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Fruit Quality Attributes of 250 Foreign and Domestic Tomato Accessions

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SUMMARY

A study of 175 *Lycopersicon esculentum,* 50 *Lycopersicon esculentum* X *Lycopersicon pimpinellifolium* and 25 *Lycopersicon pimpinellifolium* lines was made to identify germplasm of high acid potential for use in breeding for improved processing quality.

Standards for acidity were established at maximum pH 4.39 and minimum total acidity 0.70%

Individual lines within each species group were found which widened the ranges existing among current varieties:

pH—from 4.37-4.69 to 4.26-4.95
total acidity (%)—from 0.361-0.498 to 0.306-1.000
% Brix—from 3.60-5.12 to 4.05-9.86.

Of 175 *Lycopersicon esculentum* lines, the following were found to possess pH values below 4.40 and citric acid values above 0.70%:

P.I. Number	*Mo. Accession No.*
128223	98
128222	97
118785	31
272709	235
270246	197 (Stemless Penn Orange)
272689	223

Of the 50 interspecific hybrids *(L. esculentum* X *L. pimpinellifolium),* seven met or exceeded the minimum pH and acidity requirements:

P.I. Number	*Mo. Accession No.*
118405	28
118407	29
147635	135
129155	129
147609	134
204998	171
108245	16

Among the 25 *L. pimpinellifolium* lines, three possessed pH values below 4.40 and citric acid value above 0.70%:

P.I. Number	*Mo. Accession No.*
126952	82
127806	88
126953	83

Comparisons of means among the three species groups showed no difference in pH; however, total acidity and percent Brix were somewhat higher for *L. pimpinellifolium.*

To meet immediate breeding objectives, there was no justification for going outside *L. esculentum* for the desired genes. Selection must be on an individual line basis.

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INTRODUCTION

The low acidity of present-day tomato varieties is of increasing concern to food processors. Losses occur from "flat sour" spoilage when bacterial spores that survive the heating process germinate and spoil processed tomatoes that are low in acidity. Further, the production and blending of "high-acid" and "low-acid" lots is both difficult to schedule and costly.

Since the Food and Drug Administration has not yet approved the addition of organic acids to tomato products, it is desirable that processing tomato varieties be developed which possess higher acidity. The need for higher acidity takes on even more significance now that mechanical harvesting is a reality. To achieve maximum yields from the "once-over" harvest, early maturing fruit must remain on the vine longer than when hand-picked. Acidity decreases rapidly after ripening; hence, it is desirable that the raw product possess a high acidity potential.

Higher acid varieties would benefit both the processor and consumer. They would enable processors to reduce the processing time and temperature. Color deterioration and vitamin C losses would be lower with reduced processing temperatures, providing a more desirable and nutritious product for the consumer.

Acidity is affected by both heredity and environment. The control of environment necessary to gain higher acidity, however, is difficult to attain under field conditions; this further emphasizes the desirability of the breeding approach.

A large reservoir of tomato germplasm exists of the common tomato, *Lycopersicon esculentum,* the wild currant tomato, *Lycopersicon pimpinellifolium,* and interspecific hybrids of the two species, which has not been evaluated for fruit quality attributes. The primary purpose of this study was to select out of this germplasm, varieties and lines possessing wider extremes of acidity and sugar than are found among current processing varieties. These selections can then be used in the directed breeding effort to increase acidity and processing quality.

REVIEW OF LITERATURE

The chemical composition of the tomato fruit is largely responsible for its quality whether in the raw or processed state. As a result, much research has been directed in this area to quantitatively measure the quality attributes of commercial varieties as well as lines used in breeding programs. Cameron (11), in determining the composition of strained tomatoes obtained by cycloning, reported the following constituent ranges: about 1 percent insoluble solids, 4 to 6 percent soluble solids, 2 to 3 percent sugar (nearly all in the invert form), 0.3 to 0.5 percent acid (expressed as citric), 0.8 to 1.2 percent soluble protein, 0.3 to 0.6 percent mineral constituents, and 0.05 to 0.1 percent salt (sodium chloride). The sugars and acids are considered to be the most important constituents responsible for fruit quality; therefore, the following literature review has been limited to these two quality factors.

pH

The hydrogen ion concentration, commonly referred to as pH, is responsible for many of the chemical transformations that occur in food products. Bigelow and Cathcart (7) as well as Gould (15) confirmed the fact that pH is one of the most important factors affecting processing time and temperature for tomatoes. Cruess (12), in 1948, also found that products most difficult to sterilize were those low in acid and which contained spore-bearing bacteria. Thompson *et al.* (39), reported that the spoilage of canned tomato products was caused by the germination of certain thermophylic bacterial spores which were not killed by the heat process or were not controlled by an adequate amount of acidity.

Since microorganisms are responsible for considerable food spoilage, much research has been directed toward their control by means of inhibiting spore germination and growth as well as by determining the factors which affect the heat resistance of the microorganisms. Spiegelberg (37), in an extensive study in 1939, reported that a pH of 4.40 to 4.50 or below, accompanied by a 190°F temperature after cooking, insured sterility of the canned fruit. A pH of 4.50 or above required a 200°F temperature to eliminate the nonspore-forming organisms. Butyric acid-forming organisms, however, resisted even much higher temperatures. In 1955, Desrosier and Heiligman (13) reported that increased pH levels above 4.30 allowed bacterial spoilage in canned tomato juice. Rice (29), in 1954, found that a pH of 4.35 or below would not support growth of many strains of *Bacillus coagulans*. Mohr (27), in 1960, reported that the critical pH of tomato fruit above which the spoilage incidence increased markedly was 4.50. Jones and Ferguson (18) recovered a type of "flat sour" spoilage in canned whole tomatoes and tomato juice which was caused by *Bacillus coagulans.* In 1933, Berry (6) reported that *Bacillus thermoacidurans* was the organism responsible for spoilage in canned tomato juice. It is now known that this organism is the same as *Bacillus coagulans,* described by Rice and Pederson (29) in 1954. Other bacterial species are also known to cause spoilage in acid-canned fruit. Spiegelberg (37) studied the factors involved in the spoilage of acid-canned fruit resulting from the spore-forming *Clostridium pasteurianum* and the non-spore forming *Lactobacillus plantarum* and *Leuconostoc mesenteroides.*

