MEASUREMEMT OF TOMATO QUALITY

by

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ABSTRACT

Twelve tomato varieties were harvested at two maturities and stored at two temperatures and compared in quality at the table-ripe stage. Quality factors evaluated were juice color, surface color, firmness, pH, acidity, soluble solids, protopectin content and total pectin content. Varieties differed significantly for all the quality factors. Total pectin and protopectin content was not affected by temperature of ripening or maturity at harvest while firmness was affected by both.

A method for determining tomato firmness by the Allo-Kramer Shear Press was developed. Firmness was measured with a 7/16 in. diameter round-end probe on the mid-equatorial line of the tomato. Firmness was recorded as peak force and work area.

The Shear Press results correlated at P = 0.01 to protopectin content, but not with total pectin content. A comparison was made to a smaller 1/8 in. diameter round-end probe. The results using the small probe had a higher correlation coefficient to protopectin content than the larger probe, but the peak force measurement of the small probe was essentially equal to the large probe work area. Firmness and alcohol-insoluble solids correlated significantly (r = 0.36)

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INTRODUCTION

Tomato production in Manitoba is limited by the short growing season and low yields. Some success has been achieved in some years in growing tomatoes which would be suitable for processing. However, most tomatoes are grown for the local fresh market. To secure better yields and earlier maturity, tomatoes are picked in the mature green stage as defined by Sando (65) and ripened off the vine.

The chemical changes in composition of the fruit from the immature green stage to the red ripe stage have been studied and the more important factors which indicate quality are now recognized. Although no single index is sufficient, color and firmness are the two most important ones; both can be assessed rapidly and easily at the later stages of maturity. Better methods of maturity assessment are needed in this field, if better control of quality in tomatoes to be ripened after harvest, is to be achieved.

Color measurement suffered from the lack of instrumentation until about 1948 and was largely empirical. Grading on the line is still mostly done visually by inspectors, but for research purposes, sensitive color meters are now available. The Purdue Color Meter, the Hunter Color Difference Meter, and the Agtron are three of these instruments.

Tomato firmness can be determined by a variety of instruments; none has been widely accepted. Methods utilizing the shear press are still being proposed (69). The amount of variation and sources of error inherent in the shear press techniques need to be investigated. As firmness is known to be related to the content of pectic substances, it was thought that the objective determination of firmness would show a close relationship to the pectin content.

Other chemical quality factors in tomatoes are pH, acidity and soluble solids which includes the sugars. All three contribute to flavor and are important to the canning industry.

It is generally held that pink fruit ripened off the vine are comparable to freshly picked, fully ripe fruit (35, 64, 46, 70, 57). Fruit ripened after being harvested at the mature green stage are known to have some differences from the fully vine ripened fruit, but there are conflicting views as to the chemical difference between such lots of fruits and their importance (43, 76, 70, 80, 64, 65). Temperature controls the rate of ripening and affects some of the quality factors (78, 76, 66).

This study was carried out to compare the quality of mature green and pink fruit ripened at 62°F and 72°F. At the same time, typical values were found for the major quality factors in Manitoba grown varieties. These will aid in the evaluation of new varieties now being bred in Manitoba or introduced from elsewhere. A new method of measuring firmness is proposed which can be correlated with the pectin fractions of the tomato.

REVIEW OF LITERATURE

There are many physical and chemical characteristics which may indicate quality in tomatoes. The more important are: Fruit color, juice color, firmness, pectic substances, acidity, pH and soluble solids.

Color Versus Quality

To the consumer, the color of the tomato is an indication of its maturity, flavor and quality. In addition, color is important in grading, since the price to growers is dependent on the relativety small difference in color between grades. Standardization of grading is imperative, yet difficult, since graders are influenced by the light source, time of day and fatigue. Instrumentation is costly, especially on the large scale required for commercial grading.

A full definition of color is "the characteristics of light. . . . .light being that aspect of radiant energy of which a human observer is aware through the visual sensations which arises from the stimulation of the retina of the eye." (59). Physically, color is a characteristic of light having intensity and wavelength in the visual region of the spectrum.

Color has three separate attributes:

1. Hue is the dominant wavelength e.g., blue or red.

2. Saturation or chroma is the amount of reflected light at a given wavelength e.g., dull or bright colors.

3. Value or lightness is the relative amount of transmittance or absorbance at a selected wavelength e.g., grey or black.

These three properties define the three-dimensional or tristimulus theory of color which is psychological as well as physical since normal color vision is also three-dimensional (34). The International Commission on Illumination adopted a tristimulus system based on a "standard observer" which may be thought of as an "eye" consisting of three filters each having specific spectrophotometric curves (49). The spectrophotometer is recognized as the standard instrument for measuring color. By integration of the spectrophotometric curves, obtained by reflectance or absorbance, the data may be converted to the I.C.I. notation of the "standard observer".

The spectrophotometer can be used in two ways to determine tomato color. The pigments may be extracted by a suitable solvent and measured (54, 39). Difficulties occur in the interpretation of the data and small differences are highly significant. Alternately, the reflected color may be obtained from the juice or surface (63). Both procedures are cumbersome, the computations complex, and thus of limited utility.

The photoelectric tristimulus reflectometer is another approach which is designed to give the tristimulus values directly. These instruments consists of three filters, each so designed that it follows closely the spectral distribution of the "standard observer". One of these instruments, the Hunter Color Difference Meter (30) has now been widely adopted (69, 53, 63, 51, 82, 62). Correlation coefficients as high as 0.964

have been obtained between this instrument and panel scores of trained human observers (62).

The Hunter Color Difference Meter reads the color in three scales; L, a and b corresponding to the tristimulus scale. Various equations have been used incorporating these scales (81, 18). Through the use of multiple correlation analysis between the three scales and panel evaluation the more important scales may be identified. Opinions still differ as to the number of attributes needed to define tomato color (18, 51, 83).

In earlier work, the a and b values were considered of importance and the L or lightness factor was disregarded (63, 49). However, it is now felt that the L value should be used (81, 83). The utility of the a and b ratio is enhanced because it is directly proportional to the I.C.I. dominant wavelength and thus closely related to hue.

The Hunter instrument is sensitive in reading small color differences. A red tile is used as a reference to which the tomato color is compared. The total magnitude of the color difference ΔE is found by the equation

$$E = \sqrt{(\Delta L)^2 - (\Delta a)^2 - (\Delta b)^2}$$

This value does not give any information where the color differences occur. It does give a measure of how large the deviations are. Francis (18) has drawn attention to the advantages and disadvantages of the ΔE values.

The carotenoid pigments, β-carotene and lycopene give tomatoes the yellow and red color respectively. During ripening, the two pigments develop at different temperature ranges, with β - carotene predominating above 80°F. Lycopene production is inhibited above 80°F and finally stopped above 86°F (66). If the fruit are returned to lower temperatures, lycopene production recommences. Thus the lycopene synthesis mechanism is not destroyed at elevated temperatures, but only inhibited. This is fortunate since temperatures as high as 117°F have been reported from field tomatoes (22). The higher the temperature above 80°F, the more yellow color the fruit will have. Lycopene synthesis proceeds in the dark, is somewhat accelerated in diffuse light, but is inhibited by strong light (75). Optimum lycopene production is best achieved in dark, ripening chambers at 68° - 75°F (11,75).

When fruit at inception of color and the pink stage were stored for ten days at 70°F, they had equal color. However, pink tomatoes attained optimum color in six days while those at the inception stage required the full ten days. Fully sized, mature green fruit differed in color when ripened at 70°F and did not at any time attain color equal to that of fruit picked at the other stages (35). Immature green fruit do not ripen to a satisfactory color. Skok (70) found no significant differences in the color comparisons of vine-ripened and artifically-ripened fruit harvested in the pink and turning stage when assessed by either total pigment or color evaluation.

Shading of the fruit on the vine is important for color production. Differences have been found between exposed and shaded fruit (11,47,57). Hall (23) found that stages of ripeness, harvest date, and their interaction were significant. This suggests that tomato color is not constant over the harvest season, but varies with the date of picking. The reason for this variation is not explained.

Color differences between varieties occur (11,23,36) under genetic control. Different parts of the tomato have different concentrations of pigments and thus color (56,57,83). Furthermore, there are variations between the stem and flower end, the stem end being much higher in pigments (13).

Firmness Versus Quality

Kinesthetics deals with the sense of feel which has three divisions, only one of which is applicable to tomatoes. This is texture, which refers to the flow resulting from the application of a force greater than gravity. Kramer (41) defined four such forces that may be used to measure texture. They are:

1. Tensile strength
2. Cutting force
3. Compression
4. Shearing force

A standard method to determine firmness of the tomato has not been established so far. The ideal method requires reproducibility and simplicity in order to test the large samples required for statistical reasons. A number of different approaches have been used, each with inherent limitations. Comparisons of the different methods are difficult since they may not be measuring the same aspect of firmness (19).

Magness and Taylor (50) designed an instrument consisting of a blunt plunger-tipped spring which was compressed against the peeled fruit. After a known penetration into the fruit, the force on the spring was an indication of firmness. This instrument did not have the required sensitivity to distinguish small differences in firmness and was affected by the rate of depression of the plunger (26). The Cornell Pressure Tester (26) compressed the fruit between a plunger of a given diameter and a flat plate by the addition of a given weight. This method was affected by the position of the plunger on the fruit. For instance, a locule wall would support more weight and add to the apparent firmness. This effect increased in fruit with large locules.

This problem is inherent in any single point determination and led to the development of the Firm-o-meter (35). This instrument measured firmness by the squeezing action of a chain around the circumference of the tomato. The Firm-o-meter and the Cornell Pressure Tester were highly correlated, ($r = 0.9227$) for tomatoes. McCollum, as reported by Garrett et al. (19), found the force required to crush a ½ in. thick center slice, but no significant correlations were found between this method and the Firm-o-meter. Shafshak and Winson (68), using a compression test of their own design, found that firmness of two varieties increased with the number of locules per fruit. There was also a relationship between compression and the per cent wall material, as well as compression and the placental material.

