separate means (28). Quality factor correlations were computed at the .05 level of significance as outlined by Snedecor and Cochran (48). Note that when pH is said to be negatively correlated with other quality factors this is not referring to the fact that $pH = -\log[H^+]$.

CHAPTER IV

RESULTS AND DISCUSSIONS

I. CULTIVAR EXPERIMENT

Table 2 shows that the 14 cultivars differed significantly for pH, percent titratable acid, percent soluble solids, and soluble solids-titratable acid ratio.

The range of mean pH was 4.42 for Oh Boy to 4.57 for Big Boy. The mean pH of 4.48 is generally considered to be near the high end but within the range of pH (3.8-4.8) reported in the literature (15, 24, 27, 42, 44, 46). A recent study of 55 cultivars screened for pH indicated that values were sometimes above 4.5 (42). However, none had a mean pH high enough to support the growth of Clostridium botulinium. The results of this study are in agreement with previous work in that the highest mean pH recorded was 4.57 for Big Boy. However, researchers indicate there is some danger from flat-sour spoilage when the pH goes above 4.5 (12, 30).

Big Set had the highest mean percent titratable acid, 0.437, while Big Boy had the lowest, 0.364. This might be expected since Big Set had next to the lowest mean pH and Big Boy had the highest. Tomato fruit pH is generally considered to be inversely related with titratable acidity, although Lambeth et al. (27) indicate that pH is not always lowest when titratable acidity is highest and vice versa.

TABLE 2

QUALITY FACTORS OF 14 CULTIVARS OF TOMATOES AT ALL HARVEST DATES AND LOCATIONS COMBINED

Cultivar	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio
Better Boy	4.49 bcd[W]	0.368 c	6.11 ab	17.3 a
Big Boy	4.57 a	0.364 c	5.95 bc	16.8 ab
Big Girl	4.53 ab	0.372 c	5.92 cd	16.6 abc
Big Set	4.43 ef	0.437 a	5.40 g	12.7 e
Big Seven	4.48 cd	0.396 abc	5.97 bc	15.5 abcd
Early Big	4.47 de	0.389 abc	5.05 h	13.5 de
Manapal	4.52 bc	0.379 bc	6.18 a	16.5 abc
Oh Boy	4.42 f	0.430 ab	5.87 cd	14.0 de
Red King	4.47 de	0.393 abc	5.65 ef	14.6 cde
Royal Flush	4.48 cd	0.382 bc	5.46 g	14.9 bcd
Setmore	4.48 cd	0.387 abc	5.36 g	14.3 de
Ultra Boy	4.49 cd	0.371 c	5.78 de	15.7 abcd
Ultra Girl	4.50 bcd	0.387 abc	5.66 ef	14.8 bcd
Walter	4.46 de	0.406 abc	5.51 fg	14.2 de
Overall Means	4.48	0.390	5.71	15.1

[W]Cultivar means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

Table 2 shows that Manapal had the highest percent soluble solids of the cultivars studied. In general, the mean of 5.71 is high but within the range of 4 to 6 as reported (16).

The cultivar with the highest soluble solids-titratable acid ratio was Better Boy (Table 2). The mean ratio of 15.1 is generally considered to be high. Since the ratio of soluble solids and acid in a tomato can affect the taste, differences of flavor might be detected between cultivars with different ratios. Higher ratios should result in a milder flavor.

Table 3 shows the pH and percent titratable acid of the 14 cultivars at early harvest (July 15) and late harvest (July 29). The cultivars differed for both pH and percent titratable acid within each harvest date, but no interaction between cultivars and harvest dates was found for either parameter. Some cultivars had a lower pH (more acid) and higher titratable acid content at the early harvest as compared to the late harvest, while others were just the opposite. Some cultivars remained constant in these factors at both harvest dates.

There was no significant difference between the overall mean pH of the early and late harvest. However, the mean percent titratable acid was significantly greater at the late harvest than the early harvest. This is in agreement with Lower and Thompson (32) who reported cultivars reacted differentially over several sampling dates with regard to percent acid but not to pH. Seasonal trends, however, are not consistent (27, 29).

TABLE 3

pH AND TITRATABLE ACIDITY OF 14 CULTIVARS OF TOMATOES AT TWO HARVEST DATES

Cultivar	pH		Percent Titratable Acid	
	Early Harvest	Late Harvest	Early Harvest	Late Harvest
Better Boy	4.50 bcde[w]	4.48 cdefg	0.309 e	0.428 abcd
Big Boy	4.54 abc	4.60 a	0.348 de	0.381 bcde
Big Girl	4.51 bcd	4.56 ab	0.353 cde	0.390 abcd
Big Set	4.43 fgh	4.43 fgh	0.445 ab	0.429 abc
Big Seven	4.45 defgh	4.51 bcd	0.386 bcde	0.406 abcd
Early Big	4.49 cdefg	4.45 defh	0.384 bcde	0.395 abcd
Manapal	4.51 bcd	4.54 abc	0.362 cde	0.396 abcd
Oh Boy	4.41 h	4.42 gh	0.394 abcd	0.466 a
Red King	4.45 defgh	4.48 cdefg	0.402 abcd	0.384 bcde
Royal Flush	4.50 bcde	4.46 defgh	0.356 cde	0.408 abcd
Setmore	4.49 bcdef	4.47 defgh	0.354 cde	0.421 abcd
Ultra Boy	4.46 defgh	4.52 bcd	0.377 bcde	0.364 cde
Ultra Girl	4.49 cdef	4.51 bcd	0.396 abcd	0.378 bcde
Walter	4.49 cdef	4.44 fgh	0.399 abcd	0.413 abcd
Mean	4.48 y[x]	4.49 y	0.376 y	0.404 z

[w]Cultivar means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[x]Harvest means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

The soluble solids content and soluble solids-titratable acid ratio differed among cultivars within each harvest date as shown in Table 4. There was a significant interaction between cultivars and harvest dates for soluble solids but not for the soluble solids-titratable acid ratio. The mean soluble solids content of the cultivars was significantly greater at the late harvest. Eleven of the 14 cultivars had a greater percent at the late harvest. Lower and Thompson (32) found highly significant interaction of cultivars with sampling dates for soluble solids. Cultivars may vary in their composition depending on the season. In this study, it is interesting to note that the three cultivars which had lowest soluble solids, Big Set, Red King, and Walter, all have a determinate bearing habit. Since determinate cultivars bear a larger number of fruit in a more concentrated period of time than indeterminate cultivars, individual fruits might contain less solids. Also, indeterminate cultivars could have better foliage and a greater leaf to fruit ratio toward the end of the season which could account for differences in solids content.

There was no difference in the soluble solids-titratable acid ratio between the early and late harvests (Table 4).

Table 5 indicates differences among cultivars for pH and titratable acid at Knoxville and at Jackson. There was a significant interaction between location and cultivars for percent titratable acid but not for pH. The means for both parameters are significantly different from each other at each location. Fruit pH was lower (more acid) at Jackson, and the percent titratable acid was higher at Jackson.

TABLE 4

SOLUBLE SOLIDS AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO
OF 14 CULTIVARS AT TWO HARVEST DATES

Cultivar	Soluble Solids		Soluble Solids-Titratable Acid Ratio	
	Early Harvest	Late Harvest	Early Harvest	Late Harvest
Better Boy	5.71 cde[W]	6.52 a	19.2 a	15.4 bcdefg
Big Boy	5.60 defg	6.31 a	16.7 abc	16.9 ab
Big Girl	5.50 efg	6.35 a	16.8 abc	16.4 abcd
Big Set	5.45 fgh	5.36 ghi	12.8 fg	12.6 g
Big Seven	5.57 defg	6.36 a	15.2 bcdefg	15.8 bcdef
Early Big	4.98 j	5.12 ij	13.7 bcdefg	13.3 defg
Manapal	5.93 bc	6.44 a	16.8 abc	16.3 abcd
Oh Boy	5.37 ghi	6.38 c	14.0 bcdefg	14.0 bcdefg
Red King	5.80 bcd	5.51 efg	14.7 bcdefg	14.4 bcdef
Royal Flush	5.41 fgh	5.51 efg	15.8 bcdef	14.1 bcdefg
Setmore	5.23 hi	5.50 efg	15.3 bcdefg	13.4 defg
Ultra Boy	5.55 defg	6.01 b	14.9 bcdefg	16.5 abcd
Ultra Girl	5.34 ghi	5.98 b	13.7 cdefg	16.0 bcde
Walter	5.65 def	5.36 ghi	15.2 bcdefg	13.1 efg
Mean	5.50 y[X]	5.91 z	15.3 y	14.9 y