Numerous studies have been conducted regarding the pH of tomato varieties and breeding lines solely because of its importance in the inhibition of microbial growth in canned products and in determining the processing time and temperature requirements. Harvey (17), in studying 30 tomato varieties, reported a pH range of 4.148 to 4.565. In 1932, Saywell and Cruess (34) determined a range from 3.80 to 4.40 in canning tomatoes. Smith (36), in 1936, reported a pH range of 4.06 to 4.60 and, in 1960, Yamaguchi and Leonard (43) found a range of 3.90 to 4.60 with the majority falling between 4.20 and 4.50. Adams (1), in determining pH values of individual fruits, reported a range of 3.90 to 4.80. Lambeth, *et al.* (20), in a study of eleven commercial varieties and lines, gave a range of 4.37 to 4.69 for vine-ripened fruit and a 4.34 to 4.54 range for chamber-ripened fruit.

Within the past several years, several workers have reported on the varietal effects of pH in tomato fruit. In 1962, Thompson *et al.* (39) reported that particular varieties consistently produced fruits having a high pH whereas others consistently produced fruits having a low pH. In this study, the workers also noted that the varieties having low pH values possessed a high degree of firmness. Bohart (8), while making quality determinations in western-grown tomato varieties in 1940, found that pH was positively correlated to titratable acidity. A study by Thompson, *et al.* (40) in 1964 also indicated an association between pH and titratable acidity in high-acid, small-fruited accessions; however, a negative correlation was observed in larger-fruited, high-acid selections. Walkoff (42) indicated monofactorial control for the acidity characteristic and found high acidity to be highly heritable in the Morden WO24MD X Early Lethbridge crosses and backcrosses. The general concensus among workers, however, is that the inheritance of acidity is multigenic. The breeding work conducted by Thompson *et al.* (40) in 1964 between named varieties and high-acid interspecific hybrids indicated that the level of acidity is under polygenic control.

Definite changes in pH as a result of maturity have been cited by several workers. In 1925, Rosa (32) found that pH increased from the green to the turning stage with a decline to a minimum in ripened fruit. Anderson (3) found a progressive increase in pH as maturity approached. Yamaguchi (43), in 1960, also confirmed the fact that the ripening process increased the pH in California-grown tomatoes. Lambeth *et al.* (20), in making quality comparisons of vine and chamber-ripened fruit, reported that pH increased as the season progressed in both cases. The work of Hanna (16) also found increases in pH during the maturation of 15 varieties. His work indicated that a high degree of correlation existed between pH and maturity; thus, he ascertained that for any quantitative studies and comparisons of pH, the fruit should possess comparable maturity stages.

The hydrogen ion concentration also influences the flavor of both raw and processed fruit. Harvey (17), in 1920, reported that acidity is dependent upon the total acidity or quantity of acid ingested and not necessarily upon the pH alone. In 1957, Anderson (3) also reported that pH and the total free acid in the juice influenced the degree of sourness. In taste tests conducted by Lambeth *et al.* (20) in 1964, samples of tomato juice serum and model solutions possessing the extreme pH ranges found in fruit picked on the same date were compared. The pH range was from 4.28 to 4.50. Results indicated that taste panel members could significantly detect differences in pH among the model solutions; however, no significant differences were found in the samples of tomato juice serum.

Titratable Acidity

Titratable acidity, or total acidity, includes the potential as well as the dissociated hydrogen ions in solution. Harvey (17), in studying the effects of acidity on taste, reported that titratable acidity does influence the flavor of tomato fruits.

As in pH, research workers have reported wide ranges in total acidity of tomato fruit juices. Since citric acid comprises a large percent of the total acidity, most values reported are expressed in percent citric acid equivalent. Saywell and Cruess (34) reported an acid range of 0.26 to 0.81 percent citric acid equivalent in clear tomato juice samples. Scott and Walls (35), in 1947, found a 0.273 to 0.416 percent range in citric acid for fresh tomato fruit. Cameron (11), of the National Canners Association, indicated a range of 0.3 to 0.5 percent citric acid equivalent. Lambeth *et al.* (2) reported a range of 0.361 to 0.498 percent for vine-ripened fruit and a 0.354 to 0.544 percent range for chamber-ripened fruit.

Previous research seems to indicate that when the pH value is high, titratable acidity is low; likewise, when the pH value is low, titratable acidity is high. Bohart (8), in 1940, reported a definite positive correlation between pH and total acidity. Anderson (3) found in 1957 that, to the contrary in some cases, the pH value was highest where total acidity was highest. Thompson *et al.* (40), in 1964, found a negative correlation getween pH and titratable acidity in large-fruited high acid breeding lines; however, high-acid, small fruited accessions expressed some association between the two characteristics.

Although citric acid is the predominant acid found in the tomato, it is by no means the only one present. In 1920, Sando (33) indicated that tomato fruits contained citric, malic, oxalic, succinic, and tartaric acids. Nelson (28) reported that the organic acids in tomatoes were comprised of 60 percent citric acid and 40 percent malic. A study by Rice and Pederson (30) in 1954 reported citric as the predominant acid with malic in low concentrations. They also found traces of acetic and lactic acid in half the samples analyzed. Pyrrolidonecarboxylic acid was also found in high concentrations in two-year old tomato juice; however, it was not found in fresh tomato juice. Bradley (9), in 1960, found ten acids present in filtered tomato puree: citric, malic, lactic, acetic, fumaric, pyrrolidone-carboxylic, phosphoric, hydrochloric, sulfuric, and galacturonic. Koch (19), in 1962, found a higher proportion of malic to citric in early-maturing varieties. He postulated that it would be possible to select parents with a high malic acid content for use in breeding early-maturing tomato varieties.