The force required to split the tomato may be determined (16, 31). Again a dependency on fruit diameter was noted and there was some difficulty in determining when the splitting occurred. A plunger may be forced against the fruit until it punctures the skin (61), or the plunger may indent the fruit to a certain depth (24). However, the skin may not be of even strength. The stem end is least resistant to puncturing, then the middle, and the blossom end is the strongest (32).

The L.E.E. - Kramer Shear Press is widely used in the food industry and its accuracy may be improved by several refinements (2, 28). However, large coefficients of variations are still found (3). The universal shear cell of Kramer (40) has been used by orienting a given weight of tomato wedges on the bottom grating (69), or by using a tomato half (4). Kramer et al. (42), using canned, whole tomatoes and the universal shear cell, determined three aspects of the time-force curve. They were:

1. Peak force
2. Length of curve
3. Area under the curve

Other attachments have been suggested (28, 3), each with specific possible uses. When wedges are used, peak force does not agree with subjective ratings for firmness while the area under the curve gives better agreement (69).

Objective firmness testers have been employed predominantly to distinguish between hard and soft varieties. The sensitivity required to differentiate small differences was not achieved and only recently has work been done to elucidate the effect of harvest time, temperature of storage, and maturity. Difficulties in the subjective panel determinations for firmness were shown by Kattan et al. (36), who did not find any difference in twelve varieties.

Variety, harvest date, and their interaction were reported significant for firmness, and in one year the stage of ripeness was also significant (23). West and Snyder (76) found that pink and ripe tomatoes placed in storage for as long as possible showed the pink to be firmer than the ripe-harvested. Tomatoes picked at the pink stage were firmer when red ripe than those picked at the inception of color stage (35). From these observations, it seems that pink-harvested fruit are firmer when ripened than at any other stage of maturity.

Chemical Composition Versus Quality

The chemical composition of tomatoes may vary to some degree with any of the following factors: variety, maturity at harvest, light exposure, morphological structure, position on the plant, cultural treatment and season (57). Accordingly, the sampling procedure for all determinations must be designed to take into consideration, and to allow for the effect of as many of these factors as possible.

The pH is the measure of the hydrogen ion concentration. Acidity is due mostly to the free organic acids, plus some acid salts. Together, pH and acidity influence the degree of sourness, which, in conjunction with the sugars, constitute the major flavor characteristic of the tomato (29, 67). The composition of tomatoes usually varies within the following ranges; pH between 3.90 and 4.50, acidity between 0.24% and 0.89% (as citric acid equivalent), and for soluble solids between 2.00% and 5.12% (as sucrose) (29, 80, 27, 67, 43).

Variations in pH and acidity of single tomatoes from a plant will vary more than a sample over the whole plot (1). Acidity varies with the year (72, 1) although the relative response of the varieties in different years are similar. Location causes variations in acidity, but the ranking of the varieties are usually the same (8). Differences in pH and acidity occur within, as well as between, seasons (27, 79). The acidity at the beginning of the harvesting season is high, decreases, and reaches another high at the end, irrespective of moisture availability (44, 43). A gradual decline in pH over the growing season has also been observed (43).

The acid content varies in the different parts of the tomato (57, 1, 5). It is highest in the locular region, lower in the inner pericarp and lowest in the outer pericarp. Bohart (5) found that fruit with large locules tended to have more acid in comparison with fruit having small locules.

Thompson *et al*. (72) reported that the differences in acidity could not be attributed to the locule size alone.

If pH is low, the acidity is theoretically expected to be high. Thompson *et al*. (72) found a negative correlation between these factors, but others have reported positive correlations (5). The high acidity may be caused by a higher proportion of acid salts, which act as a buffer and increase the pH (1).

Two other causes of variation are moisture supply and nutrient status. Reduced total acid and soluble solids have been reported under irrigation (74, 20) and conversely an increase in acidity has been found under drought conditions, even when calculated on a dry weight basis (44).

Bradley (7) reported that potassium may produce fruit with slightly less sugar, more acid, and decreased pH with other nutrients having no effect. Conflicting results are reported by Kattan *et al*. (36) who found no response to a wide range of fertilizer applications, and by Vittum *et al*. (74) who increased total acidity and soluble solids by growing tomatoes on highly fertilized soil.

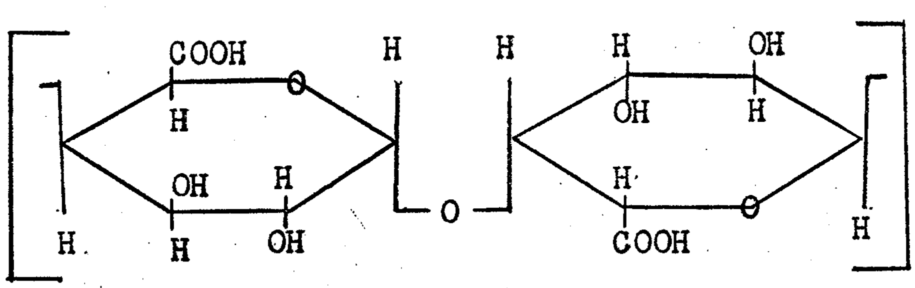
As ripening on the vine proceeds, the pH increases (79, 27, 73). Hanna (27) felt that pH may be useful as an indication of maturity, as the pH and maturity are closely correlated. As the pH increases titratable acidity increases from the pollinated ovary to a peak around the mature green or turning stage after which it decreases (77, 64, 73). There is some disagreement as to where the peak acidity occurs. Woodmansee *et al*. (77) reported one variety as having maximum acidity at the pink stage, but it is generally considered to occur at the green stage. He found that the acidity decreased rapidly after the ripe stage. The decline in acidity is due to the decrease in citric acid which usually accounts for 73 - 80% of the acid present (73) although values as high as 90% have been reported (69).

In artificially ripened tomatoes, more acid is produced at lower temperatures (e.g. 50°F) than at higher temperatures. Temperature and duration of storage had no effect on pH (1). Lambeth *et al*. (43) found greater uniformity in pH, acidity and soluble solids for the chamber-ripened fruit, harvested at the turning stage, compared to vine ripened fruit. By ripening off the vine, the variations due to moisture, light, temperature and nutrients in the later stages of development were largely eliminated. The range of values for all three factors were smaller for chamber-ripened fruit, but the levels were lower in the artificially ripened fruit.

Soluble solids as measured by the refractometer consist mainly of the sugars fructose, glucose and sucrose, and vary with genetic and environmental factors. For example, small fruit contains a higher percentage of total solids than large fruit even from the same plant (48). Solids are correlated with soil moisture (74, 9, 20). Unshaded fruit or parts of fruit may also have higher total solids and sugars than shaded fruit, possibly due to increased photosynthesis (55). The position of the fruit on the truss introduces variations in soluble solid content; the earliest fruit are higher than later fruit. Within one harvest season, there is a gradual decline in soluble solids which is possibly explained by the increased temperature and lower leaf to fruit ratio (43).

Differences occur between vine-ripened fruit and chamber-ripened (65, 57, 64, 76) with a higher amount of soluble solids in the vine-ripened fruit. On the vine, the tomato increases in soluble solids from the green to the ripe stage. Conflicting data by Skok (70) shows no differences in soluble solids between vine and room-ripened fruit harvested pink and at the turning stage. Lutz (46) was also unable to find a consistent relationship between maturity and soluble solids. It is possible that the moisture losses in storage may hide a decrease in soluble solids. Craft and Heinze (10) ripened mature green fruit at 65° and 75°F and found no significant difference for soluble solids and acidity, although the acidity was lower at 75°F.

Pectic substances are a group of complex colloidal carbohydrate derivatives which contain a large proportion of anhydrogalacturonic acid units in chain-like combination. The carboxyl group of the galacturonic acid may be partly esterified by methyl groups and partly, or completely neutralized by one or more bases.



The compound with the longest chain is protopectin which is insoluble in water. Pectinic acid are shorter chain colloidal polygalacturonic acids containing more than a negligible amount of methyl ester groups. When the methyl ester content is near zero, it becomes pectic acid. Contribution to firmness is in a descending order.

Changes in the type and quality of the pectic substances cementing the cell wall has an important role in the ripening of the tomato and its firmness. The green fruit has a higher proportion of protopectin than water soluble pectin. As the fruit softens, the pectin fractions change in proportion. Specifically, there is a decrease in the protopectin and an increase in the water soluble pectin (6, 25). Softening is interpreted as the solubilization of the pectic substances from the middle lamella of the cells with a consequent rise in soluble pectin. Hydrolysis and demethylation of the pectic substances are thought to accompany this change. The sequence of degradation of the protopectin to the pectinic acid has not been clearly established, but involves these two mechanisms. Kertesz (38) has summarized the work up to 1950 on the pectic changes and Joslyn (33) has reviewed the more recent literature on protopectin. McColloch and Kertesz (52) have discussed the pectic enzymes.

The alcohol-insoluble solids comprise the pectins, starch, proteinaceous compounds and the cellulosic compounds. The inner and outer pericarp and the placental tissues have differences in alcohol-insoluble solids content increasing in that order. Upon ripening, the placental tissue loses alcohol-insoluble solids rapidly with a much slower breakdown in the inner pericarp. The outer pericarp being initially quite high, had the lowest rate of breakdown (21). Thus the outer pericarp seems to be important for firmness. Woodmansee et al. (77) determined the alcohol-insoluble solids of tomatoes at three ripeness levels and found a highly significant decrease in one of two varieties. Total pectin on a fresh weight basis decreased also in one out of two varieties. Craft and Heinze (10) reported a decrease in alcohol-insoluble solids of artificially ripened mature green harvested fruit, as the temperature of storage increased.