[W]Cultivar means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[X]Harvest means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 5

pH AND TITRATABLE ACIDITY OF 14 CULTIVARS OF TOMATOES GROWN AT TWO LOCATIONS

Cultivar	pH		Percent Titratable Acid	
	Knoxville	Jackson	Knoxville	Jackson
Better Boy	4.52 bcd[W]	4.46 defghi	0.327 fg	0.409 abcd
Big Boy	4.60 a	4.54 abc	0.344 defg	0.384 abcdef
Big Girl	4.58 ab	4.49 bcdefg	0.319 f	0.424 abc
Big Set	4.45 efghi	4.41 hi	0.426 abc	0.448 a
Big Seven	4.51 cdef	4.45 fghi	0.355 cdefg	0.437 ab
Early Big	4.52 bcde	4.42 hij	0.392 abcdefg	0.387 abcdef
Manapal	4.56 abc	4.49 cdefg	0.365 bcdefg	0.393 abcdef
Oh Boy	4.45 efghi	4.38 j	0.416 abcd	0.444 ab
Red King	4.49 defgh	4.45 efghi	0.409 abcde	0.376 abcdef
Royal Flush	4.47 defghi	4.49 bcdef	0.428 abc	0.335 def
Setmore	4.49 cdefh	4.47 cdefghi	0.384 abcdefg	0.391 abcdef
Ultra Boy	4.52 bcd	4.45 efghi	0.369 abcdefg	0.372 abcdef
Ultra Girl	4.52 bcd	4.48 cdefgh	0.368 abcdefg	0.406 abcde
Walter	4.50 cdef	4.42 ghij	0.402 abcdef	0.410 abcd
Mean	4.51 y[X]	4.46 z	0.379 z	0.401 y

[W]Cultivar means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[X]Location means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

This indicates an inverse relationship between pH and percent titratable acid. Environmental factors which cause differences among cultivars for titratable acidity at different locations are probably the same as those causing differences at different sampling dates.

Table 6 gives the percent soluble solids and soluble solids-titratable acid ratio for cultivars at Knoxville and Jackson. There were differences among cultivars within each location for both parameters. The overall mean content of soluble solids for cultivars was significantly greater for those grown at Jackson, but there were no differences in the mean soluble solids-titratable acid ratio between those grown at Knoxville and at Jackson. No difference in the ratio would be attributed to a higher acid content at Jackson recorded along with a higher soluble solids content.

There was a significiant interaction between cultivars and locations for both soluble solids and soluble solids-titratable acid ratio. Certain environmental factors causing differences in acid content would be the same causing differences in solids content and the soluble solids-titratable acid ratio.

The quality factors studied of the 14 cultivars combined at both harvest dates and locations are shown in Table 7. There was a significant interaction between harvest dates and locations for pH and soluble solids but not for titratable acidity and soluble solids-titratable acid ratio. There was a significant decrease (more acid) in pH at both harvests at Jackson and a significant increase in soluble solids content at both harvests at Jackson. It is evident that the date

TABLE 6

SOLUBLE SOLIDS AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF 14 CULTIVARS OF TOMATOES GROWN AT TWO LOCATIONS

Cultivar	Percent Soluble Solids		Soluble Solids-Titratable Acid Ratio	
	Knoxville	Jackson	Knoxville	Jackson
Better Boy	5.91 b[W]	6.32 abc	18.8 a	15.8 abcdefg
Big Boy	5.51 cd	6.40 a	16.3 abcdef	17.3 abcd
Big Girl	5.50 cd	6.34 ab	17.7 abc	15.5 bcdefgh
Big Set	5.20 ef	5.61 fgh	12.8 gh	12.6 hi
Big Seven	5.55 cd	6.39 a	16.2 abcdef	14.9 bcdefghi
Early Big	4.92 g	5.18 i	13.3 fgh	13.8 efghi
Manapal	6.09 a	6.28 abc	16.9 abcd	16.1 abcdef
Oh Boy	5.53 cd	6.22 abc	13.4 fgh	14.6 defghi
Red King	5.56 cd	5.75 efg	13.7 efgh	15.5 bcdefgh
Royal Flush	5.10 fg	5.83 ef	11.9 h	17.9 ab
Setmore	5.20 ef	5.53 gh	14.1 defgh	14.6 defghi
Ultra Boy	5.36 de	6.20 abc	14.7 cdefgh	16.7 abcde
Ultra Girl	5.23 ef	6.08 cd	14.6 defgh	15.1 bcdefgh
Walter	5.40 de	5.62 fgh	14.1 defgh	14.2 defghi
Mean	5.43 z[X]	5.98 y	14.9 y	15.3 y

[W]Cultivar means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[X]Location means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 7

QUALITY FACTORS OF 14 CULTIVARS COMBINED AT TWO HARVEST DATES AND TWO LOCATIONS

Harvest Time and Locations	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio
Early Harvest				
Knoxville	4.52 a[W]	0.366 a	5.26 a	15.2 a
Jackson	4.44 c	0.385 a	5.75 c	15.5 a
Late Harvest				
Knoxville	4.50 a	0.391 a	5.60 b	14.6 a
Jackson	4.47 b	0.417 b	6.21 d	15.1 a
Mean	4.48	0.390	5.71	15.1

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

of sampling and the growing location can influence how tomato cultivars will perform. Certain environmental conditions found at a sampling date and at a location may cause cultivars to respond a particular way. Clearly, there is a genetic and environmental interaction for certain quality factors of tomato fruits.

Table 8 and 9 give correlation coefficients of pH and titratable acidity with quality factors for the 14 cultivars studied.

There was a negative correlation between pH and titratable acidity for 11 of the 14 cultivars. The cultivar, Walter, had the highest negative correlation value, -0.705.

It is interesting to note that the cultivar, Oh Boy, which had the lowest (most acid) pH, had one of the lowest correlation values between

TABLE 8

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF 14 CULTIVARS OF TOMATOES WITH LOCATIONS AND HARVEST DATES COMBINED

Cultivar	pH vs. Titratable Acidity	pH vs. Soluble Solids	pH vs. Soluble Solids-Titratable Acid Ratio
Better Boy	-.656*	-.340*	+.628*
Big Boy	-.152	-.133	+.020
Big Girl	-.644*	-.241	+.699*
Big Set	-.656*	-.481*	+.546*
Big Seven	-.476*	+.010	+.597*
Early Big	-.555*	-.723*	+.412*
Manapal	-.406*	+.056	+.420*
Oh Boy	-.445*	-.186	+.337
Red King	+.109	-.115	-.146
Royal Flush	-.633*	+.259	+.579*
Setmore	-.654*	-.152	+.551*
Ultra Boy	-.238	-.325	-.053
Ultra Girl	-.450*	-.293	+.356*
Walter	-.705*	+.023	+.778*

*Significant at .05 level.

TABLE 9

CORRELATION COEFFICIENTS OF TITRATABLE ACIDITY WITH pH, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF 14 CULTIVARS OF TOMATOES WITH LOCATIONS AND HARVEST DATES COMBINED

Cultivar	Titratable Acidity vs.		
	pH	Soluble Solids	Soluble Solids-Titratable Acid Ratio
Better Boy	-.656*	+.700*	-.884*
Big Boy	-.152	+.555*	-.785*
Big Girl	-.644*	+.591*	-.929*
Big Set	-.656*	+.182	-.922*
Big Seven	-.475*	+.538*	-.894*
Early Big	-.555*	+.508*	-.923*
Manapal	-.406*	+.358*	-.929*
Oh Boy	-.445*	+.496*	-.790*
Red King	+.109	+.036	-.908*
Royal Flush	-.633*	-.339*	-.937*
Setmore	-.654*	+.351*	-.906*
Ultra Boy	-.238	+.253	-.716*
Ultra Girl	-.450*	+.374*	-.805*
Walter	-.705*	+.064	-.913*

*Significant at .05 level.

pH and titratable acidity. However, it can be said that pH and titratable acidity are negatively correlated which is in agreement with other studies (32. 51).

In general, pH was not correlated with soluble solids content (Table 8), but there was a general positive correlation between titratable acidity and soluble solids of cultivars (Table 9). Organic acids will actually contribute to the soluble solids content.

Generally, the pH was positively correlated with the soluble solids-titratable acid ratio of the 14 cultivars (Table 8). Titratable acidity would be expected to be highly correlated with the soluble solids-titratable acid ratio as shown in Table 9.