Research results have indicated that total acidity is influenced by maturity stage. Rosa (32) found that total acidity increased from the green to turning stage and then declined to a minimum in ripened fruit. Likewise, Anderson (3) reported a progressive decline in total acidity from the turning stage to the very ripe stage of maturity. He also found total acidity ranges in the various sections of the tomato fruit. The outer pericarp possessed the lowest total acidity, the inner pericarp was intermediate, and the locular jelly contained the highest total acidity. Bohart (8), MacGillavray and Clemente (25), and McCollum (26) have also confirmed the fact that total acidity is higher in the locular jelly than in the flesh of the fruit; thus, Bohart concluded that fruits possessing large locules would tend to be more acid than those having small locules and more flesh. In 1964, however, Thompson *et al.* (40) reported that the difference in acidity within large and small-fruited lines could not be attributed to the variation of locular content alone. He concluded that small-loculed tomato varieties could be developed while still maintaining satisfactory acidity levels.

Freeman (14), in 1960, also reported that total acidity increased from the premature stage to a peak soon after maturation and then decreased with ripening. Yamaguchi (43), in studying the total acidity-maturity relationship of Pearson tomatoes in California, also reported that total acidity decreased once the fruits reached maturity and ripened. In 1962, Winsor (41) indicated that total acidity of English-grown tomatoes increased significantly from the green to the mature-green stage, accompanied by a decreased pH value; however, no consistent changes in acidity could be established after the first appearance of yellow color, as acidity increased in some fruit and declined in others. Lambeth *et al.* (20) found a consistent increase in total acidity until the end of the season in 11 commercial varieties and lines.

The amount of total acidity does influence the degree of sourness of tomato products. Harvey (17) reported that the degree of sourness was due to the two variables, pH and total acidity. Lambeth *et al.* (20) reported that taste panel members could not distinguish significant differences between high (0.510) and low (0.388) acidity values in tomato juice serum. He concluded that the acidity was being masked by the presence of other constituents in the serum.

Sugars

As with pH and total acidity, the presence of sugars also influences the quality of both raw and processed tomato products. Ranges in sugar content have been reported. In 1947, Scott and Walls (35) reported a range of 2.28 to 3.57 percent sugar in fresh tomatoes. Cameron (11), in the analysis of cycloned tomato juice samples, reported a range from 2.0 to 3.0 percent sugar with most of it being in the invert form. Saywell and Cruess (34) and Scott and Walls (35) also confirmed the fact that practically all the sugars are in the invert form. Lambeth *et al.* (20), in 1964, found a range of 3.60 to 5.12 percent sugar in vine-ripened fruit and a range of 3.12 to 4.52 percent in chamber-ripened fruit. Approximately 70 to 75 percent of the total sugar was found to be in the invert form. Saywell and Cruess (34) reported there was some correlation between high total solids and high reducing sugar. In 1953, Airan (2) indicated he had found glucose, fructose, and sucrose with small amounts of raffinose in well-ripened fruit.

The effect of maturity stage upon sugar content has been studied by several workers. In 1925, Rosa (32) found that sugar content increased steadily from the green stage to the ripened condition. Yamaguchi (43) also found an increase of sugar as ripeness approached. In England, Winsor (41) found a significant increase of sugars from the green to the red stage. In studying the percent change in sugar after the turning stage, Freeman (14) found only a slight increase in sugar. The work of Hanna (16) in 1961 also revealed no appreciable change in soluble solids after the turning stage. There were, however, differences in soluble solids among the varieties studied.

In regard to the effect of harvest date upon sugar content, Rosa (32) reported that fruit picked in the mature-green stage and ripened artificially had a lower sugar content than vine-ripened fruit. This would indicate that a rapid movement of organic substances from the plant into the fruit throughout the natural ripening process. Beadle (5), in 1937, reported an important relationship between the position of the fruit on the truss and the sugar content. He noticed that the fruits which ripened first possessed the highest percent sugar. Premature picking of the fruit resulted in a decreased sugar content even though the fruits were artifically ripened. Lambeth *et al.* (20) confirmed these results in studying the qualities of vine and chamber-ripened fruit.

The sugar content imparts an effect upon the flavor of tomato products. Harvey (17) reported that the addition of sugar to acid solutions did alter the taste but had no effect upon the pH or total acidity. In 1947, Scott and Walls (35) also reported that the presence of sugar in sample solutions was easily detected by taste panel members. He indicated that the addition of sugar increased the sugar-acid ratio, thereby giving a "bland" flavor.

Leonard *et al.* (23), in 1960, reported that additions of citric acid to canned tomatoes impaired palatability and that sugar additions were necessary to improve their flavor quality. He advocated that for every 0.1 percent citric acid added, 1.0 percent sugar should be added to compensate for the sour taste. Results indicated that there was no apparent advantage in using more than 0.2 percent citric acid and 2.0 percent sugar; flavor quality was not improved by subsequent sugar and acid additions. Lambeth *et al.* (20), in a study of eleven commercial varieties and lines, found that taste panel members could detect sugar ranges of 3.2 to 4.3 percent Brix in model solutions; however, these same ranges could not be distinguished in actual tomato juice serum samples.

Sugar-Acid Ratio

Most research conducted on fruit quality today utilizes the sugar-acid ratio as one means of quality measurement and evaluation. The value is computed by dividing the sugar content (expressed as percent Brix) by the acidity (expressed as percent citric acid equivalent). Scott and Walls (35) found that, as a rule, the sugar content was inversely correlated with the total acidity; as a result, the calculated sugar-acid ratios expressed wider variations among varieties than either the sugar or acid concentration alone. The two workers also found the sugar-acid ratios to be in close agreement with organoleptic ratings of blandness and acidity. Varieties possessing high sugar-acid ratios were bland, lacked sharpness in taste, and had a tendency to be flat. The low sugar-acid ratios, however, were sharp and acid. The sugar-acid range reported by Scott and Walls (35) was from a low of 6.9 to a high of 10.8. Lambeth *et al.* (20), in 1964, reported a 7.28 to 9.66 range in chamber-ripened fruit and a 8.38 to 13.11 range in vine-ripened fruit.