Pectic substances differ between varieties (17, 14, 25, 45). A large part of this was due to the variations in the initial level of the protopectin. During storage the total pectin decreased (71, 45). However, no increase in galacturonic acid was found over prolonged storage (6) between varieties (69). Thus, the decrease in total pectin does not lead to increased levels of galacturonic acid.

Hamson (25) found correlation coefficients between firmness, as measured by the Cornell Pressure Tester, and the pectic constituents, as differentiated by their solubilities in water, acid and ammonium oxalate. Significant correlation coefficients were found for total pectins ($r = -0.88$). El Sayed et al. (14) found that only the protopectin was consistently correlated with firmness, as defined by the Firm-o-meter. Deshpande (12) found the total pectin to be correlated to firmness in canned tomatoes. Foda (17) determined firmness on the inner pericarp tissue and found protopectin to be correlated with it.

There is one report (71) that pectin content varies over the harvest season requiring replications to be harvested at the same time.

The determination of the pectins is complex and difficult. In the isolation of the various fractions, the conditions used for the extraction may irreversibly alter them. Owens _et al_. (60) discussed various methods for extracting the alcohol-insoluble solids, with a minimum amount of degradation. The determination of the pectin fractions may be done by the different solubilities in various solvents such as water, dilute acid and ammonium oxalate. However, the solubilities overlap and only a relative seperation is achieved. The galacturonic acid content of the various fraction indicates their pectin content. The McComb and McCready (58) carbazole method is currently preferred.

Maturity Definitions

Mature green tomatoes cannot be defined by any one characteristic (57). The following factors may be useful: age since fruit set, well developed locules with seeds not cut by a knife, development of a brownish ring under the calyx, appearance of yellowish or cream colored streaks at the stylar end, and a brownish ring formation on the shoulders of the fruit (46, 57). Sando (65) has prepared an excellent report on the problems of defining maturity in tomatoes.

The best method for obtaining mature green fruit is the occasional cutting of the fruit to correlate the internal development with the external characteristics of the lot. A final replication on the date of turning color ensures equal maturity. Because the immature green fruit ripen with inferior quality, the picking of mature green fruit is paramount. McCollum (57) recommends the turning stage as the best indication of maturity.

MATERIALS AND METHODS

The first experiment consisted of the analysis of the tomato varieties for the various quality factors under the influence of the different maturities at harvest and storage temperatures. After the determination of firmness certain improvements were thought possible and were investigated in Experiment 11. Concurrently, the relationship between firmness as determined by the shear press methods were compared to the pectic fractions.

Experiment 1

Ten determinate and two indeterminate tomato varieties were grown at the University of Manitoba field plots for quality analysis. The varieties with their respective seed supplier are as follows:

Determinates

1.	Starfire recrossed	Stokes Seed Ltd., St. Catharines, Ont.
2.	Starfire	" " " " " "
3.	M - 3	Univ. of Man., Winnipeg 19, Man.
4.	Bush Beefsteak	Stokes Seed Ltd., St. Catharines, Ont.
5.	Cheyenne	Wills' Seed House, Bismark, N.D. 58501
6.	Cavalier	" " " " " "
7.	Galaxy	Joseph Harris Co. Inc., Rochester, N.Y. 14624
8.	Fireball	" " " " " "
9.	M - 2	Univ. of Man., Winnipeg 19, Man.
10.	Summerdawn	Can. Dept. of Agr. Summerland, B.C.

Indeterminates

1.	Moreton Hybrid	Joseph Harris Co. Inc., Rochester, N.Y. 14624
2.	Vogue	Stokes Seed Ltd., St. Catharines, Ont.

All varieties were seeded in the greenhouse on April 25 and transplanted May 6 into two inch bands. The plants were hardened in cold frames a week prior to the final transplanting to the field plots on June 6 to 8. All varieties were planted in rows three feet apart. In the rows, the indeterminates were spaced two feet between plants and determinates three feet apart.

The fruit was harvested at two maturities. The mature green stage was defined by well developed locules filled with jelly. At this stage, the seeds were not cut when the fruit was sliced. The pink or turning stage was limited to fruit showing approximately 50%, ± 10% red or green. The harvesting was done as the varieties attained the proper ripeness level. All fruit having the proper maturity were then harvested on the dates shown below:

Harvesting Dates of Mature Green and Pink Ripe Fruit

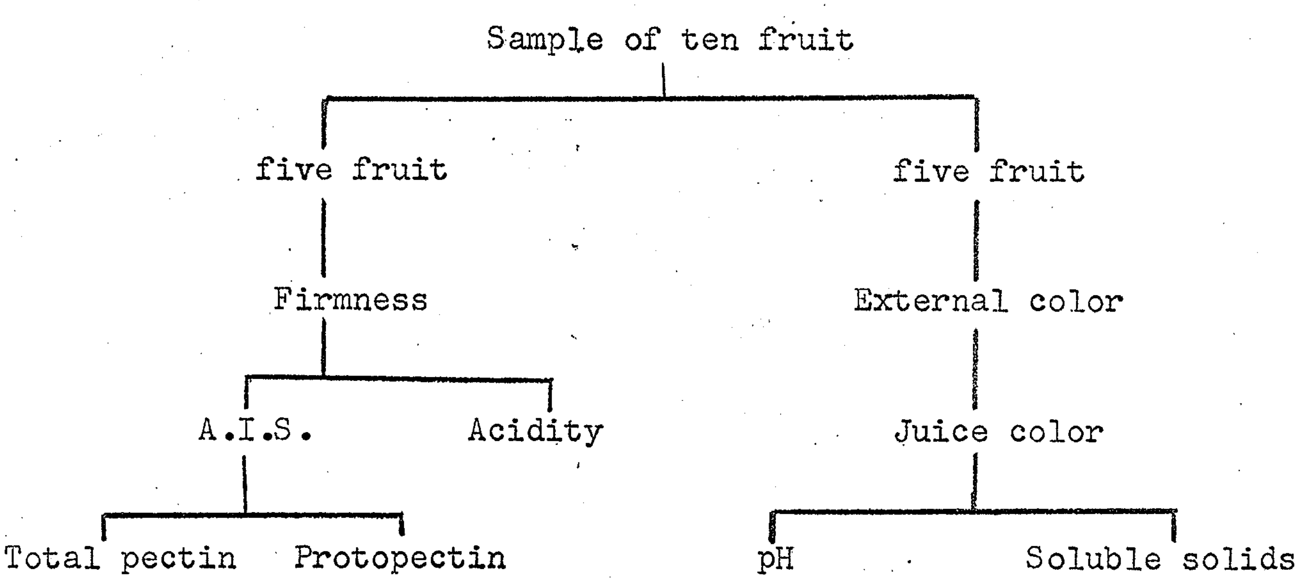
Variety	Green	Pink
Starfire recrossed	August 19	August 24 - August 30
Starfire	August 15	August 25 - September 6
M - 3	August 18	August 24 - August 30
Bush Beefsteak	August 22	August 25 - September 9
Cheyenne	August 22	August 27 - September 9
Cavalier	August 17	August 25 - August 30
Galaxy	August 15	August 25 - September 6
Fireball	August 12	August 24 - August 30
M - 2	August 19	August 24 - August 27
Summerdawn	August 18	August 25 - September 9
Moreton Hybrid	August 22	August 27 - September 6
Vogue	August 19	August 27 - September 9

The mature green harvest, for all varieties, required ten days. The pink were harvested over fifteen days. Because an insufficient number of fruit in the pink mature stage were available for each variety, it became necessary to harvest at two different dates to obtain the required number. To ensure equal maturity in the mature green stage, the final replication was done in storage on the basis of equal pink color. All tomatoes harvested were of equal size, characteristic for each variety and were well formed, free from disease and (or) blemishes.

The fruit were stored in dark enclosed chambers at $62^\circ \pm 2^\circ$ and $72^\circ \pm 2^\circ$F. The fruit were placed one layer deep in wire-bottomed flats. Continuous air circulation and relative humidity of 80% $\pm$ 5% were maintained in the cabinet.

When optimum quality was reached as shown by full color and a slight softening, the fruit were removed for analysis.

Each sample of ten fruit was analysed according to the outline below.



Laboratory Methods

Procedures used for the tests were as follows:

1. Shear Press values were obtained using the L.E.E.-Kramer Shear Press, Model S.P.-12 equipped with a 100 lb ring. A 7/16 in. diameter round-end probe was used with a down stroke of 30 seconds. The firmness was measured on the mid-equatorial line of the fruit, avoiding the locule walls. Two maximum peak force readings were taken on each fruit and averaged over the whole sample.

2. Soluble solids were found by blending the sample and reading the refractive index on a Gaertner Turbid Liquid Refractometer Model L-128-94 with water as the standard. Results were converted to per cent sucrose.

3. Color was measured by the Hunter Color Difference Meter, Model D-25, using a red standard tile with values of L-24.6, a-26.6, b-12.4. The skin color was read on the mid-equatorial plane using a 1 1/16 in. diameter opening. Internal color was recorded after removal of the seeds and deaeration of the juice. Small illumination lenses were used with a viewing aperture of two inches. In both determinations, the results of the five fruit were averaged for the L, a and b values and the ΔE calculated using the formula:

$$\Delta E = \sqrt{(\Delta L)^2 - (\Delta a)^2 - (\Delta b)^2}$$

4. pH of the blended juice was measured using a Beckman pH meter.

A subsample of five fruit was quartered, sealed in polyethylene bags and frozen at -20°C. For analysis, the samples were thawed for fifteen minutes and then macerated while still at 0°C in a Waring Blender. This slurry was used to determine the alcohol-insoluble solids and acidity.

5. Acidity was determined on a 25 g sample. After boiling in 200 ml of water for twenty minutes, the slurry was transferred to a 250 ml volumetric flask, cooled, made up to volume and filtered. Duplicate 50 ml samples were added to 100 ml of water and titrated with 0.1N NaOH to pH 8.1 using a pH meter. Results were expressed as per cent citric acid.