Tables 10 and 11 indicate that pH and titratable acidity were correlated when cultivars were combined at two harvest dates and at two locations. The pH was positively correlated with soluble solids-titratable acid ratio (Table 10) while titratable acidity was negatively correlated with this ratio (Table 11). No highly positive or negative relation existed between either pH or titratable acidity with soluble solids at each harvest and each location.

II. FERTILIZATION EXPERIMENT

Table 12 shows that the seven fertilizer treatments did not significantly influence the pH, percent titratable acid, percent soluble solids, or the soluble solids-titratable acid ratio of tomatoes.

Tables 13 and 14 show no significant differences between fertilizer treatments at Knoxville, Crossville, and Jackson for any of the

TABLE 10

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF 14 CULTIVARS OF TOMATOES AT TWO HARVEST DATES AND TWO LOCATIONS

Harvest Time and Locations	pH vs. Titratable Acidity	pH vs. Soluble Solids	pH vs. Soluble Solids-Titratable Acid Ratio
Early Harvest			
Knoxville	-.501*	-.113	+.488*
Jackson	-.601*	+.037	+.570*
Late Harvest			
Knoxville	-.775*	+.287*	+.794*
Jackson	-.433*	+.234*	+.653*

*Significant at .05 level.

TABLE 11

CORRELATION COEFFICIENTS OF TITRATABLE ACIDITY WITH pH, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF 14 CULTIVARS OF TOMATOES AT TWO HARVEST DATES AND TWO LOCATIONS

Harvest Time and Locations	Titratable Acidity vs. pH	Titratable Acidity vs. Soluble Solids	Titratable Acidity vs. Soluble Solids-Titratable Acid Ratio
Early Harvest			
Knoxville	-.501*	+.100	-.927*
Jackson	-.601*	-.094	-.949*
Late Harvest			
Knoxville	-.775*	-.152	-.903*
Jackson	-.433*	+.491	-.721*

*Significant at .05 level.

TABLE 12

THE INFLUENCE OF FERTILIZATION ON QUALITY FACTORS
OF TOMATOES WITH LOCATIONS COMBINED

Rate (kg/ha)							
At Planting			Sidedress				
N	P_2O_5	K_2O	N	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio
0	0	0	0	4.51 a[w]	0.346 a	5.82 a	18.0 a
33.6	0	0	33.6	4.53 a	0.354 a	5.89 a	17.3 a
33.6	67.3	67.3	33.6	4.49 a	0.344 a	5.79 a	17.4 a
33.6	67.3	134.6	33.6	4.47 a	0.370 a	5.79 a	16.1 a
33.6	134.6	67.3	33.6	4.49 a	0.331 a	5.80 a	18.3 a
33.6	134.6	134.6	33.6	4.48 a	0.386 a	5.94 a	15.7 a
100.9	134.6	134.6	33.6	4.48 a	0.365 a	5.89 a	16.5 a
Mean				4.49	0.356	5.84	17.0

[w]Fertilizer treatment means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 13

THE INFLUENCE OF FERTILIZATION ON THE pH AND TITRATABLE ACIDITY OF TOMATOES GROWN AT THREE LOCATIONS

Rate (kg/ha)				pH			Percent Titratable Acid		
At Planting			Sidedress						
N	P_2O_5	K_2O	N	Knoxville	Crossville	Jackson	Knoxville	Crossville	Jackson
0	0	0	0	4.52 a[w]	4.54 a	4.47 a	0.302 a	0.377 a	0.358 a
33.6	0	0	33.6	4.53 a	4.53 a	4.52 a	0.306 a	0.413 a	0.345 a
33.6	67.3	67.3	33.6	4.50 a	4.48 a	4.50 a	0.325 a	0.374 a	0.333 a
33.6	67.3	134.6	33.6	4.48 a	4.49 a	4.44 a	0.366 a	0.412 a	0.332 a
33.6	134.6	67.3	33.6	4.51 a	4.49 a	4.48 a	0.327 a	0.388 a	0.277 a
33.6	134.6	134.6	33.6	4.51 a	4.48 a	4.46 a	0.323 a	0.399 a	0.374 a
100.9	134.6	134.6	33.6	4.48 a	4.49 a	4.48 a	0.370 a	0.424 a	0.365 a
Mean				4.51 y[x]	4.50 y	4.48 y	0.331 y	0.398 y	0.340 y

[w]Fertilizer treatment means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[x]Location means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 14

THE INFLUENCE OF FERTILIZATION ON THE SOLUBLE SOLIDS AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF TOMATOES GROWN AT THREE LOCATIONS

Rate (kg/ha)				Percent Soluble Solids			Soluble Solids-Titratable Acid Ratio		
At Planting			Sidedress						
N	P_2O_5	K_2O	N	Knoxville	Crossville	Jackson	Knoxville	Crossville	Jackson
0	0	0	0	5.96 a[w]	5.90 a	5.60 a	20.0 a	15.7 a	18.5 a
33.6	0	0	33.6	5.93 a	6.00 a	5.73 a	20.0 a	14.5 a	17.4 a
33.6	67.3	67.3	33.6	5.80 a	5.82 a	5.75 a	18.0 a	15.9 a	18.3 a
33.6	67.3	134.6	33.6	5.88 a	5.77 a	5.71 a	16.8 a	14.0 a	17.5 a
33.6	134.6	67.3	33.6	5.85 a	5.95 a	5.62 a	18.2 a	15.5 a	21.1 a
33.6	134.6	134.6	33.6	6.00 a	5.82 a	5.86 a	18.6 a	14.6 a	16.5 a
100.9	134.6	134.6	33.6	6.02 a	5.95 a	5.85 a	16.4 a	14.1 a	16.2 a
Mean				5.92 y[x]	5.88 y	5.73 y	18.3 y	14.9 y	17.9 y

[w]Fertilizer treatment means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[x]Location means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

parameters studied. These findings are in agreement with those of Kattan et al. (24) who reported that the quality constituents of tomatoes were not related to any fertility factors. However, potassium has been reported to affect the acid content and buffer system of tomato fruits (6, 18, 22, 29). Apparently, potassium is the major cation present in tomato fruits, and any increase in the potassium content of the fruit will produce an increase in organic acids, thereby maintaining a constant pH. This could possibly affect the change in pH when tomatoes are acidified in order to lower the pH.

A study was made of the influence of fertilization treatments on the volume of 0.5 percent citric acid solution required to lower the pH of the puree 0.1, 0.2 and/or 0.3 units. It has been indicated that a solution of this strength, or slightly more concentrated, is needed to lower the pH, although it is pointed out that individual tomatoes will vary to the extent they are buffered and will, therefore, vary in their reaction to citric acid (4). The results of the study with growing locations combined are presented in Table 15. There was no significant difference in amounts of citric acid needed at each increment to bring about the change in fruits from any of the fertilizer treatments. Apparently, there was no change in the buffering system that could be attributed to fertilizer treatment, including those with higher amounts of potassium. Possible potassium treatments in this test were not sufficiently high to affect this response.

The volume of citric acid solution needed to lower the pH of tomatoes grown at these locations is shown in Table 16. It generally

TABLE 15

THE INFLUENCE OF FERTILIZATION ON THE VOLUME OF CITRIC ACID SOLUTION USED TO LOWER TOMATO FRUIT pH BY 0.1, 0.2, OR 0.3 UNITS WITH LOCATIONS COMBINED

Rate (kg/ha)				Mean	Ml. Citric Acid to Lower pH		
At Planting			Sidedress				
N	P_2O_5	K_2O	N	pH	0.1 unit	0.2 unit	0.3 unit
0	0	0	0	4.51 a[W]	10.9 a	22.0 a	34.8 a
33.6	0	0	33.6	4.53 a	11.8 a	23.1 a	36.8 a
33.6	67.3	67.3	33.6	4.49 a	12.0 a	23.5 a	37.4 a
33.6	67.3	134.6	33.6	4.47 a	11.9 a	24.6 a	39.1 a
33.6	134.6	67.3	33.6	4.49 a	11.3 a	22.6 a	36.0 a
33.6	134.6	134.6	33.6	4.48 a	12.4 a	24.7 a	39.7 a
100.9	134.6	134.6	33.6	4.48 a	11.0 a	23.9 a	39.0 a
Mean				4.49	11.6	23.5	37.6

[W]Fertilizer treatment means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 16

THE INFLUENCE OF DIFFERENT GROWING LOCATIONS ON THE VOLUME OF CITRIC ACID SOLUTION USED TO LOWER TOMATO FRUIT pH BY 0.1, 0.2, OR 0.3 UNITS WITH FERTILIZER TREATMENTS COMBINED

Location	Mean pH	Ml. Citric Acid to Lower pH		
		0.1 Unit	0.2 Unit	0.3 Unit
Knoxville	4.51 a[W]	10.3 b	21.1 c	33.9 b
Crossville	4.50 a	12.2 a	25.8 a	41.9 a
Jackson	4.48 a	12.4 a	23.6 b	36.8 ab
Mean	4.49	11.6	23.5	37.6

[W]Location means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

took more acid solution to lower the pH to each of the three increment levels in fruits from Crossville than it did in fruits from either Jackson or Knoxville. This probably can be attributed to a slightly greater acid content of tomatoes grown at Crossville (Table 13, pg. 50). This would agree with results reported by Lopez and Schoenemann (31).