MATERIALS AND METHODS

Commercial varieties and breeding lines consisting of 175 *Lycopersicon esculentum,* 50 *Lycopersicon esculentum* X *Lycopersicon pimpinellifolium,* and 25 *Lycopersicon pimpinellifolium* were analyzed in this study. The collection, composed primarily of foreign accessions but containing domestic lines as well, was obtained from the Plant Introduction Station at Ames, Iowa. Descriptions of their horticultural characteristics and disease resistance have been published in North Central Regional Bulletin 65 which is available from the Iowa State Agricultural Experiment Station. The analyses of the 250 accessions should identify tomato lines having a wide range in quality constituents. Lines having desirable qualities exceeding those of our domestic commercial varieties should be considered for further study and possible use in breeding programs.

Cultural Practices

On April 1 and 2, 1964, eight to nine seeds of each of the 250 accessions were seeded directly into peat pots containing a standard soil mixture. Approximately a week after germination, the seedlings were thinned to three plants per pot. The plants were watered daily and were fertilized with a 5-10-5 nutrient solution weekly to prevent the occurrence of mineral deficiencies.

The plants remained in the greenhouse until May 4 and 5 at which time they were transferred to cold frames for hardening. On May 14 and 15, the seedlings were thinned to one plant per pot and transplanted to the experimental field plots at the New Franklin Research Farm. Ten plants of each line were set 30 inches apart in a single row plot. Rows were spaced four feet apart.

Soil tests of the plots on which the accessions were grown gave the following ranges (Missouri procedure) prior to fertilization:

Organic matter	2.2-2.5%
Phosphorus	326-432 pounds per acre
Exchangeable Potassium	530-640 pounds per acre
Exchangeable Calcium	3150-3300 pounds per acre
Exchangeable Magnesium	250-380 pounds per acre
pH	5.3-5.7

As shown in Table 1, a plow-down application of 300 pounds of 0-0-60 and 300 pounds of 16-48-0 was made prior to planting; two side dressings were applied during the growing season. Additional applications were withheld because of the intensive vegetative growth.

TABLE 1-FERTILIZATION, SPRAYING, IRRIGATION, AND HARVESTING PROGRAMS FOR 250 ACCESSIONS IN THE QUALITY STUDY

Treatment	Amount	Date
Fertilization		
0-0-60	300 lb./acre	April (plowed)
16-48-0	300 lb./acre	April (down)
16-48-0	25 lb.N/acre	June 10, 1964
33-0-0	25 lb.N/acre	July 7, 1964
Spraying		
Guthion, Zineb, Malathion	2 lb. each/100 gal.	June 2, 1964
Guthion, Zineb, Malathion	2 lb. each/100 gal.	June 11, 1964
Diazion, Zineb, Malathion	2 lb. each/100 gal.	June 19, 1964
Diazion, Zineb Malathion	2 lb. each/100 gal.	June 29, 1964
Sevin, Zineb	2 lb. each/100 gal.	July 9, 1964
Sevin, Zineb	2 lb. each/100 gal.	July 22, 1964
Sevin, Zineb	2 lb. each/100 gal.	August 5, 1964
Irrigation		
Sprinklers	1 1/2 inches	May 20, 1964
Sprinklers	2 inches	July 23, 1964
Harvesting		
Hand	1 quart	July 29, 1964
Hand	1 quart	August 5, 1964
Hand	1 quart	August 12, 1964
Hand	1 quart	August 19, 1964

For insect and disease control, the plants were sprayed approximately every 10 days with an insecticide-fungicide mixture. Table 1 contains the date, concentration, and the spray materials used throughout the season.

The rainfall during the growing season was near normal and included a dry period extending from the middle of July until the end of the harvest season which ended August 19, 1964. Approximately 3½ inches of irrigation water were applied during the course of the growing season (Appendix, Table 22). The average maximum and minimum temperatures by two-week periods for the growing season may also be found in Appendix Table 23.

Sample Preparation

The harvesting of the fruit samples began the last week in July and continued at weekly intervals for four consecutive weeks. The samples were picked in a "firm-red" stage and were selected at random from the 10 plants representing each accession. The fruits were placed into quart freezer bags and transferred to the Horticultural Laboratories where they were cooled overnight at 40°F. The following day the samples were thoroughly washed and drained; fruits possessing comparable stages of maturity as determined visually were stemmed and then blended to a homogeneous mixture in a Waring blendor. The slurry was then filtered and the serum was collected in four-ounce sample bottles and frozen immediately at 0°F.

Analytical Procedure

The quantitative determinations were started the latter part of August. An adequate number of samples for a day's determination was removed from the freezer the evening prior to analysis and allowed to thaw. A 15 ml aliquot of each sample was centrifuged for two minutes at 2,000 r.p.m. A 10 ml aliquot of the centrifuged juice was then transferred to a beaker containing 40 ml distilled water. The pH determination was made from this sample on a Beckman Zeromatic pH meter. This same sample was also used to measure the titratable acidity by titrating to an end point of 8.1 with 0.1 N NaOH. The total acidity was expressed as percent citric acid equivalent.

The soluble solids determinations were made on a precision model 3L Bausch and Lomb refractometer. Two drops of the filtered juice were placed on the prism and the percent solids was read directly from the Brix scale which was superimposed over the refractive index scale. These values were then adjusted for temperature corrections at 20°C.

The sugar-acid ratios of the accessions were computed by dividing the percent sugar expressed as Brix by the percent citric acid equivalent. The values given are the means of at least two sample determinations; the majority, however, are of three sample determinations.

Table 21 in the Appendix contains the mean values of pH, percent citric acid equivalent, soluble solids, and sugar-acid ratios of each of the 250 accessions in this study.

RESULTS AND DISCUSSION

pH

As indicated in the Review of Literature, Rice and Pederson (29), Spiegelberg (37), and Mohr (27) established critical pH values for tomato fruit used for processing. The values reported by these workers ranged from 4.35 to 4.50. To limit the discussion in this study, the arbitrary pH value of 4.39 or below was used in determining low pH lines; however, many of the accessions, as indicated in Table 21 of the Appendix, exhibit pH values between 4.40 and 4.50 and could be considered low pH lines.