6. Alcohol-Insoluble Solids were determined by placing 200 g of the sample in 600 ml of boiling 95% ethyl alcohol. After boiling for thirty minutes, the alcohol-insoluble solids were separated by filtration and washed three times with 200 ml of cold 95% ethyl alcohol. The residue was dried overnight at 98°F, weighed, placed in polyethylene bags and later analysed for pectins.

7. Total pectin and protopectin were isolated by the procedure of Esau et al. (15). The galacturonic acid content of each fraction was determined by the McComb and McCready carbazole method (58). The pectic content of each fraction was expressed as mg anhydrogalacturonic acid per 100 g fresh weight.

The results were analysed statistically as a factorial experiment replicated three times. All non-significant terms were added in the error term.

Experiment 2.

In the second experiment, green turning tomatoes were stored for up to 20 days at 67°F and 70% relative humidity. Storage conditions were identical to those described before. The tomatoes were bought from a local fruit wholesaler and were of equal size and maturity. The fruit were randomly assigned to one of six lots. One lot was analysed every fourth day for firmness and pectic constituents. A lot for analysis was divided randomly into three replications of ten fruit each. Five fruit of each replication were tested with a 7/16 in. probe as described before; the other five with a 1/8 in. probe. The shear press was calibrated before use with a beam balance using known weights.

The calibration curve obtained was used to correct readings. Maximum peak height and the area under the curve was recorded for the large probe. Area under the curve was measured by cutting out the curve and weighing it on an analytical balance. All readings were averaged as before. For the small probe, only a peak maximum was recorded. After the determination of the two measures of firmness, the two subsamples were combined and analysed for alcohol-insoluble solids, protopectin and total pectin.

Correlation coefficients were determined for the two probes, by comparing peak force and area under the curve with per cent total pectin and protopectin.

RESULTS AND DISCUSSIONS

This study of tomato quality was carried out during the 1966 growing season. As described before, moisture, sunlight, season and fertility of the soil are variable factors in tomato quality. In this study, these were considered to be essentially uniform for the experiment plots at the University field station.

The method outlined on page 21 for harvesting and storage of tomatoes proved satisfactory. No rotting or shrivelling of the fruit was noticed. The three replications, however, did not simultaneously attain optimum quality for analysis. Table 1 gives the average length of time and the range required for artificially ripening each treatment.

Table 1. Average length of time in days required for ripening of each treatment.

Variety	Maturity and Ripening Temperature							
	Green 62°F		Green 72°F		Pink 62°F		Pink 72°F	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range
Starfire Recrossed	28	5	18	6	10	3	7	2
Starfire	28	19	16	9	9	2	8	1
M - 3	21	6	17	8	11	5	4	1
Bush Beefsteak	22	4	19	5	9	2	8	2
M - 2	21	10	16	4	9	5	8	4
Cheyenne	22	4	20	2	9	0	6	2
Cavalier	28	7	17	8	7	2	7	4
Galaxy	21	18	15	8	10	5	7	1
Fireball	17	5	11	2	8	4	5	0
Summerdawn	24	9	17	5	11	5	9	0
Moreton Hybrid	22	2	16	0	11	4	5	0
Vogue	20	1	14	3	6	1	9	0
Average	23		16		9		7	

The variability in ripening between replications was greatest in the mature green stage. This procedure did ensure equality within each replication, at the expense of some variation amongst replications due to length of storage. The alternate method would have been to remove a treatment on a certain day and then to replicate the fruit for analysis. The latter method leads to variations within the sample, while the former method leads to differences between replications. Homogeneity in the sample was considered to be more important.

The differences between pink harvested fruit stored at the two temperatures was two days. Mature green required an average of 23 days to ripen which would mean that Manitoba tomatoes could be marketed for an average of three weeks after the first frost. There were pronounced differences in ripening time requirements between varieties.

The range of values found for each quality factor is given below:

Surface color (as ΔE)	5.59	-	10.82
Juice color (as ΔE)	2.06	-	7.72
pH	4.12	-	4.65
Acidity (per cent citric acid eq.)	0.245	-	0.449
Soluble Solids (as per cent sucrose)	4.3	-	5.3
Alcohol-insoluble solids g per 100 g fresh wt	1.45	-	2.30
Firmness (lb)	3.30	-	6.72
Total Pectin (mg galacturonic acid per 100 g fresh weight)	289.7	-	455.1
Protopectin	210.4	-	339.7

The differences in quality between fruit picked at the two maturity stages and stored at different temperatures will be discussed under each quality heading. Values averaged for the three replications of each variety are found in Appendix 1. The L values and the A/B ratios are given in Appendix X111 as an average of the three replications. It must be kept in mind that quality is an interaction of many different factors. Although ranges may be found indicating quality as determined by panel evaluation, this was not done in this study since Ayres and Peirce (4) found that panel evaluations are relatively insensitive for this purpose.

Color

The Hunter Color Difference Meter was used to read both the juice and surface color. Color was expressed as ΔE values which incorporates all three scales and gives readily comparable values. The larger values of ΔE denote large deviations from the standard.

Juice color was measured after the removal of the seeds and deaeration of the juice. The juice required deaeration, since a rough comparison between the freshly prepared juice and deaerated juice indicated that dispersed air bubbles could cause errors in juice color measurement. Yeatman and Sidwell (80), in their study, found that differences existed between the deaerated and crude juice. But, as the variations were essentially constant, they felt the simplification of the procedure by omitting the deaeration was better suited to grading. In this study, as accuracy was important, deaeration of the juice was done.

Appendix 11 gives the factorial analysis for juice color. Varieties and temperature were found to be highly significant for the main factors. Variety differences are given in Table 11. In this table and others where the Duncan Multiple Range Test is used, vertical lines denote no significant differences between varieties at P = 0.05.

Table 11. Mean juice color of twelve varieties when red ripe.

Varieties	ΔE Value
Vogue	4.86
Starfire Recrossed	4.56
M - 3	4.46
M - 2	4.35
Galaxy	4.30
Starfire	4.05
Cavalier	3.88
Cheyenne	3.78
Summerdawn	3.78
Bush Beefsteak	3.67
Moreton Hybrid	3.67
Fireball	3.36

In this study, temperature of storage was found to be an important factor. It is involved in the pigment production mechanism with optimum lycopene being produced at 70° - 75° (11). The higher temperature gave a higher color difference in each variety.

Of the first order interactions, both variety times maturity and maturity times temperature were significant at P = 0.05. Table 111 shows the means of the varieties for each maturity. The L.S.D. was 1.12 and any two varieties may be compared for significance at P = 0.05 using $(A-B) - (C-D) \geq$ L.S.D. In the maturity times temperature interaction, the pink fruit at 62°F was highest while at 72°F the mature green was highest, with the reversal being significant.

Table 111. Mean juice color of twelve varieties picked mature green and pink and ripened to full red stage.

Variety	ΔE Values: Mature Green	ΔE Values: Pink
Starfire Recrossed	4.97	4.17
M - 2	4.86	3.84
Vogue	4.73	5.05
Starfire	4.64	3.47
Galaxy	4.36	3.70
Summerdawn	4.06	3.50
M - 3	4.02	3.79
Cheyenne	3.96	3.60
Bush Beefsteak	3.94	3.40
Moreton Hybrid	3.43	3.90
Cavalier	3.46	4.30
Fireball	3.29	3.42

L.S.D. = 1.12

Surface color was measured on the mid-equatorial plane of the fruit. This avoided areas of sunscald and other color variations associated with the ends of the fruit. Leakage of light was prevented by pressing the tomato over the aperture. This meant that a curved surface, rather than the flat surface, was presented to the instrument. The results, however, were reproducible.

Even with the use of the mid-equatorial region for color measurement, variations did occur. Differences between fruit occurred mainly in the b or yellow scale. Table 1V shows the values from one treatment. The tomatoes were nearly alike to the eye, but differences were found by the Hunter Color Difference Meter.

Table 1V. Variations in surface color measured as L, a and b values on one tomato lot.

Reading	L	a	b
1st	20.7	19.5	8.9
2nd	19.9	19.6	9.0
1st	19.9	20.3	7.1
2nd	19.7	21.1	6.8
1st	21.0	19.5	9.0
2nd	21.6	18.0	9.0
1st	21.0	20.0	8.1
2nd	21.0	20.0	9.0
1st	21.2	19.5	9.1
2nd	20.4	20.0	8.1
Average	20.7 ± .637	19.8 ± .787	8.3±.839

Appendix 111 gives the factorial analysis for the surface color. The coefficient of variation was 9.3% compared to the 20.3% found for juice color.

Both varieties and maturities were found to be highly significant. Table V shows the varieties ranked in order.

Table V. Mean Surface Color of twelve varieties when red ripe.

Variety	ΔE Value
M - 3	9.500
Cheyenne	8.760
Cavalier	8.690
Moreton Hybrid	8.635
M - 2	8.217
Galaxy	7.813
Vogue	7.793
Fireball	7.623
Bush Beefsteak	7.593
Starfire	7.303
Starfire Recrossed	7.197
Summerdawn	6.815

It is known that mature green tomatoes do not yield as good a color as pink fruit when ripened. The ΔE values confirmed this as the pink fruit had higher color differences from the standard than the mature green ones.

It is difficult to explain why temperature was significant in juice color, but not significant for surface color. Robinson et al. (62) found that color development was influenced by environmental temperature, and that during cool seasons internal color development did not parallel the external color. This may apply to tomatoes in storage. The correlation coefficient between surface and juice color was calculated to be -0.20. Although this was significant at P = 0.01, it means that only four per cent of juice color can be accounted for by the surface color. In only a third of cases, according to Yeatman and Sidwell (80), were inspectors able to predict juice color by observing only the external color.

The cause of the large coefficient of variation for juice color compared to surface color is not apparent, especially since juice color is considered the better measurement. Juice color is dependent on the dispersion of the pigment, volume of soluble solids in the juice and the presence of other pigments (63). The lycopene, because of its insolubility in water, is carried on the suspended solids of the juice. Thus, two juices with the same pigment content, but differing in soluble solids would give different color. Mavis and Gould (51) recommend dilution of the pulp to a standard soluble solid content.