Correlation coefficients between pH and titratable acidity and other quality factors due to fertilizer treatments are given in Tables 17 and 18. There were no high correlations between pH and titratable acidity. Only three treatments had a significant negative correlation between pH and titratable acidity. It has been previously mentioned that pH may not always be correlated with percent acid (2, 51).

Neither pH nor titratable acidity was generally correlated with soluble solids (Tables 17 and 18).

No high positive or negative correlation existed between pH and soluble solids-titratable acid ratio. This would be expected since pH was not correlated with titratable acidity generally speaking. However, titratable acidity was highly correlated with the soluble solids-titratable acid ratio.

III. RIPENESS EXPERIMENT

Harvesting of tomatoes considered overripe or over mature undoubtedly occurs in home gardens, and such fruit may differ in certain quality factors from those harvested in a ripe stage of maturity. A

TABLE 17

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF TOMATOES FOR SEVEN FERTILIZER TREATMENTS WITH LOCATIONS COMBINED

Rate (kg/ha)				pH vs.		
At Planting			Sidedress			
N	P_2O_5	K_2O	N	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio
0	0	0	0	-.633*	-.115	+.459*
33.6	0	0	33.6	-.300	+.541*	+.337
33.6	67.3	67.3	33.6	-.585*	+.251	+.469*
33.6	67.3	134.6	33.6	-.328	+.218	+.354
33.6	134.6	67.3	33.6	+.030	-.108	-.123
33.6	134.6	134.6	33.6	-.068	+.410*	+.066
100.9	134.6	134.6	33.6	-.563*	+.380	+.510*

*Significant at .05 level.

TABLE 18

CORRELATION COEFFICIENTS OF TITRATABLE ACIDITY WITH pH, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF TOMATOES FOR SEVEN FERTILIZER TREATMENTS WITH LOCATIONS COMBINED

Rate (kg/ha)				Titratable Acidity vs.		
At Planting			Sidedress			
N	P_2O_5	K_2O	N	pH	Soluble Solids	Soluble Solids-Titratable Acid Ratio
0	0	0	0	-.633*	+.450*	-.954*
33.6	0	0	33.6	-.300	+.240	-.985*
33.6	67.3	67.3	33.6	-.588*	-.117	-.977*
33.6	67.3	134.6	33.6	-.328	-.060	-.959*
33.6	134.6	67.3	33.6	+.030	+.655*	-.966*
33.6	134.6	134.6	33.6	-.068	+.338	-.987*
100.9	134.6	134.6	33.6	-.563*	-.395	-.983*

*Significant at .05 level.

study comparing ripe fruits with overripe fruits at three harvest dates is discussed below.

Table 19 indicates significant differences between ripe and overripe fruits for pH, percent titratable acid, and the soluble solids-titratable acid ratio. Fruit pH was considerably higher in the overripe fruits than in the ripe fruits. It has been indicated that pH increases, and acid content decreases as a tomato fruit ripens (19, 35, 39). Metabolism of citric and malic acids during ripening has been suggested as the reason for the change in acidity (7, 10). Supposedly, organic acids decrease while sugars increase. However, in this study, there was no change in soluble solids content.

A high soluble solids-titratable acid ratio, as indicated in Table 19 for the overripe fruit, would probably result in a mild flavored fruit.

TABLE 19

QUALITY FACTORS OF TOMATOES ANALYZED AT RIPE AND OVERRIPE MATURITY

Maturity	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio
Ripe	4.47 b[W]	0.403 a	5.48 b	14.6 b
Overripe	4.71 a	0.288 b	5.27 b	18.7 a

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

Table 20 shows certain quality factors of tomato fruits analyzed ripe and overripe at three harvest dates. There was a significant interaction between ripeness levels and harvest dates for all four parameters studied. The pH of overripe fruits was significantly higher (less acid) as compared to ripe fruit at all three harvest dates. There was no difference in the pH of overripe fruit between harvest, but the pH of ripe fruit was significantly lower at the salvage harvest. Lower soil moisture, poor foliage, and small fruit size are probably responsible for a lower pH at the salvage harvest.

TABLE 20

QUALITY FACTORS OF TOMATOES ANALYZED AT RIPE AND OVERRIPE MATURITY AT THREE HARVEST DATES

Harvest and Maturity	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio
Early Harvest				
Ripe	4.52 b[W]	0.338 bc	5.46 abc	17.6 ab
Overripe[1]	4.72 a	0.297 cd	5.18 bc	17.6 ab
Late Harvest				
Ripe	4.50 b	0.384 b	5.77 a	15.1 b
Overripe	4.69 a	0.272 d	5.12 c	19.3 a
Salvage Harvest[2]				
Ripe	4.38 c	0.487 a	5.21 bc	10.9 c
Overripe	4.73 a	0.296 cd	5.52 ab	19.1 a
Mean	4.59	0.346	5.38	16.6

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[1]Overripe fruits were those kept for 25 days after harvest before analysis.

[2]Salvage harvest was field run fruit which included culls along with U.S. No. 1 and No. 2 grade fruit.

Titratable acidity was lower for the overripe fruits at each harvest date. The organic acids were metabolized while fruits were being kept for 25 days, hence the lower acid content.

There was a decrease in soluble solids content of overripe fruit from the level of ripe fruit at both the early and late harvest but just the opposite occurred at the salvage harvest. Sugars would be continually respired when kept for 25 days which would explain the lower content of the overripe fruit, but no explanation is given for the increase in solids content for overripe fruit at the salvage harvest.

Correlation coefficients of pH and titratable acidity with other quality factors for ripe and overripe fruits at three harvest dates are given in Tables 21 and 22. Both pH and titratable acidity were significantly negatively correlated for both conditions of ripeness at all three harvest dates. Highest correlations were obtained at the late harvest date (July 29).

It can be said that there was no correlation between either pH and soluble solids or titratable acidity and soluble solids, although r values for the salvage harvest (Table 22) between titratable acidity and soluble solids shows significance. However, there was no clear indication of a consistent relationship.

The pH was positively correlated with the soluble solids-titratable acid ratio (Table 21) while titratable acidity was negatively correlated with the ratio (Table 22).

These data indicate a close relationship between pH and acid content of fruit in a ripe or past-ripe stage all during the harvest season, and this may account for differences in flavor of tomato fruits.

TABLE 21

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF TOMATOES FOR THREE HARVEST DATES AND TWO RIPENESS LEVELS

Harvest and Ripeness Level	pH vs. Titratable Acidity	pH vs. Soluble Solids	pH vs. Soluble Solids-Titratable Acid Ratio
Early Harvest			
Ripe	-.569*	+.240	+.662*
Overripe	-.638	+.023	+.636*
Late Harvest			
Ripe	-.840*	+.607*	+.871*
Overripe	-.873*	+.080	+.736*
Salvage Harvest			
Ripe	-.652*	+.100	+.491*
Overripe	-.552*	-.474*	+.264

*Significant at the .05 level.

TABLE 22

CORRELATION COEFFICIENTS OF TITRATABLE ACIDITY WITH pH, SOLUBLE SOLIDS, AND SOLUBLE SOLIDS-TITRATABLE ACID RATIO OF TOMATOES FOR THREE HARVEST DATES AND TWO RIPENESS LEVELS

Harvest and Ripeness Level	Titratable Acidity vs. pH	Titratable Acidity vs. Soluble Solids	Titratable Acidity vs. Soluble Solids-Titratable Acid Ratio
Early Harvest			
Ripe	-.569*	-.106	-.938*
Overripe	-.638*	+.360	-.847*
Late Harvest			
Ripe	-.840*	-.354	-.856*
Overripe	-.873*	-.073	-.827*
Salvage Harvest			
Ripe	-.652*	-.420*	-.855*
Overripe	-.552*	+.480*	-.752*

*Significant at the .05 level.