Minimum, Maximum, and Mean pH Values of 175 Lycopersicon esculentum Lines

The 175 *L. esculentum* lines had a pH range from 4.26 to 4.82 with a mean value of 4.53 (Table 2). The extreme low pH value of 4.26 is near that reported

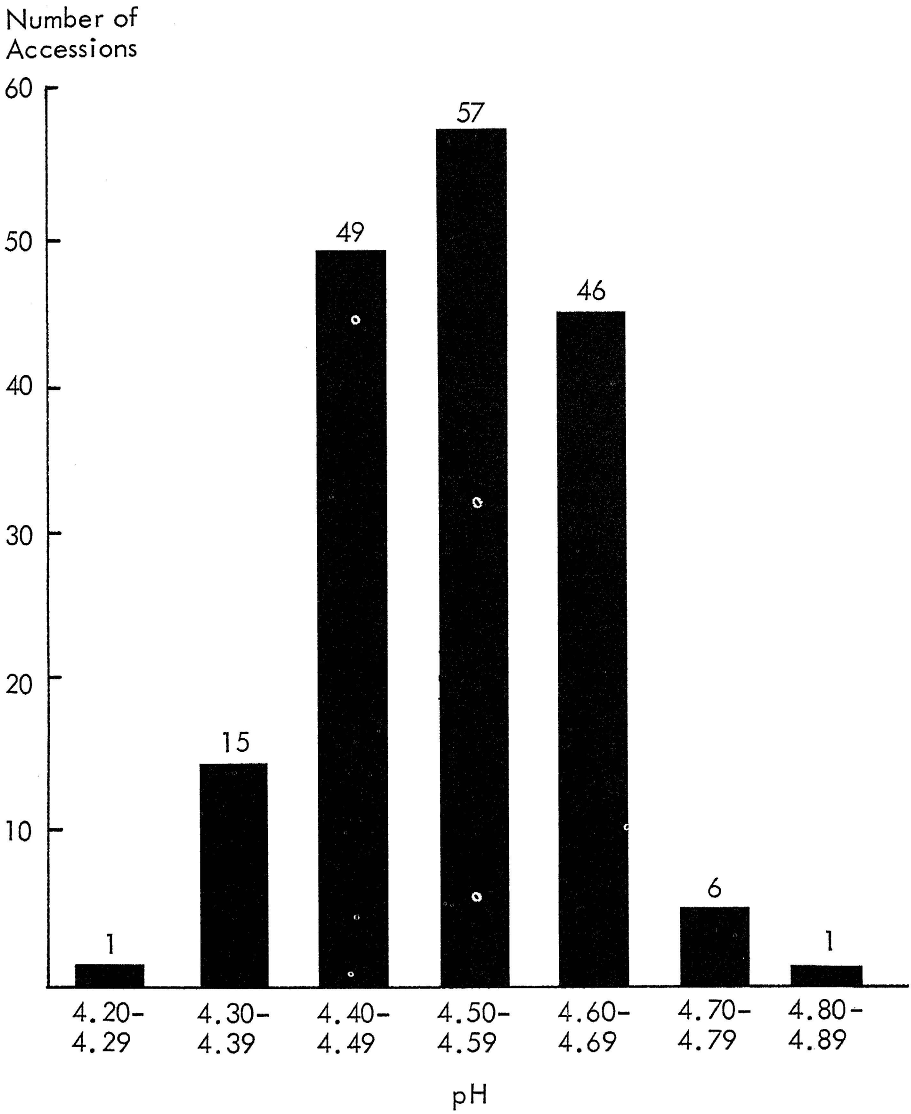
TABLE 2–EXTREME MEAN pH VALUES OF 175 L. ESCULENTUM LINES

	pH	Missouri No.*	Name
Low pH Values	4.26	98	
	4.30	64	
	4.31	85	
	4.31	97	
	4.33	100	
	4.34	31	
	4.34	63	
	4.34	95	
	4.35	235	
	4.37	86	
	4.37	99	
	4.38	96	
	4.38	155	
	4.38	197	Stemless Penn Orange
	4.38	223	
	4.39	111	
High pH Values	4.82	90	
	4.78	242	
	4.77	214	
	4.75	4	
	4.72	117	Merveille des Marches
	4.70	2	Primrose Gage
	4.70	218	
Over-all Mean	4.53		

*Corresponding Plant Introduction Number in Table XXI of Appendix

by Harvey (17) and Lambeth *et.al.* (20) for 11 commercial varieties and lines. The high pH value (4.82), however, was considerably higher than the 4.56 and 4.69 high pH values reported by these workers.

FIGURE 1
DISTRIBUTION OF 175 *L. ESCULENTUM* LINES INTO pH CLASSES



Sixteen of the *L. esculentum* lines possessed pH values below the critical 4.40 value. All lines were found to fall within the 4.30-4.39 pH class (Figure 1), with the exception of number 98 which had a pH of 4.26. Stemless Penn Orange (number 197) was the only named variety having a pH below the critical 4.40 value. Its value was 4.38.

Seven of the lines possessed pH values above 4.70; two were found to be named varieties. Primrose Gage from India (number 2) had a pH of 4.70 while Merveille des Marches from France (number 117) possessed a pH of 4.72.

Minimum, Maximum, and Mean pH Values of 50 Lycopersicon esculentum x Lycopersicon pimpinellifolium Lines

The pH values of the 50 interspecific hybrid lines ranged from 4.27 to 4.78 with a mean value of 4.50 (Table 3). These values are in close agreement with