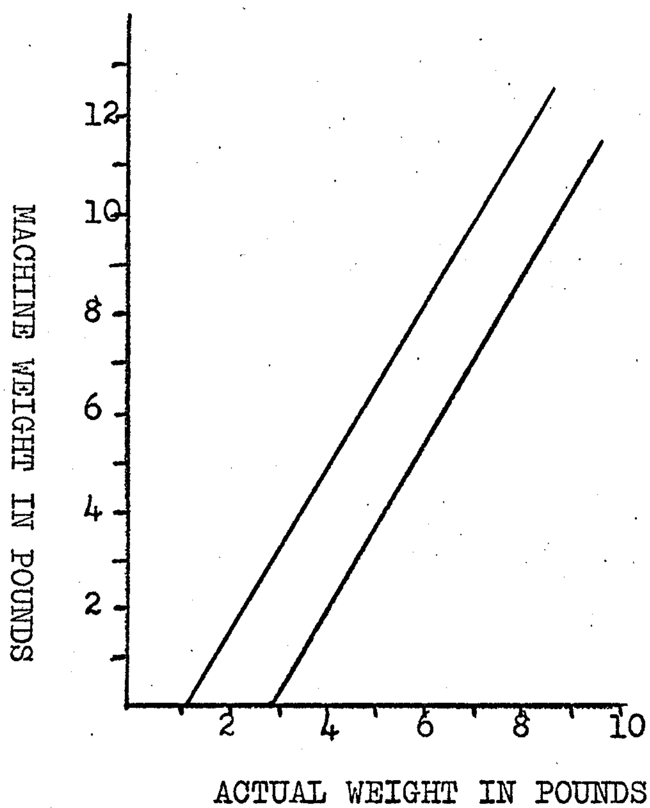
Firmness

The method chosen for determining firmness utilized the shear press with a 7/16 in. diameter round-end probe. This size of probe was the same as those of the Magness and Taylor Pressure Tester (50) and of the Cornell Pressure Tester (26). Smaller probes have been used, especially in cracking studies where skin strength is important. It was assumed that with this probe the initial pressure of the plunger would depress the fruit and then shear through the skin to give characteristic measures of firmness. Hamson's (26) work showed that the inherent firmness was more important than any other factor such as skin strength, thickness of walls or the structural arrangement.

Two readings at opposite sides were made per fruit. As the second reading was taken, the pressure forced out some of the locular juices. This may have affected the second reading. Yet, if only one reading per fruit was taken, the number of determinations was halved and the variability was increased. By tracing the vascular rays radiating from the blossom end, the locule walls could be avoided. The fruit was cut occasionally to check that no firmness determination was made near the locule wall.

Certain sources of error became apparent when working with the shear press. The calibration procedure does not seem to be accurate or reproducable. There is no fixed point of calibration. Calibration directions with the shear press gave a range of values. Figure 1 was obtained using a calibration beam and shows the two extreme series of values. Day to day calibrations will vary between these extremes. The error is largest at the 100 per cent range and decreases at the lower ranges.

<u>Figure 1</u>. Relationship between machine force and the actual force at two extreme calibration points.



The beam was made to calibrate the true force applied by the shear press. Figure 1 shows that there was a marked difference between the shear press readings and the true force. The hysteresis curve showed some discrepancies. It was observed that when the beam was loaded, values were lower than when the weights were removed. This may be due to "sticking" in the various components. Values are summarized for two hysteresis curves in Table Vl.

Table Vl. Values for two hysteresis curves of the shear press.

Actual weight in lb	Machine weight in lb			
	Addition of wt	Removal of wt	Addition of wt	Removal of wt
1	.3	1.1	.3	1.2
2	1.9	2.1	2.0	2.0
3	3.7	3.8	3.6	3.8
4	5.2	6.0	5.2	6.0
5	7.0	7.1	7.0	7.1
6	8.8	8.9	8.9	8.8
7	10.3	11.1	10.7	11.1
8	12.1	12.1	12.2	12.2
9	13.9	14.5	14.0	14.8
10	15.6	15.6	15.8	15.8

Appendix lV summarizes the factorial analysis for firmness as measured by the 7/16 in. probe. Replications were highly significant showing that an increase in precision was obtained by the use of replications. The overall coefficient of variation was 9.9%, which suggested adequate accuracy.

All the main factors were highly significant. Table Vll shows the differences in firmness of the varieties.

Table Vll. Mean firmness of twelve varieties when red ripe.

Variety	Firmness in lb
M - 3	5.640
Cheyenne	5.585
Moreton Hybrid	5.383
M - 2	5.350
Vogue	5.195
Galaxy	5.163
Fireball	4.970
Summerdawn	4.933
Cavalier	4.913
Starfire recrossed	4.907
Starfire	4.807
Bush Beefsteak	4.740

It was interesting that two pairs of varieties with common breeding lines showed nearly the same firmness. Starfire and Starfire recrossed did not differ significantly and neither did the firmer M-2 and M-3 varieties.

The mature green fruit were firmer than the pink. Kattan (35) found a difference, but in the reverse order. The mature green fruit had been off the vine and in storage longer than the pink and still retained their firmness. Harvest date was reported by Hall (23) to be significant for firmness. This factor was not constant in this study and may have contributed to some of the effects observed.

Table V111. Mean firmness of twelve varieties picked mature green and pink and ripened to full red stage.

Variety	Firmness in lb	
	Mature green	Pink
Cheyenne	6.03	5.14
M - 2	5.63	5.08
M - 3	5.47	5.82
Moreton Hybrid	5.38	5.39
Galaxy	5.36	4.97
Starfire recrossed	5.36	4.46
Starfire	5.30	4.32
Vogue	5.20	5.20
Fireball	5.18	4.77
Cavalier	4.95	4.88
Summerdawn	4.80	5.07
Bush Beefsteak	4.79	4.69

L.S.D. = 0.69

The fruit stored at 62°F were firmer than those stored at 72°F. This seems to explain why the mature green fruit were firmer than the pink ones. The mature green fruit were subjected continuously to lower temperatures than the pink as the pink were left on the vine longer and were exposed to more elevated field temperatures. This is no evidence, of course, that the retention of the fruit on the vine may not be involved. Woodmansee _et al._ (77) reported that ripe fruit stored at cool temperatures preserved their firmness much longer. He interpreted his results as an increase in the rate of demethylation at higher temperatures. Cooler storage slows the demethylation.

Variety times maturity was the only significant first order interaction at P = 0.01. The L.S.D. was 0.69 and in conjunction with Table V111, it may be used to calculate significant differences between varieties and maturities.

The second order interaction was also significant at P = 0.01. The interpretation of it becomes complex and contributes little of practical interest.

Procedures for firmness used by Hanson (26) and Shafshak and Winsor (68) were dependent on diameter or locule number. Usually a positive correlation was found, indicating that an increase in size gave an increase in firmness. Fruit size or locule number were not recorded in this study. The average weight per fruit of each variety was known and was correlated with the average firmness as measured by the large probe peak force method. The correlation coefficient was -0.62 which was significant at P = 0.01. The negative correlation shows that as weight increases the firmness decreases. The explanation of this may be due to the total solid content of the fruit. Since the total solids contribute to the firmness, eg the resistance to the probe, this factor may be of importance in overall firmness trends. This question is unresolved in the literature, and the data gathered in this project was insufficient to clarify it.

pH

The factorial experiment data for pH is summarized in Appendix V, which shows variety and maturity to be significant at P = 0.01, and temperature at P = 0.05. The pH decreased between mature green harvested and pink harvested, each ripened to optimum quality, while storage at 62^{O}F had a lower pH than at 72^{O}F. Table IX shows the varieties in order from the highest.

The observed variations in pH may be due to the respiration in the stored fruit, as well as to the original content of the constituents at the time of harvest. pH increases on the vine with development of the fruit (79, 27, 73) and would lead to the conclusion that mature green fruit should be lower in pH than pink harvested. However, the reverse was found.

Maturity times temperature was the only interaction significant at p = 0.01. On further investigation, pH were equal at 62^{O}F for each harvest maturity when ripened, but at 72^{O}F the mature green fruit were higher in pH. The coefficient of variation in this experiment was 1.7%, Skok (70) found a similar low value of 2.2% for pH and 13% for soluble solids.

Table IX. Mean pH of twelve varieties when red ripe.

Variety	pH when red ripe
M - 3	4.427
Cheyenne	4.427
Galaxy	4.410
Fireball	4.410
Starfire recrossed	4.383
Bush Beefsteak	4.377
Summerdawn	4.377
Cavalier	4.350
Starfire	4.325
M - 2	4.287
Moreton Hybrid	4.265
Vogue	4.203

Acidity

Appendix VI shows that there was a significant difference at P = 0.01 only for varieties. The varieties are ranked in order in Table X.

Table X. Mean acidity of twelve varieties when red ripe.

Variety	Acidity as per cent citric acid
Starfire	0.3910
Moreton Hybrid	0.3850
Starfire recrossed	0.3785
Vogue	0.3735
M - 2	0.3660
Summerdawn	0.3615
M - 3	0.3565
Cheyenne	0.3565
Galaxy	0.3350
Fireball	0.3310
Cavalier	0.3265
Bush Beefsteak	0.3140

Maturity and temperature were without effect. It has been reported that maturity does have an effect on tomato quality; the longer the fruit was left on the vine, the lower the acidity should be. Temperature of storage controls respiration rates and so would also be expected to be a significant factor. The first order interaction of maturities times temperature was significant. At 62°F the mature green were highest in acidity while at 72°F a significant reversal occurred as the pink were highest. The former agrees with facts already explained. The latter may be caused by an increase in respiration of the fruit at 72°F. Variety times maturity was significant at P = 0.05. Table Xl shows the mean values for acidity.

Table Xl . Mean acidity of twelve varieties picked mature green and pink and ripened to full red stage.