IV. TRAINING SYSTEM EXPERIMENT

The results of a study to determine the effects of harvesting tomato fruit at several stages of maturity from plants trained different ways in the field are discussed below.

Table 23 shows training systems had no significant effect on pH or percent reducing sugars, but significant differences were found in percent titratable acid, percent soluble solids, and soluble solids-titratable acid ratio. Those plants staked and pruned to two stems had the lowest acid content, soluble solids, and soluble solids-titratable acid ratio. It was observed that fruits from those plants staked and pruned were larger than those from other methods of training, and the leaf to fruit ratio was less for those staked and pruned. This could explain the lower organic acid and soluble solids content. Even though no differences were found in pH, it has been mentioned previously that pH is not always correlated with the acid content.

The mean pH 4.57 (Table 23) is considerably higher than that recorded for the Better Boy cultivar in the cultivar experiment (Table 2, pg. 36). Since the same analytical methods including the same buffer to standardize the pH meter were used in this experiment as were used in the cultivar experiment, this confirms the fact that cultivars can perform differently under different environmental conditions.

The effects of two different harvest dates of the four training systems on quality factors are shown in Table 24. There was a

TABLE 23

THE INFLUENCE OF FOUR SYSTEMS OF TRAINING PLANTS
ON QUALITY FACTORS OF TOMATOES

Training System	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
Staked and pruned	4.56 a[w]	0.395 c	5.21 b	13.6 a	3.10 a
Florida weave	4.56 a	0.464 a	5.47 a	12.2 b	3.09 a
Caged	4.58 a	0.446 b	5.37 a	12.2 b	3.02 a
No support	4.57 a	0.440 b	5.47 a	12.7 b	2.99 a
Mean	4.57	0.436	5.38	12.7	3.05

[w]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 24

THE INFLUENCE OF FOUR SYSTEMS OF TRAINING PLANTS ON QUALITY FACTORS OF TOMATOES AT TWO HARVEST DATES

Date of Harvest and Training System	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
August 27					
Staked and pruned	4.56 bcd[W]	0.419 c	4.81 d	11.7 c	3.12 bc
Florida weave	4.58 abc	0.463 a	5.19 c	11.4 c	3.38 a
Caged	4.62 a	0.436 abc	4.84 d	11.3 c	3.06 bc
No support	4.59 ab	0.447 ab	5.28 c	12.1 c	3.25 ab
September 14					
Staked and pruned	4.56 bcd	0.370 d	5.61 b	15.6 a	3.09 bc
Florida weave	4.54 d	0.464 a	5.76 ab	13.0 b	2.80 de
Caged	4.55 cd	0.455 ab	5.90 a	13.2 b	2.97 cd
No support	4.56 bcd	0.432 bc	5.66 b	13.3 b	2.72 e
Overall Mean	4.57	0.436	5.38	12.7	3.05
Harvest Mean					
August 27	4.59 y[X]	0.442 y	5.03 z	11.6 z	3.20 y
September 14	4.55 z	0.430 y	5.73 y	13.8 y	2.89 z

[W]Training system means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

[X]Harvest means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

significant interaction between date of harvest and training system for all parameters studied except for pH. Although there was no consistent way the systems of training influenced the acid content at either harvest, there were harvest time differences for pH, soluble solids, soluble solids-titratable acid ratio, and reducing sugar. The pH was lower at the September 14 harvest which agrees with an earlier ripeness study of lower values at a late harvest. Soluble solids and, hence, the soluble solids-titratable acid ratio was generally higher at the September 14 harvest. However, percent reducing sugar was generally lower at the later harvest. A greater fruit-to-leaf ratio is probably the reason why the soluble solids content is higher the second harvest. The amount of foliage was considered good and since there were fewer fruit on the plants leading to the second harvest, a greater soluble solids percent would be expected. The reducing sugar content decreased at the September 14 harvest which is interesting since most of the sugars found in tomato fruits are said to be reducing sugars (23). However, Lambeth et al. (27) did not find a correlation between soluble solids and reducing sugar.

Tomato fruits were harvested from the four systems of training plants in four stages of maturity. The results of the effects of stage of maturity harvested are given in Table 25.

There was significant differences among the stages of fruit maturity for all quality factors studied. Those fruits harvested when firm ripe had the lowest pH and highest acid content. The soft ripe fruits had the highest pH, lowest acid, highest soluble solids content,

TABLE 25

THE INFLUENCE OF FOUR STAGES OF MATURITY ON QUALITY FACTORS OF TOMATOES

Stage of Maturity	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
Turning	4.55 c[W]	0.419 b	5.46 a	13.1 b	2.83 b
Firm ripe	4.46 d	0.512 a	5.19 c	10.2 d	3.27 a
Canning ripe	4.58 b	0.437 b	5.33 b	12.5 c	3.28 a
Soft ripe	4.67 a	0.376 c	5.55 a	14.9 a	2.82 b
Mean	4.57	0.436	5.38	12.7	3.05

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

and highest soluble solids-titratable acid ratio. The reducing sugar content was highest for those harvested and analyzed when firm ripe and canning ripe. The trends of increasing pH, soluble solids, and sugar-acid ratios with decreasing titratable acidity as fruits ripen found in this study, are in general agreement with several studies (19, 35, 39, 55, 58).

It is interesting that fruit harvested in the turning stage and subsequently ripened and analyzed when at the canning ripe stage had the same percent reducing sugar and soluble solids as those harvested and analyzed when soft ripe (Table 25). It would be expected that both soluble solids and reducing sugar would be lower for those fruits harvested at earlier maturities and higher for those harvested at later stages of maturity. This study did not show this. As mentioned

previously, soluble solids and reducing sugar may not always be correlated.

Table 26 gives the effects on quality factors of fruits of each training system with each maturity harvested. There was no significant interaction between system of training and stage of maturity harvested for any of the quality factors.

The data indicate that fruit harvested from any of the standard systems of training plants in a soft ripe stage may have too high a pH to be used for canning purposes. Risk of spoilage and risk of botulism poisoning would be greater than for fruits harvested in an earlier stage of maturity, although the mean pH of all fruit recorded in this study is considered high.

Tables 27 and 28 show correlation coefficients of pH and titratable acidity with other quality factors for the systems of training. As expected, pH and titratable acidity were negatively correlated. Fruit pH was positively correlated with the soluble solids-titratable acid ratio while titratable acidity was negatively correlated with the ratio.

Neither pH nor titratable acidity showed a relationship with soluble solids and reducing sugar.

Correlation coefficients between quality factors due to stage of maturity harvested are given in Tables 29 and 30. Again pH and titratable acidity were negatively correlated. Higher r values were found for the canning ripe and soft ripe fruits. There was a low relationship between both pH and titratable acidity and soluble solids

TABLE 26

THE INFLUENCE OF FOUR STAGES OF MATURITY WITH FOUR SYSTEMS OF TRAINING PLANTS ON QUALITY FACTORS OF TOMATOES

Stage of Maturity and Training System	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
Turning					
Staked and pruned	4.54 b[W]	0.371 gh	5.30 bcd	14.4 bc	2.87 d
Florida weave	4.55 b	0.446 cd	5.52 ab	12.4 d	2.76 d
Caged	4.57 b	0.440 cd	5.53 ab	12.6 d	2.91 d
No support	4.55 b	0.420 def	5.48 ab	13.1 cd	2.76 d
Firm Ripe					
Staked and pruned	4.46 c	0.460 cd	5.00 e	11.0 ef	3.32 ab
Florida weave	4.45 c	0.561 a	5.29 bcd	9.4 g	3.35 ab
Caged	4.47 c	0.522 b	5.20 cde	9.9 fg	3.35 ab
No support	4.47 c	0.504 b	5.28 bcd	10.4 fg	3.04 bcd
Canning Ripe					
Staked and pruned	4.58 b	0.399 efg	5.11 de	13.3 cd	3.23 abc
Florida weave	4.58 b	0.467 c	5.50 ab	12.0 de	3.45 a
Caged	4.59 b	0.433 cde	5.18 de	12.2 de	3.06 bcd
No support	4.59 b	0.449 cd	5.52 ab	12.5 d	3.39 a
Soft Ripe					
Staked and pruned	4.66 a	0.349 h	5.44 abc	14.8 ab	2.99 cd
Florida weave	4.66 a	0.381 fgh	5.58 a	14.8 ab	2.80 d
Caged	4.69 a	0.388 fgh	5.56 a	14.3 bc	2.74 d
No support	4.68 a	0.385 fgh	5.60 a	14.8 ab	2.76 d

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 27

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR FOUR SYSTEMS OF TRAINING PLANTS

	pH vs.			
System of Training	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Staked and pruned	-.705*	+.141	+.595*	-.196
Florida weave	-.848*	+.092	+.752*	+.013
Caged	-.858*	-.082	+.632*	-.188
No support	-.798*	+.192	+.773*	+.039

*Significant at the .05 level.