TABLE 3-EXTREME MEAN pH VALUES OF 50 L. ESCULENTUM X L. PIMPINELLIFOLIUM LINES

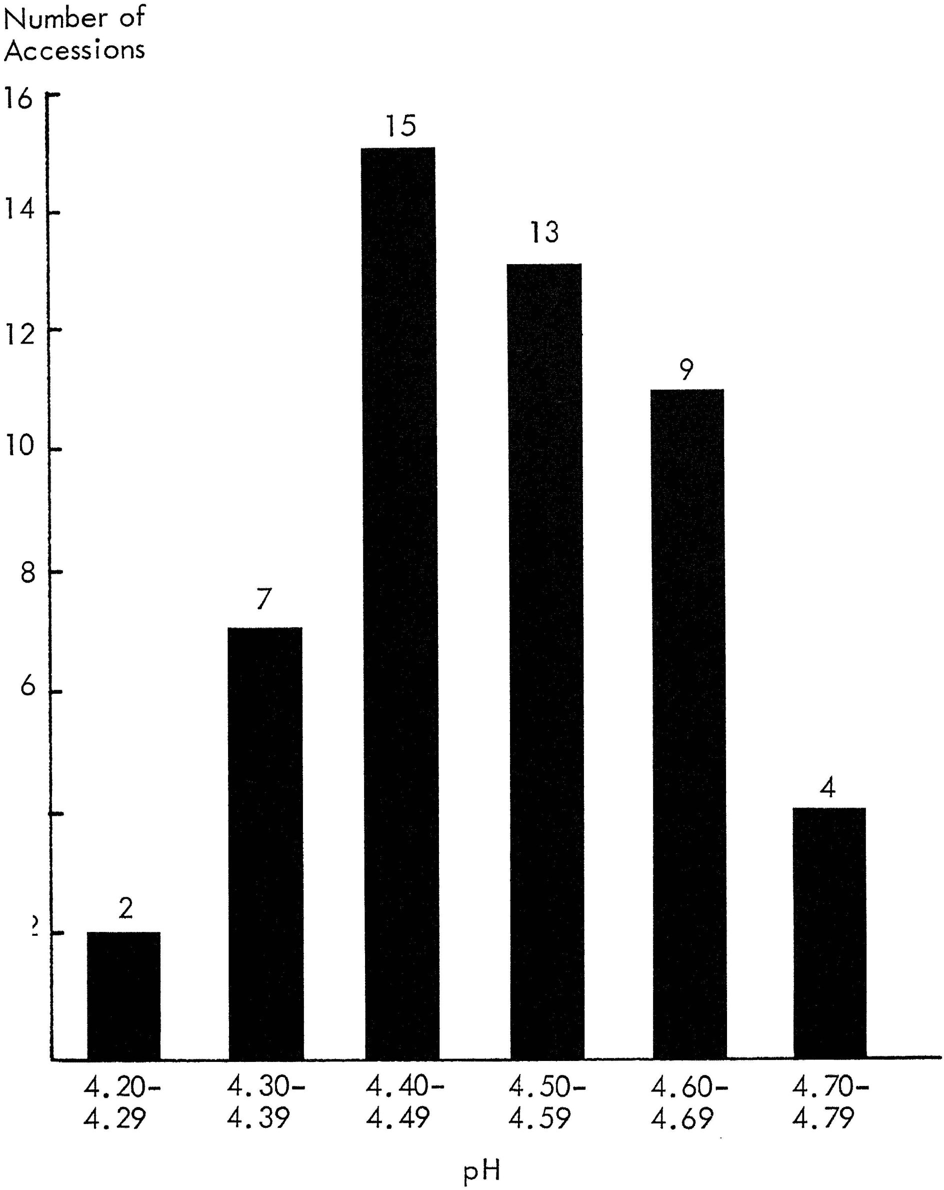
	pH	Missouri No.
Low pH Lines	4.27	28
	4.28	29
	4.30	138
	4.34	135
	4.36	129
	4.36	134
	4.36	171
	4.38	173
	4.39	16
High pH Lines	4.78	163
	4.73	122
	4.72	126
	4.71	169
Over-all Mean	4.50	

those reported by Lambeth *et.al.* (20) on commercial varieties of *L. esculentum* grown under similar conditions in 1962.

Nine of the accessions were found to possess pH values below 4.40 (Table 3). Of this number, two ranked in the 4.20-4.29 class while the remaining seven fell into the 4.30-4.39 class (Figure 2).

Four of the accessions fell into the highest pH class of 4.70-4.79 while 28 accessions were near the mean pH value of 4.50 (Figure 2). No lines were found with pH values above 4.80, as was the case in the *L. esculentum* group.

FIGURE 2
DISTRIBUTION OF 50 *L. ESCULENTUM* X *L. PIMPINELLIFOLIUM* LINES INTO pH CLASSES



Minimum, Maximum, and Mean pH Values of 25 Lycopersicon pimpinellifolium Lines

The extreme pH values of the 25 *L. pimpinellifolium* lines had a range from 4.33 to 4.95 with a mean value of 4.55. In the analysis of numerous *L. esculentum* varieties and lines, Saywell and Cruess (34), as well as Yamaguchi and Leonard (43), have reported values well below the 4.33 minimum found herein; however, the extreme high value of 4.95 was considerably higher than any value reported by these same workers. Adams (1) observed the highest pH among the other workers reporting extreme pH values; he reported a high of 4.80 in his study of pH variation in individual fruits.

As indicated in Table 4, accessions 82, 83, and 88 were found to have pH values below 4.40. All three of the accessions originated in Peru.

TABLE 4-EXTREME MEAN pH VALUES OF 25 LYCOPERSCION PIMPINELLIFOLIUM LINES

	pH	Missouri No.
Low pH Lines	4.33	82
	4.35	88
	4.36	83
High pH Lines	4.95	59
	4.93	65
Over-all Mean	4.55	

Of the 25 *L. pimpinellifolium* lines analyzed, numbers 59 and 65 possessed pH readings in the extremely high range of 4.90-4.99 (Table 4). It should be noted that the next highest values fell with the lower 4.60-4.69 class (Figure 3). The remaining wild accessions were grouped rather closely to the 4.55 mean pH value with 10 lines falling in the 4.50-4.59 class that also contained the mean.