Acidity as per cent citric acid eq.

Variety	Mature Green	Pink
Starfire	0.408	0.375
Starfire recrossed	0.398	0.360
Vogue	0.395	0.352
M - 2	0.385	0.347
Moreton Hybrid	0.372	0.398
Cheyenne	0.364	0.350
M - 3	0.360	0.353
Summerdawn	0.354	0.369
Fireball	0.330	0.332
Galaxy	0.326	0.344
Cavalier	0.311	0.342
Bush Beefsteak	0.307	0.321

L.S.D. .0308

A significant correlation coefficient of -0.40 was obtained between pH and total acidity. The negative value confirms the results of Thompson *et al*. (72). Thus when acidity is high, pH will tend to be low.

Soluble Solids

Variety and temperature were two significant factors at P = 0.01 as shown in Appendix VII. Table XII shows the mean values for soluble solids for each variety tested. Tomatoes ripened at 62°F had lower soluble solids than at 72°F. Thus higher temperature seemed to preserve the soluble solids.

Table XII. Mean soluble solids for twelve varieties when red ripe.

Variety	Soluble solids as per cent sucrose
M - 3	4.95
Starfire recrossed	4.90
Galaxy	4.90
Vogue	4.90
Moreton Hybrid	4.85
Starfire	4.85
Cheyenne	4.83
Summerdawn	4.80
Fireball	4.77
M - 2	4.70
Cavalier	4.67
Bush Beefsteak	4.67

Findings differ as to the importance of maturity. In this study, no obvious effects were found. However, it cannot be completely eliminated as a factor, since the method of determination by the refractometer did not account for the water loss in storage.

Typical water loss values reported averaged 2 - 4% per fruit from the mature green to the fully red ripe.

Table XIII summarizes the mean values for comparisons of the variety times maturity interaction. The maturity times temperature interaction shows that at 62°F and 72°F the pink fruit were highest in soluble solids. Maturity is significant, therefore, in conjunction with storage temperature, but not as a primary effect.

Table XIII. Mean soluble solids of twelve varieties picked mature green and pink and ripened to full red ripe.

Variety	Soluble solids as per cent sucrose	
	Mature Green	Pink
M - 3	4.95	4.95
Starfire	4.95	4.75
Fireball	4.90	4.65
Galaxy	4.90	4.90
Starfire recrossed	4.80	5.00
Cheyenne	4.80	4.85
Summerdawn	4.80	4.80
Vogue	4.80	5.00
M - 2	4.75	4.65
Cavalier	4.65	4.70
Moreton Hybrid	4.65	5.05
Bush Beefsteak	4.60	4.75

L.S.D = 0.233

Alcohol-Insoluble Solids

In the statistical analysis for alcohol-insoluble solids in Appendix VIII, varieties and maturities were significant at P = 0.01. Varieties differed in alcohol-insoluble solids content as shown in Table XIV. Mature green fruit had higher alcohol-insoluble solids than the pink fruit.

Table XIV. Mean alcohol-insoluble solids for twelve varieties when red ripe.

Variety	Alcohol-insoluble solids g/100g fresh wt
Vogue	2.030
M - 2	1.970
Moreton Hybrid	1.955
Fireball	1.903
Cheyenne	1.777
Starfire	1.763
M - 3	1.747
Galaxy	1.737
Bush Beefsteak	1.713
Cavalier	1.707
Summerdawn	1.685
Starfire recrossed	1.680

The variety times maturity interaction was significant at P = 0.05. Table XV gives the means for the mature green and pink for each variety for the alcohol-insoluble solids.

It seems that little importance can be attached to the alcohol-insoluble solids as an indicator of maturity. However, it is a simple test compared to the isolation and determination of the pectins, and has been found to be very useful in estimating harvest maturity in corn (37) and other crops. It may also be of some value for tomatoes. The correlation coefficient between the shear press and the alcohol-insoluble solids was +0.36, which is significant at P = 0.01. Only 13% of firmness may be accounted for by the alcohol-insoluble solids.

Table XV. Mean alcohol-insoluble solids of twelve varieties picked mature green and pink and ripened to full red stage.

Variety	Alcohol-insoluble solids (g) 100g fresh wt Mature Green	Pink
M - 2	2.14	1.80
Vogue	2.09	1.98
Fireball	2.02	1.79
Moreton Hybrid	2.02	1.90
Starfire	1.96	1.57
M - 3	1.87	1.63
Cheyenne	1.86	1.70
Galaxy	1.84	1.64
Bush Beefsteak	1.79	1.64
Starfire recrossed	1.77	1.59
Cavalier	1.77	1.64
Summerdawn	1.70	1.68

L.S.D. = 0.156

It has been reported (10) that increasing temperature will decrease the alcohol-insoluble solids in mature green harvested tomatoes. This suggests pectin breakdown as maturity proceeds. No temperature effect was found in this study.

Pectins

Two varieties, Moreton Hybrid and Starfire recrossed, were analysed for total pectin and protopectin. For both pectic fractions, only the varieties showed significant differences. For both protopectin and total pectin, Moreton Hybrid was higher than Starfire recrossed. Appendix IX and Appendix X show the complete analysis of variance table. The coefficients of variation were 9.8% for total pectin and 9.7% for protopectin.

Appendix XI summarizes some pertinent data for the two varieties tested for pectins. The coefficient of variation for ten firmness readings ranged from 12.0 to 20.9%. Unfortunately, none of the methods used by others has shown the variability of their readings, and thus no comparisons were made.

Correlation coefficients between the shear press firmness and the pectin fractions were calculated. Between firmness and total pectin the correlation coefficient was +0.436 (significant at $P = 0.05$) and between firmness and protopectin +0.504 (significant at $P = 0.01$).

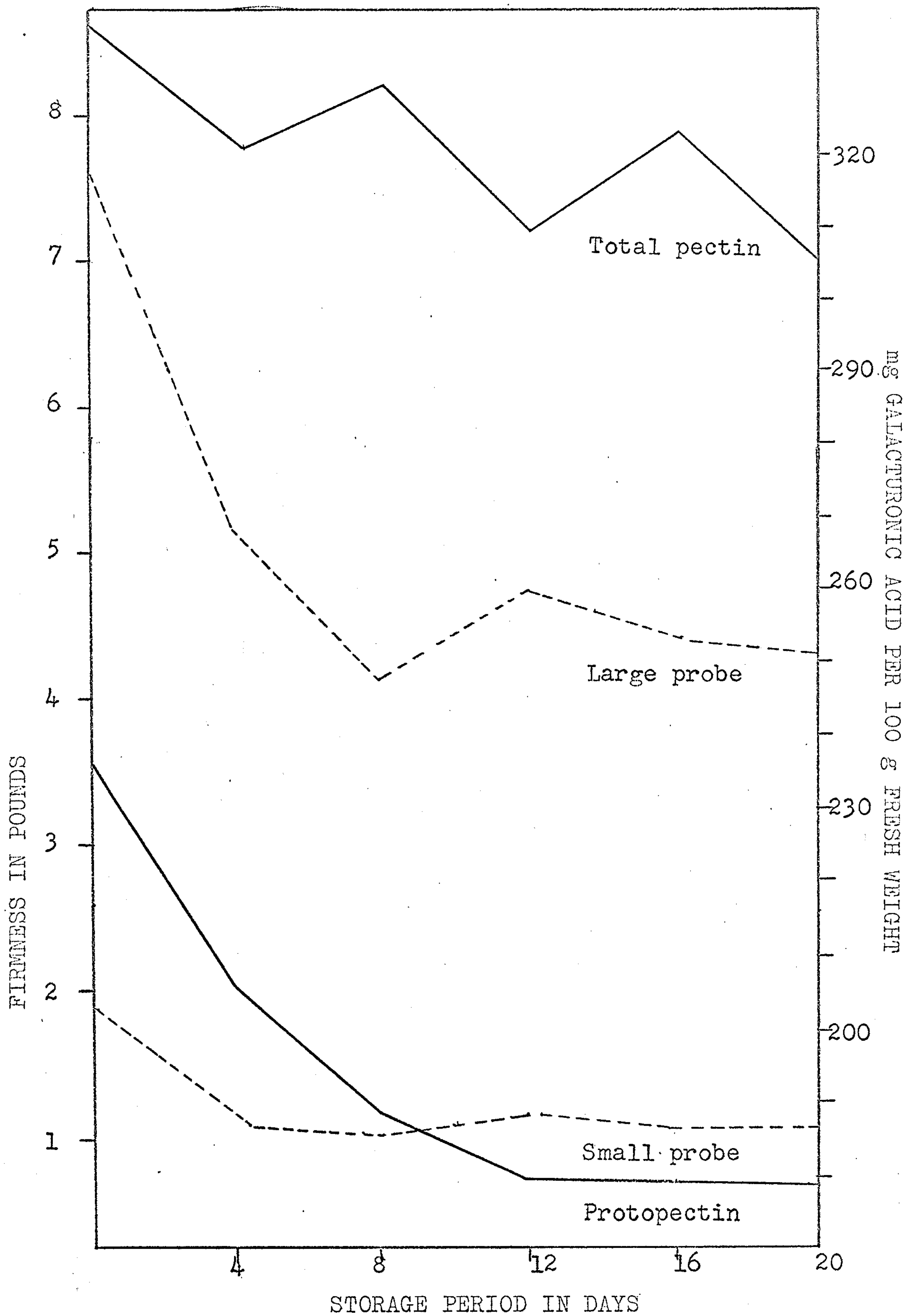
In the determination of the factors affecting firmness, it was found that variety, maturity and temperature were important. None of these factors affected the total pectin or the protopectin content. Other factors not investigated may be of more importance. They are the calcium pectate, which forms by the interaction of the calcium ion with the pectic acid, and the magnesium to calcium ratio. Esau et al. (15) showed the A.I.S., total pectin, water soluble pectin, total calcium, and total magnesium were correlated with firmness in apples. The ratio of magnesium to calcium which correlated to firmness, differed greatly in detached fruit and tree ripened fruit. The activity of the pectic enzymes at different storage temperatures may lead to differences in demethylation as suggested by Woodmansee et al. (77). This leads to a greater production of calcium pectate which increases the firmness.