TABLE 28

CORRELATION COEFFICIENTS OF TITRATABLE ACIDITY WITH pH, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR FOUR SYSTEMS OF TRAINING PLANTS

	Titratable Acidity vs.			
System of Training	pH	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Staked and pruned	-.705*	-.433*	-.897*	+.091
Florida weave	-.848*	-.105	-.862*	+.198
Caged	-.858*	+.041	-.766*	+.196
No support	-.798*	-.248*	-.931*	+.121

*Significant at the .05 level.

TABLE 29

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR FOUR STAGES OF MATURITY

	pH vs.			
Stage of Maturity	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Turning	-.458*	-.424*	+.128	+.100
Firm ripe	-.417*	-.237*	+.209	+.543*
Canning ripe	-.760*	+.144	+.698*	+.062
Soft ripe	-.626*	-.062	+.409*	-.111

*Significant at the .05 level.

TABLE 30

CORRELATION COEFFICIENTS OF TITRATABLE ACIDITY WITH pH, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR FOUR STAGES OF MATURITY

	Titratable Acidity vs.			
Stage of Maturity	pH	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Turning	-.458*	+.286*	-.734*	-.158
Firm ripe	-.417*	+.324*	-.746*	-.140
Canning ripe	-.760*	-.077	-.898*	-.001
Soft ripe	-.626*	-.003	-.728*	-.240*

*Significant at the .05 level.

for tomatoes picked in the turning and firm ripe stage. No consistent correlation between both pH and titratable acidity with reducing sugar was found.

V. MOISTURE AND SHADE EXPERIMENT

Effects of Moisture

The results of a study on the effects of moisture on quality factors of tomate fruits are given in Table 31. There was a significant difference between those plants subjected to high moisture stress and those subjected to low moisture stress for all the factors studied.

The pH was lower and titratable acidity content was higher for those plants subjected to high moisture stress. Percent soluble solids and percent reducing sugar were also significantly higher for plants subjected to high moisture stress.

TABLE 31

THE INFLUENCE OF MOISTURE SUPPLY ON QUALITY FACTORS OF TOMATOES

Moisture Supply	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
Adequate	4.47 a[W]	0.351 b	6.01 b	17.4 a	3.72 b
Limited	4.42 b	0.451 a	6.98 a	16.4 b	4.46 a
Mean	4.45	0.401	6.50	16.9	4.09

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

Several contradictions abound in the literature as to the effect of moisture supply on acidity of tomato fruits. The results of this study are in agreement with those of Lee and Sayre (29) for both pH and titratable acidity. They reported that an increase in acidity was not a mere proportional decrease in water content but an actual increase in acids produced.

Higher solids and sugar content under restricted moisture supply have been reported (29, 43, 55). This condition can be explained by the dilution effect due to more water in the fruit where moisture is plentiful. Soluble solids-titratable acid ratios indicate no appreciable change in flavor of fruits would be expected when plants are grown with restricted moisture supply.

Table 32 shows that the weight of individual fruit from plants grown with either adequate or limited water had little correlation with quality factors studied.

Table 33 shows that pH was negatively correlated with titratable acidity for both moisture treatments. Also, pH was positively correlated with soluble solids-titratable acid ratio.

Effects of Shade

The influence of shaded as compared to nonshaded plants on quality factors of tomato fruits is given in Table 34. There was no difference in any factor except soluble solids where a significantly higher percentage was found in fruits from shaded plants. Just the opposite would be expected as shaded leaves would not assimilate as much

TABLE 32

CORRELATION COEFFICIENTS OF WEIGHT OF TOMATO FRUIT WITH pH, TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR TWO LEVELS OF MOISTURE SUPPLY

	Weight of Fruit vs.				
Moisture Supply	pH	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Adequate	+.021	+.042	+.090	-.022	-.035
Limited	+.008	-.135	-.151	+.056	-.011

TABLE 33

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR TWO LEVELS OF MOISTURE SUPPLY

	pH vs.			
Moisture Supply	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Adequate	-.595*	+.252*	+.694*	+.205
Limited	-.629*	-.131	+.442*	+.040

*Significant at the .05 level.

TABLE 34

THE INFLUENCE OF SUBJECTING PLANTS TO TWO LIGHT TREATMENTS ON QUALITY FACTORS OF TOMATOES

Light Treatment	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
No shade	4.44 a[W]	0.400 a	6.36 b	16.9 a	4.00 a
Shade	4.45 a	0.402 a	6.63 a	16.9 a	4.19 a
Mean	4.45	0.401	6.50	16.9	4.09

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

photosynthetate as those not shaded. Table 35 may help explain this. It shows that weight of fruit was negatively correlated with soluble solids content of fruit from shaded plants. Smaller fruits obtained from the shaded plants resulted in a higher solids content.

TABLE 35

CORRELATION COEFFICIENTS OF WEIGHT OF TOMATO FRUIT WITH pH, TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR SUBJECTING PLANTS TO TWO LIGHT TREATMENTS

	Weight of Fruit vs.				
Light Treatment	pH	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
No shade	+.147	-.185	-.154	+.042	-.169
Shade	+.153	-.376*	-.410*	+.154	-.245

*Significant at the .05 level.

Table 35 also indicates a low negative relationship between weight of fruit and acid content.

Fruit pH was negatively correlated with titratable acidity and positively correlated with soluble solids-titratable acid ratio as shown in Table 36.

There was no interaction between moisture supply and light treatments for any of the factors studied.

VI. EFFECTS OF PROCESSING

Data in Table 37 indicates that reducing sugar content was the only parameter studied to differ between tomatoes analyzed fresh and those 24 hours after canning. The sugar content was higher after canning which would not be expected since soluble solids content did not change, and since it has been reported that sugars are broken down upon heating (16). The reasons for this behavior were unknown.

Processing has been reported to decrease the pH and increase the percent acid and soluble solids (1, 24, 25). An explanation for no differences in this study between fresh and canned tomatoes may be because fruits were not cored or peeled when canned. Adams (1) found that tomatoes which had been cored has a lower pH than those analyzed whole.

Table 38 shows the influence of stage of maturity at harvest on tomatoes analyzed fresh and after canning. There was a significant interaction among maturities harvested and the time of analysis (fresh and 24 hours after canning) for all quality factors except pH.

TABLE 36

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES FOR SUBJECTING PLANTS TO TWO LIGHT TREATMENTS

	pH vs.			
Light Treatment	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
No shade	-.646*	-.248	+.447*	-.089
Shade	-.671*	-.167	+.744*	-.037

*Significant at the .05 level.

TABLE 37

THE INFLUENCE OF TIME OF ANALYSIS ON QUALITY FACTORS OF TOMATOES ANALYZED FRESH AND 24 HOURS AFTER CANNING

Time of Analysis	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
Fresh	4.56 a[W]	0.394 a	5.18 a	13.6 a	3.09 b
Canned	4.58 a	0.388 a	5.15 a	13.7 a	3.63 a
Mean	4.57	0.391	5.16	13.7	3.35

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

TABLE 38

THE INFLUENCE OF TIME OF ANALYSIS ON QUALITY FACTORS OF TOMATOES AT FOUR STAGES OF MATURITY ANALYZED FRESH AND 24 HOURS AFTER CANNING

Stage of Maturity and Time of Analysis	pH	Percent Titratable Acid	Percent Soluble Solids	Soluble Solids-Titratable Acid Ratio	Percent Reducing Sugar
Turning					
Fresh	4.54 def[W]	0.371 cde	5.30 ab	14.4 bc	2.83 e
Canned	4.57 cde	0.366 de	5.35 a	14.8 ab	3.22 d
Firm Ripe					
Fresh	4.46 f	0.460 a	4.87 d	11.0 e	3.32 cd
Canned	4.48 ef	0.442 a	4.95 d	11.3 c	3.91 a
Canning Ripe					
Fresh	4.58 cde	0.399 bc	5.11 c	13.3 cd	3.23 d
Canned	4.60 bcd	0.403 b	5.15 bc	13.2 cd	3.92 a
Soft Ripe					
Fresh	4.66 abc	0.345 de	5.44 a	15.8 a	2.99 e
Canned	4.68 ab	0.340 e	5.15 bc	15.4 ab	3.50 bc
Mean	4.57	0.391	5.16	13.7	3.35

[W]Means in each column followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

There were differences between different maturities for all parameters studied. However, no differences between those analyzed fresh and after canning within each maturity were detected except for the reducing sugar percentage. Reducing sugar was significantly higher after canning for each maturity. The firm ripe and canning ripe maturities had the highest sugar content both before and after canning.