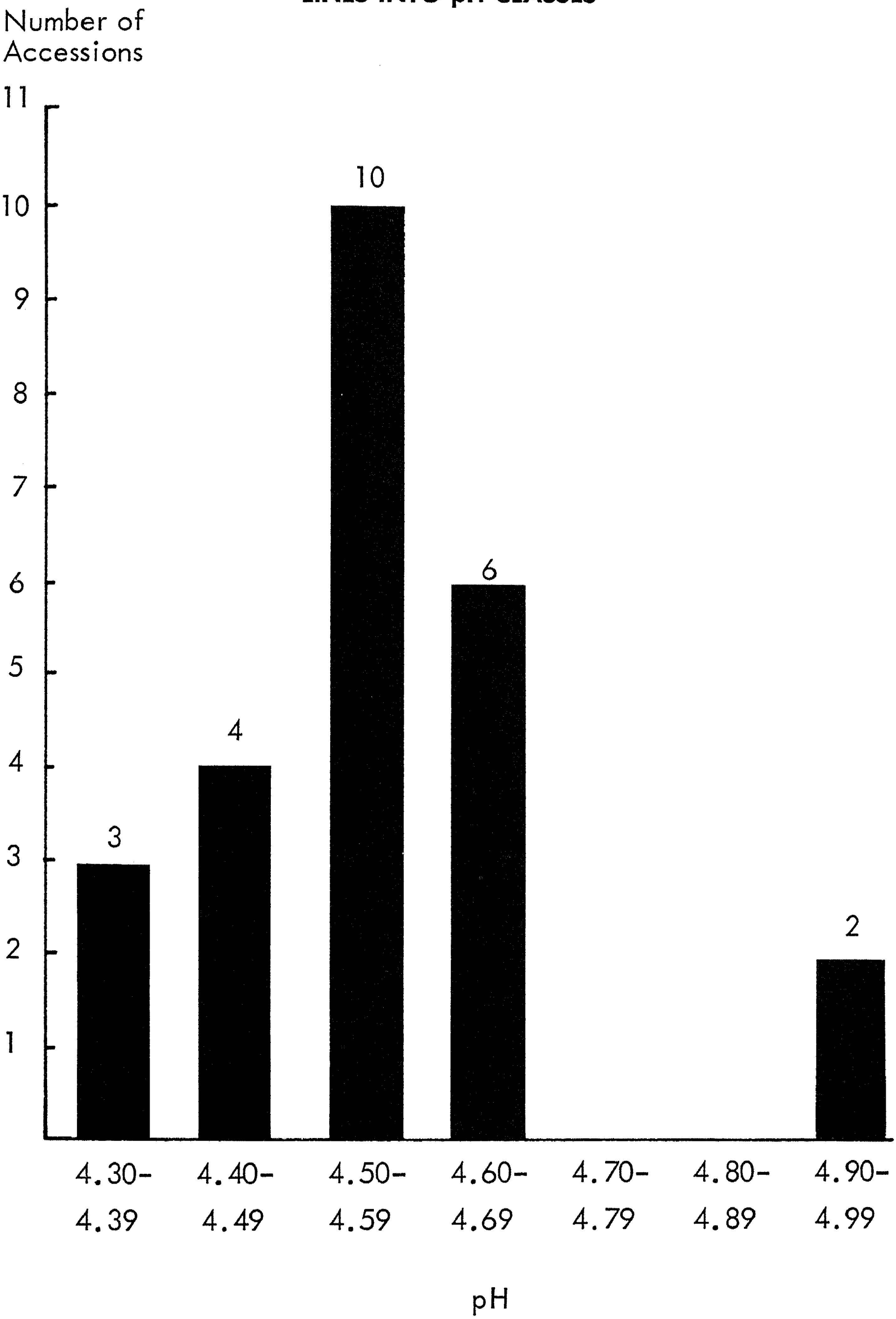
Comparisons of the Minimum, Maximum, and Mean pH Values of L. esculentum, L. esculentum x L. pimpinellifolium, and L. pimpinellifolium Lines

As indicated in Table 5, there is little difference in the overall mean pH values of the *L. esculentum*, *L. esculentum* x *L. pimpinellifolium*, and *L. pimpinelli-*

TABLE 5-COMPARISONS OF MINIMUM, MAXIMUM, AND MEAN pH VALUES OF 175 L. ESCULENTUM, 50 L. ESCULENTUM X L. PIMPINELLIFOLIUM, AND 25 L. PIMPINELLIFOLIUM LINES

Species	pH Values			Species Variation
	Low	High	Mean	
L. esculentum	4.26	4.82	4.53	0.56
L. esculentum X L. pimpinellifolium	4.27	4.78	4.50	0.51
L. pimpinellifolium	4.33	4.95	4.55	0.62

FIGURE 3
DISTRIBUTION OF 25 *L. PIMPINELLIFOLIUM* LINES INTO pH CLASSES



folium lines. This would suggest that selection for pH should be on an individual line basis rather than by species.

From the breeder's viewpoint, it would probably be best to select lines from the *L. esculentum* group because of their superior horticultural characteristics. For pH alone, the choice of a *L. pimpinellifolium* line would not be feasible due to extremely small fruit size. If used in breeding programs, several years would be required to transfer a hereditary factor to a commercially acceptable variety.

Titratable Acidity

Minimum, Maximum, and Mean Citric Acid Equivalent Values of 175 L. esculentum Lines

As indicated in Table 6, the percent citric acid values ranged from a low of 0.306 to a high of 0.907. The mean was 0.518. This range is comparable to the 0.26 to 0.81 range reported by Saywell and Cruess (34); however, both of the extreme values reported herein are relatively high when compared to those

TABLE 6–EXTREME MEAN CITRIC ACID EQUIVALENT VALUES OF 175 L. ESCULENTUM LINES

	Percent Acid	Missouri No.	Name
	0.907	89	
	.809	223	
	.770	236	
High Citric Acid Values	.747	31	
	.724	204	
	.714	202	
	.713	235	
	.710	98	
	.706	97	
	0.697	197	Stemless Penn Orange
	0.306	117	Merveille des Marches
	.324	90	
	.349	4	
	.361	2	Primrose Gage
	.370	6	
	.372	40	
	.374	198	Burgess Lemon
	.377	247	
Low Citric Acid Values	.382	186	
	.384	187	
	.387	18	Joffre
	.390	230	
	.391	226	
	.391	224	
	.391	26	
	.392	182	Doublerich
	.392	124	
	.395	216	
	0.399	150	Rutgers' Mould Res
Over-all Mean	0.518		

reported by Scott and Walls (35), Cameron (11), and Lambeth *et.al.* (20) for commercial varieties of *L. esculentum.*

Ten accessions possessed relatively high titratable acidity values (Table 6). Of the 10, five (numbers 31, 97, 98, 223, and 235) are also listed in Table 2 (page 14) which contains the low pH lines. Line number 89 from Peru showed the highest total acidity with a value of 0.907 while accession number 223 from El Salvador gave the second highest value with a 0.809 citric acid value. No named varieties were among the lines having high percent citric acid values. The remaining 147 accessions exhibited citric acid equivalent values near the mean 0.518 value (Figure 4).