The second experiment was designed to improve upon the shear press method. Different aspects of the curve may be more favorably related to firmness than maximum peak height. The size of the probe was changed in the hope of better correlations. Finally, with the beam balance, the peak values could be corrected by a calibration curve.

It became evident that, as the tomatoes ripened, the curve for the 7/16 in. probe showed a more gentle slope. The base of the curve became broader. The slope, however, was difficult to measure since the curve was not a straight line. The 1/8 in. probe curve did not change in shape with maturity of each lot. For these reasons only the area under the curve when the large probe was used, was recorded for this study.

Appendix XIII contains the various values found by the different methods and the pectin content. The results show that peak force of the curve decreased as the fruit ripened, while the area increased as the fruit ripened. This area increase indicates that more work (force x time) is being done to puncture a ripe tomato, compared with a firmer one. It may be that with a firm tomato the probe essentially shears through the skin and pericarp. In a ripe fruit, stretching of the skin occurs, as well as squeezing of the whole fruit before the fruit is punctured.

Figure 11. Firmness and pectin content in relation to the length of storage.



The coefficients of variation were calculated to find the more precise method. The peak force of the large probe seems to be the least variable technique.

Table XVI gives the various simple correlation coefficients. The protopectin is consistently related to firmness. However, the most firmness that can be explained by the protopectin is about 50%. Thus, the other half is either a random effect or due to other factors.

Table XVI. Simple correlation coefficients between three methods of determining firmness and two pectic fractions.

	Total Pectin	Protopectin
Small probe peak	0.293	0.708**
Large probe peak	0.345	0.624**
Large probe area	0.100	0.690**

** Significant at P = .01

The small probe peak was nearly equal to the large probe area method, as shown by the correlation coefficients. These two methods also have the greatest variability. Thus, sample size will be more important than in the large probe peak force method. Figure II shows graphically some of the data of Appendix XII. The total pectin content tends to decrease. The variations are probably due to experimental variations and the inherent differences in the samples. The protopectin showed a decline, predominantly in the first four days of storage. Both the small and large probe peak force methods showed a steep decline in firmness, paralleling the decrease of protopectin content in this first time interval.

Using area measurement for the large probe, the firmness increased during this time. The explanation for this is not known.

The advantages of the calibration curve were not obvious. The uncorrected data coefficients of variation were higher than the adjusted coefficients. This may be caused by the decrease in both of the members of this ratio. The calibration curves had nearly identical slopes for any one particular range. Only when more than one range of the instrument is used may benefits be gained.

SUMMARY AND CONCLUSIONS

Tomatoes harvested mature green required an average of 23 days and 16 days at 62°F and 72°F, respectively to ripen to the same optimum table quality. Pink harvested fruit required nine and seven days at those temperatures. Varieties differ in the length of time required for ripening, even between replications harvested on the same day. The difference was greatest in the mature green and storage at 62°F. Least variation occurred in the pink harvested fruit stored at 72°F. This may be the best ripening condition for analytical work.

Ranges of values were found for the twelve Manitoba grown varieties for the following quality factors: external color, juice color, pH, acidity, soluble solids, firmness, total pectin, protopectin and alcohol-insoluble solids. The fruit for analysis were harvested in the mature green and pink stages and ripened at 62°F and 72°F. Of the main factors, variety and temperature showed highly significant differences for juice color while for surface color varieties and maturities showed highly significant differences. The divergence of juice and external color was shown by a correlation coefficient of -0.20 between these two factors. Juice color which is regarded as a better indication of fruit color showed a high coefficient of variation.

Firmness showed highly significant differences for variety, maturity and temperature. The firmest fruit were stored at 62°F and picked in the mature green stage. Variety and maturity showed highly significant and temperature significant differences for pH. All varieties tested were below pH 4.5 which is the upper limit for the suitability for canning. Total acidity showed highly significant differences for varieties only, while soluble solids showed highly significant differences for variety and temperature. Total pectin and protopectin content showed highly significant differences between varieties only. The alcohol-insoluble solids, however, had highly significant differences for variety and maturity. The A.I.S. was highly significantly correlated, r = 0.36, to firmness. As this value is low the utility of this relationship is limited.

Firmness was measured by the shear press with a 7/16 in. and a 1/8 in. round-end probe. Firmness readings were compared to the pectic fractions which contribute to the firmness of the tomato. Protopectin was consistantly correlated to the firmness readings with correlation coefficients ranging from 0.504 to 0.707, both being highly significant. There was little difference between the maximum force of the small probe, r = 0.707, and the area under the curve for the large probe, r = 0.690. Maximum force of the large probe was nearly in the same range and was easier to measure than area under the curve. The variations in the readings of maximum force for the large probe were less than for the other determinations of firmness. Comparison to other instruments would be desirable to substantiate this method.

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APPENDIX 1

SOME CHARACTERISTICS OF TWELVE TOMATO VARIETIES PICKED IN THE MATURE GREEN AND PINK STAGES AND STORED AT 62° and 72°

VARIETY	pH				ACIDITY AS PER CENT CITRIC ACID				JUICE COLOR ΔE				SURFACE COLOR ΔE			
	G62	G72	P62	P72	G62	G72	P62	P72	G62	G72	P62	P72	G62	G72	P62	P72
Starfire Recrossed	4.37	4.42	4.39	4.35	.398	.397	.360	.359	4.34	5.59	3.44	4.89	6.67	6.49	8.18	7.36
Starfire	4.32	4.43	4.35	4.30	.422	.393	.388	.361	3.94	5.33	3.34	3.59	6.39	5.92	8.25	8.65
M-3	4.47	4.49	4.44	4.31	.370	.350	.340	.366	3.82	4.23	3.93	5.66	8.86	8.83	10.43	9.88
Bush Beefsteak	4.34	4.54	4.32	4.31	.331	.283	.309	.333	3.80	4.08	3.48	3.33	6.74	7.37	8.14	8.12
Cheyenne	4.43	4.45	4.37	4.46	.375	.352	.363	.336	3.49	4.42	3.72	3.47	8.53	8.09	8.94	9.46
Cavalier	4.35	4.48	4.28	4.29	.345	.277	.338	.346	2.70	4.23	3.25	5.34	8.29	8.49	8.25	9.73
Galaxy	4.35	4.44	4.40	4.45	.327	.325	.343	.345	4.09	4.64	4.43	4.05	7.35	7.44	8.16	8.30
Fireball	4.36	4.47	4.43	4.38	.338	.322	.317	.347	2.87	3.71	3.21	3.63	7.09	6.29	8.58	8.53
M-2	4.29	4.28	4.27	4.31	.386	.384	.344	.350	4.23	5.50	3.71	3.96	7.12	8.01	8.51	9.23
Summerdawn	4.38	4.44	4.38	4.31	.381	.327	.368	.370	3.34	4.79	3.30	3.71	6.49	6.85	6.71	7.21
Moreton Hybrid	4.22	4.39	4.31	4.14	.397	.347	.362	.434	3.01	3.85	3.52	4.29	7.64	8.13	9.51	9.26
Vogue	4.24	4.23	4.14	4.20	.363	.427	.354	.350	3.91	5.43	5.48	4.62	6.93	6.92	8.23	9.09

APPENDIX 1 (Cont'd)

SOME CHARACTERISTICS OF TWELVE TOMATO VARIETIES PICKED IN THE MATURE GREEN AND PINK STAGES AND STORED AT 62° and 72°

	ALCOHOL-INSOLUBLE SOLIDS				SHEAR PRESS LB				SOLUBLE SOLIDS PER CENT SUCROSE			
VARIETY	G62	G72	P62	P72	G62	G72	P62	P72	G62	G72	P62	P72
Starfire Recrossed	1.78	1.76	1.66	1.52	5.52	5.19	5.74	4.18	4.7	4.9	4.9	5.1
Starfire	1.87	2.05	1.54	1.59	5.40	5.19	4.50	4.14	4.9	5.0	4.6	4.9
M - 3	1.77	1.97	1.58	1.67	5.90	5.03	5.48	6.15	4.8	5.1	4.7	5.2
Bush Beefsteak	1.82	1.76	1.65	1.62	5.02	4.55	5.18	4.21	4.7	4.5	4.7	4.8
Cheyenne	1.81	1.90	1.68	1.72	6.12	5.94	6.06	4.22	4.7	4.9	4.9	4.8
Cavalier	1.75	1.80	1.64	1.64	5.19	4.71	4.63	5.12	4.6	4.7	4.5	4.9
Galaxy	1.87	1.80	1.54	1.74	5.39	5.32	5.41	4.53	4.8	5.0	4.8	5.0
Fireball	1.96	2.07	1.86	1.72	5.42	4.93	4.65	4.88	4.8	5.0	4.5	4.8
M - 2	2.10	2.17	1.77	1.84	5.57	5.68	5.11	5.04	4.7	4.8	4.6	4.7
Summerdawn	1.71	1.68	1.68	1.67	4.93	4.67	5.15	4.98	4.8	4.8	4.9	4.7
Moreton Hybrid	2.04	1.99	1.89	1.90	4.99	5.76	5.47	5.31	4.6	4.7	4.9	5.2
Vogue	2.10	2.07	1.93	2.02	5.38	5.01	5.52	4.87	4.6	5.0	5.1	4.9

APPENDIX 11

ANALYSIS OF VARIANCE FOR THE EFFECT ON JUICE COLOUR OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	3.2953	1.64765	
Varieties	11	22.2595	2.0236	2.88**
Maturities	1	1.5211	1.5211	
Temperatures	1	22.6259	22.6259	32.21**
Var x Mat	11	15.2105	1.38277	1.97*
Mat x Temp	1	3.5721	3.5721	5.08*
Error	116	81.4662	.7023	
TOTAL	143	149.9506		