These data indicate that stage of maturity of harvest does not have any influence on quality factors of whole tomatoes after processing as compared to fresh tomatoes.

Table 39 shows that pH was negatively correlated with titratable acidity and positively correlated with the soluble solids-titratable acid ratio.

TABLE 39

CORRELATION COEFFICIENTS OF pH WITH TITRATABLE ACIDITY, SOLUBLE SOLIDS, SOLUBLE SOLIDS-TITRATABLE ACID RATIO, AND REDUCING SUGAR OF TOMATOES ANALYZED FRESH AND 24 HOURS AFTER CANNING

	pH vs.			
Time of Analysis	Titratable Acidity	Soluble Solids	Soluble Solids-Titratable Acid Ratio	Reducing Sugar
Fresh	-.704*	+.147	+.595*	-.178
Canned	-.517*	-.083	+.409*	-.027

*Significant at the .05 level.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the influence of certain genetic, cultural and environmental factors on several quality factors of tomato fruits and to explore their relationship. The factors studied for influence on tomato fruit quality were cultivars, fertilization rates, ripeness levels, training systems, shade and moisture effects, and processing.

The quality factors determined by laboratory analysis were pH, percent titratable acid, percent soluble solids, soluble solids-titratable acid ratio, and percent reducing sugar.

The findings of this study are summarized below.

I. CULTIVAR EXPERIMENT

There were differences among 14 cultivars for pH, percent titratable acid, percent soluble solids, and soluble solids-titratable acid ratio. The mean pH for all cultivars was 4.48 with a mean range from 4.42 to 4.57.

The cultivars differed for the previously mentioned quality factors within both the early harvest and late harvest date. Except for soluble solids, no interaction between cultivars and harvest date was found. The mean soluble solids content was greater at the late harvest.

There were significant differences among cultivars for all four quality factors between two locations, Knoxville and Jackson. There was

an interaction between location and cultivars for titratable acidity, soluble solids, and soluble solids-titratable acid ratio but not for pH. The pH was lower (more acid), and percent acid was higher in fruit from Jackson, indicating an inverse relationship. Soluble solids were higher in the Jackson fruit also.

There was an interaction between harvest date and location for pH and soluble solids. Fruit pH was lower at both harvests at Jackson while soluble solids were higher at both harvests at Jackson.

The pH of the 14 cultivars was inversely related to percent acid, but no relationship was evident with soluble solids. Both pH and titratable acidity were related to soluble solids-titratable acid ratio.

II. FERTILIZATION EXPERIMENT

Seven fertilizer treatments did not influence pH, percent titratable acid, percent soluble solids, or the soluble solids-titratable acid ratio.

The volume of 0.5 percent citric acid needed to lower the pH 0.1, 0.2, and/or 0.3 pH units was not influenced by fertilization treatments, indicating the buffer system of tomato fruits in this study was not affected by fertilizer treatments. It took slightly more citric acid to lower the pH of Crossville grown fruit than it did either Knoxville or Jackson grown fruit.

Fruit pH and titratable acidity were not related to each other nor was either related to soluble solids content.

III. RIPENESS EXPERIMENT

Fruits overripe when analyzed had a considerably higher pH, lower acid content, and higher soluble solids-titratable acid ratio than fruits analyzed at a ripe stage of maturity.

There was a significant interaction between ripeness levels and three harvest dates for all four parameters previously mentioned. The pH of overripe fruit was higher at each harvest date than ripe fruit while titratable acidity was lower for overripe fruit at each harvest. This was attributed to the metabolism of organic acids which occurred in the fruits while they were being kept for 25 days after harvest. Soluble solids of overripe fruit were lower in the early and late harvest than ripe fruit, but just the opposite was found in the salvage harvest

Fruit pH and titratable acidity were negatively related with highest correlations obtained at the late harvest date. There was little relationship between either pH or titratable acidity with soluble solids.

IV. TRAINING SYSTEM EXPERIMENT

The different training systems did not influence pH and reducing sugar but did influence titratable acidity, soluble solids, and the soluble solids-titratable acid ratio. Those plants staked and pruned to two stems had the lowest acid and soluble solids content.

There was an interaction between date of harvest and training system for all parameters except pH. No consistent trend of acid content due to the training system was evident at either harvest, but soluble

solids was generally higher at the September 14 harvest while reducing sugar was highest at the August 27 harvest. The soluble solids-titratable acid ratio was highest at the September 14 harvest.

There were differences between the stage of maturity harvested for all quality factors previously mentioned. Soft ripe fruit had the highest pH (less acid), lowest acid content, highest soluble solids, and highest soluble solids-titratable acid ratio.

There was no interaction between system of training and stage of maturity harvested for any of the quality factors.

Correlation coefficients of the training systems indicated pH was negatively correlated with titratable acidity but not soluble solids. Titratable acid was not correlated with soluble solids but was with soluble solids-titratable acid ratio.

Correlation coefficients due to the stage of maturity of harvested fruits indicate generally the same trends as for the training systems.

V. MOISTURE AND SHADE EXPERIMENT

The pH was lower and titratable acidity content was higher in fruits from those plants subjected to moisture stress than from those grown at optimum moisture levels. Soluble solids and reducing sugar content were also significantly higher than in fruits with no moisture stress. The weight of individual fruits was not related to quality factors for either moisture treatment. Fruit pH was related to titratable acidity.

Of the quality factors studied, shaded plants influenced only soluble solids. The shaded plants had a significantly higher content. The pH was related to titratable acidity for both light treatments.

There was no interaction between moisture supply and light treatments for any of the quality factors studied.

VI. EFFECTS OF PROCESSING

The only quality factor to differ between tomatoes analyzed fresh and 24 hours after canning was reducing sugar content. It was higher in canned than in fresh tomatoes.

There was an interaction between maturities harvested and the time of analysis for all quality factors except pH. There were differences between maturities harvested and the time of analysis for all quality factors except pH. There were differences between maturities, but no differences between those analyzed fresh and after canning were detected within each maturity, except for reducing sugar. The pH was related to titratable acidity for both canned and fresh tomatoes.

VII. GENERAL CONCLUSIONS

It is concluded that certain genetic, environmental, and cultural factors affect quality factors of tomato fruits. There are differences among cultivars, and cultivars behave differently as environmental conditions vary. The stage of fruit maturity affected the composition with fruit overmature having the highest pH. Fruit harvested from plants grown under restricted moisture supply had a lower pH and higher

acid content. Fertilization rates, methods of training plants, shading plants, and processing whole tomatoes had little or no effect on level of quality factors studied.

Fruit pH and titratable acidity were generally related to each other, but neither was related to soluble solids and reducing sugar. As fruit pH and titratable acidity varied, soluble solids-titratable acid ratios did not undergo an appreciable change.

LITERATURE CITED

LITERATURE CITED

1. Adams, H. W. 1960. A statistical survey of pH variation and sodium content of tomatoes. J. Food Technol. 15:16-17.

2. Anderson, R. E. 1957. Factors affecting the acidic constituents of the tomato. Ph.D. Thesis. University of Illinois.

3. Anonymous. 1966. Acidification of whole tomatoes. Canning Trade. Sept. 19, 1966, p. 10.

4. _____. 1970. The practice of adding acid to tomatoes. Canner/Packer. May, 1970, pp. 18-19.

5. Boe, A. A. and D. K. Salunkhe. 1967. Ripening tomatoes: Ethylene, oxygen, and light treatments. J. Econ. Bot. 21:312-319.

6. Bradley, D. B. 1962. Influence of K, Ca, Mg application on acid content, composition, and yield of tomato fruit. J. Agr. Food Chem. 10:450-452.

7. _____. 1964. Varietal and location influence on acid composition of tomato fruit. J. Agr. Food Chem. 12:213-216.

8. Carangal, A. R., Jr., E. K. Alban, J. E. Varner and R. C. Burrell. 1954. The influence of mineral nutrition on the organic acids of the tomato, Lycopersicum esculentum. Plant Phys. 29:355-360.