C.V. = 20.3%

** Significant at P = 0.01
* Significant at P = 0.05

APPENDIX 111

ANALYSIS OF VARIANCE FOR THE EFFECT ON SURFACE COLOUR OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	.98184	.49092	
Varieties	11	80.12712	7.28428	12.73**
Maturities	1	55.06877	55.06877	96.22**
Temperatures	1	.78766	.78766	
Error	128	73.25713	.5723	
Total	143	210.22252		

C.V. = 9.3%

** Significant at P = 0.01

APPENDIX 1V

ANALYSIS OF VARIANCE FOR THE EFFECT ON FIRMNESS IN POUNDS OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	2.67504	1.33752	4.93**
Varieties	11	11.98104	1.08918	4.01**
Maturities	1	3.32151	3.32151	12.25**
Temperatures	1	3.19516	3.19516	11.78**
Var x Mat	11	6.76847	.61531	2.27*
Mat x Temp x Var	11	6.32859	.57532	2.12*
Error	106	28.73233	.271059	
Total	143	63.00210		

C.V. = 9.9%

** Significant at P = 0.01
* Significant at P = 0.05

APPENDIX V

ANALYSIS OF VARIANCE FOR THE EFFECT ON pH OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	.03090	.015450	
Varieties	11	.673158	.061196	9.3**
Maturities	1	.080750	.080750	12.3**
Temperatures	1	.04033	.04033	6.12*
Mat x Temp	1	.061812	.061812	9.4**
Error	127	.835898	.006582	
Total	143	1.722850		

C.V. = 1.7%

** Significant at P = 0.01
* Significant at P = 0.05

APPENDIX V1

ANALYSIS OF VARIANCE FOR THE EFFECT ON TOTAL ACIDITY AS PER CENT CITRIC ACID OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	.00041716	.0002085	
Varieties	11	.08047525	.007315	6.6 **
Maturities	1	.00113335	.0011333	
Temperatures	1	.00122495	.0012249	
Var x Mat	11	.02405645	.0021869	1.97*
Mat x Temp	1	.00913017	.0091301	8.25**
Error	116	.12836242	.0011066	
Total	143	.24479975		

C.V. = 8.9%

** Significant at P = 0.01
* Significant at P = 0.05

APPENDIX V11

ANALYSIS OF VARIANCE FOR THE EFFECT ON SOLUBLE SUGARS AS PER CENT SUCROSE OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	.089306	.044653	
Varieties	11	1.221389	.1110354	4.17**
Maturities	1	.089996	.089996	
Temperatures	1	.722496	.722496	27.17**
Var x Mat	11	1.008331	.0916665	3.44**
Mat x Temp	1	.498893	.498893	18.76**
Mat x Temp x Var	11	.810837	.0737125	2.77**
Error	105	2.791808	.0265886	
Total	143	7.233056		

C.V. = 3.6%

** Significant at P = 0.01

APPENDIX V111

ANALYSIS OF VARIANCE FOR THE EFFECT ON ALCOHOL-INSOLUBLE SOLIDS CONTENT OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWELVE TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	.008707	.0043535	
Varieties	11	2.014173	.183107	13.8**
Maturities	1	1.282556	1.282556	97.1**
Temperatures	1	.027778	.027778	
Var x Mat	11	.342115	.031101	2.35*
Error	117	1.544965	.013204	
Total	143	5.220294		

C.V. = 6.38%

** Significant at P = 0.01
* Significant at P = 0.05

APPENDIX 1X

ANALYSIS OF VARIANCE FOR THE EFFECT ON TOTAL PECTIN OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWO TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	207.130	1,353.565	
Varieties	1	20,079.736	20,079.736	16.97**
Maturities	1	1,284.807	1,284.807	
Temperatures	1	748.168	748.168	
Error	18	21,293.498	1,182.972	
Total	23	46,113.339		

C.V. = 9.86%

** Significant at P=0.01

APPENDIX X

ANALYSIS OF VARIANCE FOR THE EFFECT ON PROTOPECTIN OF TWO MATURITIES AND TWO STORAGE TEMPERATURES ON TWO TOMATO VARIETIES

Source	d.f.	s.s.	M.S.	F
Replications	2	3,069.00	1,534.5	
Varieties	1	17,382.784	17,382.784	27.46**
Maturities	1	.22	.22	
Temperatures	1	1,211.26	1,211.26	
Error	18	11,393.81	632.989	
Total	23	33,056.64		

C. V. = 9.73%

** Significant at P = 0.01

APPENDIX XI

SOME MEASUREMENTS PERTAINING TO THE FIRMNESS OF TWO TOMATO VARIETIES

Variety	Mean Shear Press lb	Coefficient of Variation lb	Total Pectin mg.gal/100gm.	Protopectin mg.gal./100gm.
Starfire Recrossed				
Green 62	5.52	16.4	341.6	243.7
Green 72	5.19	15.4	327.4	257.8
Pink 62	4.74	16.6	329.0	236.4
Pink 72	4.18	20.9	330.7	243.1
Moreton Hybrid				
Green 62	4.99	12.0	397.0	291.9
Green 72	5.78	16.2	407.7	294.9
Pink 62	5.47	15.9	354.5	288.3
Pink 72	5.31	13.6	401.0	321.2

CHANGES IN PECTIC CONTENT AND VARIOUS METHODS OF DETERMINING FIRMNESS AT FOUR DAY INTERVALS

Length of Storage Days	Total Pectin mg gal/100 gm	Protopectin mg gal/100 gm	Large Probe Peak Max	Large Probe C.V. %	Large Probe Area	Large Probe C.V. %	Small Probe Peak Max	Small Probe C.V. %
0	331.8	245.7	7.77	22.1	177	39.9	1.98	27.4
	326.3	256.2	7.37	21.1	161	33.2	2.13	15.7
	353.0	216.1	7.92	16.5	197	24.1	1.77	25.5
4	322.0	222.2	4.81	17.5	124	27.8	1.20	20.0
	341.7	207.8	5.32	18.1	117	33.9	1.19	31.1
	296.4	188.3	5.33	24.2	107	25.1	1.11	22.5
8	354.6	160.2	3.78	19.8	329	26.2	1.13	15.5
	294.6	209.0	4.07	17.6	326	27.9	1.03	32.8
	341.0	193.9	4.49	21.3	409	32.5	1.11	17.3
12	303.0	222.7	4.39	20.4	353	27.5	1.20	15.8
	328.7	172.6	4.53	13.9	415	25.3	1.08	12.0
	295.8	145.8	5.20	17.9	482	22.2	1.27	12.4
16	339.0	165.2	4.75	19.8	425	26.6	1.14	24.7
	304.8	194.0	3.97	15.2	331	19.4	1.03	27.2
	328.0	180.8	4.60	11.4	429	27.7	1.10	21.9
20	290.6	190.8	4.18	19.1	398	49.4	1.13	23.3
	347.5	175.1	4.67	18.6	492	25.4	1.03	22.1
	277.1	171.7	3.98	20.6	376	37.2	.97	20.1

APPENDIX XIII

Surface color expressed as L value and A/B ratio of twelve tomato varieties picked in the mature green and pink stages and stored at 62° and 72°

Variety	Green 62		Pink 62		Green 72		Pink 72	
	L	A/B	L	A/B	L	A/B	L	A/B
Starfire Recrossed	22.1	2.25	21.3	2.31	22.8	2.44	22.1	2.13
Starfire	21.7	2.24	21.6	2.18	22.7	2.46	21.3	2.17
M - 3	21.1	2.36	20.5	2.26	21.8	2.43	22.1	1.91
Bush Beefsteak	21.4	2.35	21.4	2.18	21.9	2.51	22.3	2.04
Cheyenne	20.9	2.42	21.8	2.06	21.8	2.50	21.2	2.20
Cavalier	20.5	2.56	21.2	2.23	21.4	2.63	21.4	2.03
Galaxy	21.6	2.46	21.7	2.17	22.2	2.51	21.7	2.17
Fireball	21.4	2.47	21.1	2.30	22.5	2.48	21.6	2.15
M - 2	22.1	2.49	21.6	2.19	21.5	2.32	22.1	2.02
Summerdawn	21.8	2.43	22.2	2.08	22.1	2.54	22.3	2.09
Moreton Hybrid	21.3	2.35	20.3	2.38	22.2	2.56	21.2	2.10
Vogue	22.0	2.44	21.8	2.05	22.6	2.46	21.1	2.32

APPENDIX XIII (con't)

Juice color expressed as L values and A/B ratios of twelve tomato varieties picked in the mature green and pink stages and stored at 62° and 72°

Variety	Green 62		Pink 62		Green 72		Pink 72	
	L	A/B	L	A/B	L	A/B	L	A/B
Starfire Recrossed	28.2	2.09	25.5	2.57	28.1	2.00	26.3	2.28
Starfire	27.0	2.28	26.7	2.41	26.6	2.14	26.4	2.38
M - 3	25.4	2.53	24.0	2.75	26.4	2.25	26.6	2.25
Bush Beefsteak	27.2	2.17	27.3	2.27	26.7	2.20	26.7	2.15
Cheyenne	26.4	2.44	27.1	2.31	27.4	2.15	24.7	2.56
Cavalier	26.1	2.40	26.5	2.33	25.8	2.15	27.7	2.01
Galaxy	27.8	1.94	25.6	2.37	28.0	1.95	26.1	2.32
Fireball	26.8	2.20	27.2	2.26	27.9	2.04	26.5	2.23
M - 2	28.3	2.29	27.5	2.43	24.5	2.11	27.2	2.36
Summerdawn	26.8	2.31	26.9	2.32	26.7	2.23	27.2	2.23
Moreton Hybrid	27.0	2.32	25.3	2.50	26.7	2.24	27.2	2.27
Vogue	27.3	2.16	28.9	1.95	28.3	1.97	27.6	2.06