9. Coffey, D. L., J. F. Brown, C. A. Mullins and H. D. Swingle. 1975. Tomato production in Tennessee—cultivar, training, ripening, fertilization. Tennessee Agr. Exp. Sta. Bull. 546.

10. Davies, J. N. and G. A. Maw. 1972. Metabolism of citric and malic acids during ripening of tomato fruit. J. Sci. Food Agric. 23:969-976.

11. Dennison, R. A. 1955. A discussion of the factors that influence color, flavor, and firmness in tomato fruits. Mkt. Grow. Jour. 84:6.

12. Desrosier, N. W. and F. Heiligman. 1955. Some factors affecting growth of Bacillus coagulans in tomato juice. Food Res. 21:47-53.

13. Froshey, C. G. and E. K. Alban. 1954. Seasonal quality changes in greenhouse tomatoes. Proc. Amer. Soc. Hort. Sci. 64:372-378.

14. Gorev, L. H. 1959. Some biochemical changes in the tomato fruit under different irrigation systems. Chem. Abstracts 54:17574.

15. Gould, W. A. 1957. Changes in pH values alter time, temperature of cook. Food Packer. Oct., 1957, p. 16.

16. _____. 1974. Tomato production, processing and quality evaluation. Avi Publishing Co., Inc., Westport, Conn.

17. Hamdy, M. K. and W. A. Gould. 1962. Varietal differences in tomatoes: A study of alpha-keto acids, alpha-amino compounds, and citric acid in eight tomato varieties before and after processing. J. Agr. Food Chem. 10:499-503.

18. Hamner, K. C. and L. A. Maynard. 1942. Factors affecting the nututive value of the tomato. USDA Misc. Pub. No. 502.

19. Hanna, G. C. 1961. Changes in pH and soluble solids of tomatoes during vine storage of ripe fruit. Proc. Amer. Soc. Hort. Sci. 78:459-463.

20. Harvey, R. B. 1920. The relation between the total acidity, the concentration of the hydrogen ion, and the taste of acid solutions. J. Amer. Chem. Soc. 42:712-715.

21. Hendren, R. 1976. Canning Foods. Tennessee Agr. Ext. Ser. Pub. 724.

22. Hester, J. B. 1951. Fundamental factors influencing the composition of tomato puree. Agron. J. 4:400-402.

23. Hobson, G. E. and J. N. Davies. 1971. The Tomato, in The Biochemistry of Fruits and Their Products, Vol. 2, A. C. Hulme, Ed. Academic Press, New York and London.

24. Kattan, A. A., F. C. Stark and A. Kramer. 1956. Effects of certain preharvest factors on yield and quality of raw and processed tomatoes. Proc. Amer. Soc. Hort. Sci. 69:327-342.

25. _____, W. L. Ogle and A. Kramer. 1956. Effect of process variables on quality of canned tomato juice. Proc. Amer. Soc. Hort. Sci. 69:470-481.

26. Kerr Glass Manufacturing Corp. 1972. Home Canning Book. Kerr Glass Manufacturing Corporation, Sand Springs, Oklahoma.

27. Lambeth, V. N., M. L. Fields and D. E. Huecker. 1964. The sugar-acid ratio of selected tomato varieties. Mo. Agr. Exp. Sta. Res. Bull. 850.

28. Le Clerg, E. L. 1966. Mean separation by the functional analysis of variance and multiple comparisons. Agr. Research Service, U. S. Dept. of Agr., U. S. Govt. Printing Office, Washington, D.C.

29. Lee, F. A. and C. B. Sayre. 1946. Factors affecting the acid and total solids content of tomatoes. N. Y. St. Agr. Exp. Sta. Tech. Bull. 278.

30. Leonard, S., R. Pangborn and B. S. Luh. 1959. The pH problem in canned tomatoes. Food Technol. 13:418-419.

31. Lopez, A. and D. E. Schoenemann. 1971. Updating developments in acidification of canned whole tomatoes. Cann. Trade. April 12, 1971, pp. 8-9.

32. Lower, R. L. and A. E. Thompson. 1966. Sampling variation of acidity and solids in tomatoes. Proc. Amer. Soc. Hort. Sci. 89:512-522.

33. _____. 1967. Inheritance of acidity and solids content of small-fruited tomatoes. Proc. Amer. Soc. Hort. Sci. 91:486-494.

34. McCollum, J. P. 1946. Effect of sunlight exposure on the quality constituents of tomato fruits. Proc. Amer. Soc. Hort. Sci. 65:413-416.

35. Massey, L. M., W. B. Robinson, N. N. Peck and G. A. Marx. 1962. Yield and raw product quality of processing tomatoes resulting from onceover harvest. Proc. Amer. Soc. Hort. Sci. 80:544-549.

36. Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem. 153:375-380.

37. Patterson, H. J. 1890. Experiments with tomatoes. Maryland Agr. Exp. Sta. Bull. 11.

38. Rice, A. C. and C. S. Pederson. 1954. Factors influencing growth of Bacillus coagulans in canned tomato juice. II. Acidic constituents of tomato juice and specific organic acids. Food Res. 19:125-133.

39. Rosa, J. T. 1925. Ripening of tomatoes. Proc. Amer. Soc. Hort. Sci. 22:315-322.

40. Sakiyama, R. and M. A. Stevens. 1976. Organic acid accumulation in attached and detached tomato fruits. J. Amer. Soc. Hort. Sci. 101:394-396.

41. Sando, C. E. 1920. Ripening of tomatoes. USDA Bull. 859.

42. Sapers, G. M., J. G. Phillips and A. K. Stoner. 1976. Tomato acidity and the safety of home canned tomatoes. Hort. Sci. 12(3): 204-208.

43. Saywell, L. G. and W. V. Cruess. 1932. The composition of canning tomatoes. Univ. of Calif. Agr. Exp. Sta. Bull. 545.

44. Scott, L. E. and E. P. Walls. 1947. Ascorbic acid content and sugar-acid ratios of fresh fruit and processed juice of tomato varieties. Proc. Amer. Soc. Hort. Sci. 40:269-272.

45. Shewfelt, A. L. 1970. Effects of a light treatment on the ripening of detached tomato fruits. Food Technol. 24:101-105.

46. Simandle, P. A., J. L. Brogdon, J. P. Sweeney and E. O. Mobley. 1966. Quality of six tomato varieties as affected by some compositional factors. J. Amer. Soc. Hort. Sci. 89:532-537.

47. Skoh, J. 1951. Quality of artificially ripened tomatoes for canning purposes. Food Res. 16:147-153.

48. Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods. 6th ed. Iowa State University Press, Ames, Iowa.

49. Somogyi, M. 1952. Notes on sugar determination. J. Biol. Chem. 195:19-23.

50. Stevens, M. A. 1972. Citrate and malate concentrations in tomato fruits: Genetic control and maturational effects. J. Amer. Soc. Hort. Sci. 97:655-658.

51. _____. 1972. Relationships between components contributing to quality variation among tomato lines. J. Amer. Soc. Hort. Sci. 97:70-73.

52. Thompson, A. E., R. W. Hepler, R. L. Lower and J. P. McCollum. 1962. Characterization of tomato varieties and strains for constituents of fruit quality. Illinois Agr. Exp. Sta. Bull. 685.

53. Ulrich, R. 1971. Organic Acids in The Biochemistry of Fruits and Their Products, Vol. 1, A. C. Hulme, Ed. Academic Press, New York and London.

54. Villarreal, F., B. S. Luh and S. J. Leonard. 1960. Influence of ripeness level on organic acids in canned tomato juice. Food Technol. 14:176-179.

55. Vittum, M. T., W. B. Robinson and G. A. Marx. 1962. Raw-product quality of vine-ripened processing tomatoes as influenced by irrigation, fertility level and variety. Proc. Amer. Soc. Hort. Sci. 80:535-543.

56. Ware, G. W. and J. P. McCollum. 1975. Producing Vegetable Crops. 2nd ed. Interstate Printers and Publishers, Inc., Danville, Illinois.

57. Williams, K. T. and H. Bevenue. 1954. Some carbohydrate components of tomato. J. Agr. Food Chem. 2:472-474.

58. Yamaguchi. M., F. D. Howard, B. S. Luh and S. J. Leonard. 1960. Effect of ripeness and harvest dates on the quality and composition of fresh canning tomatoes. Proc. Amer. Soc. Hort. Sci. 76:560-567.

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