Nineteen accessions had low titratable acidity (Table 6). Only four of these lines (numbers 2, 4, 90, and 117) are listed in Table 2 (page 14) which contains the high pH lines. The named varieties, Primrose Gage of India and Merveille des Marches of France, are high in pH as well as low in total acidity.

Minimum, Maximum, and Mean Citric Acid Equivalent Values of 50 L. esculentum X L. pimpinellifolium Lines

The 50 interspecific hybrids expressed a percent citric acid equivalent range from 0.392 to 1.000 (Table 7). The mean was 0.615. Thirty-six lines were within reasonable range of the mean value of 0.615 as indicated in Figure 5.

TABLE 7-EXTREME MEAN CITRIC ACID EQUIVALENT VALUES OF 50 L. ESCULENTUM X L. PIMPINELLIFOLIUM LINES

	Percent Acid	Missouri No.
High Acid Lines	1.000	29
	.888	16
	.869	129
	.839	28
	.824	171
	.789	172
	.786	154
	.773	152
	.772	162
	.726	134
	.716	130
	.709	135
	0.700	175
Low Acid Lines	0.392	120
Over-all Mean	0.615	

Thirteen lines expressed citric acid equivalent values above 0.700 (Table 7). Accession 29 possessed an extremely high titratable acidity value when compared to the other lines. Four lines fell into the 0.800-0.899 class including accession 28. It may be recalled that this same line also possessed a low pH value (Table 3,

FIGURE 4
DISTRIBUTION OF 175 *L. ESCULENTUM* LINES INTO CITRIC ACID EQUIVALENT CLASSES

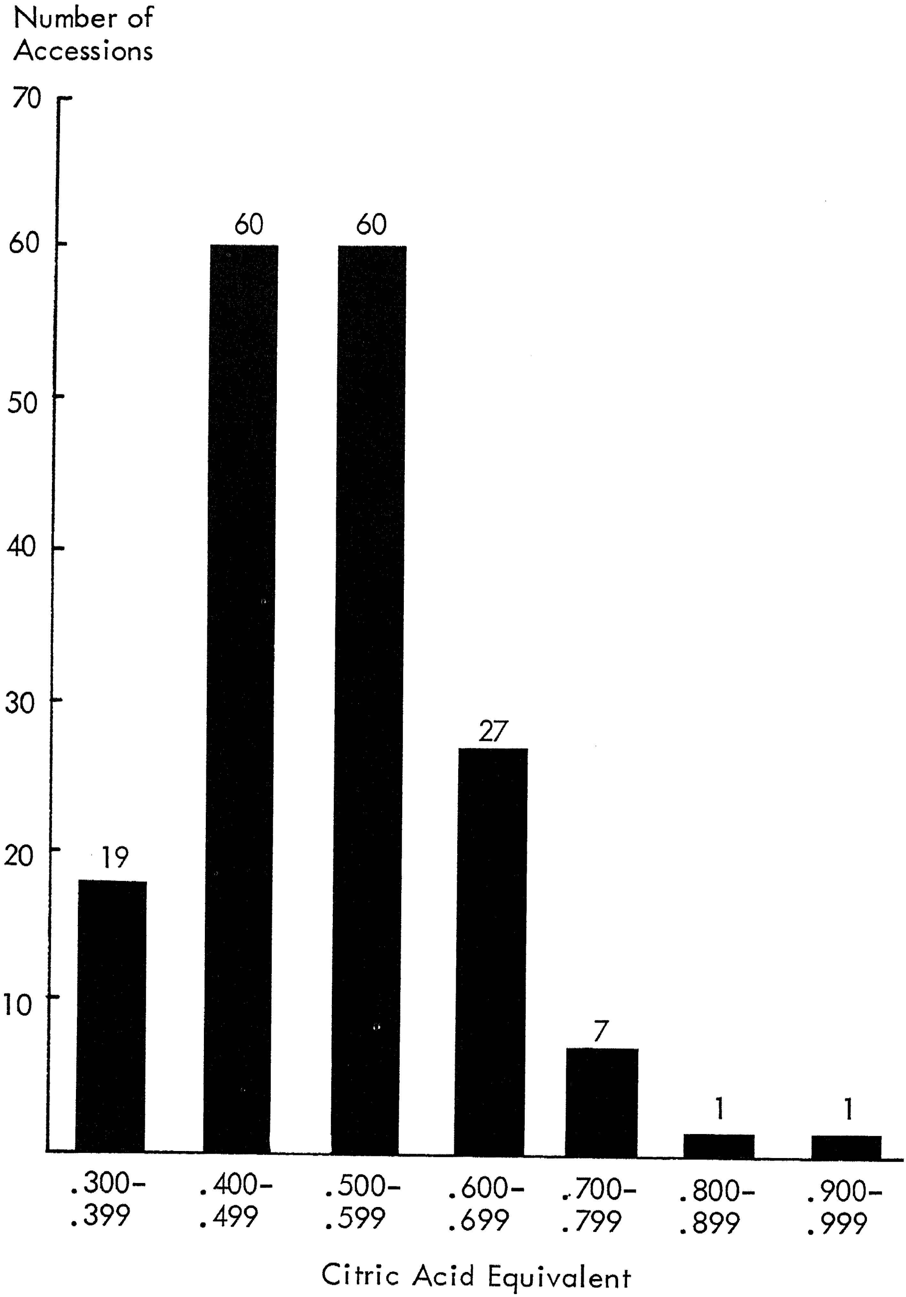
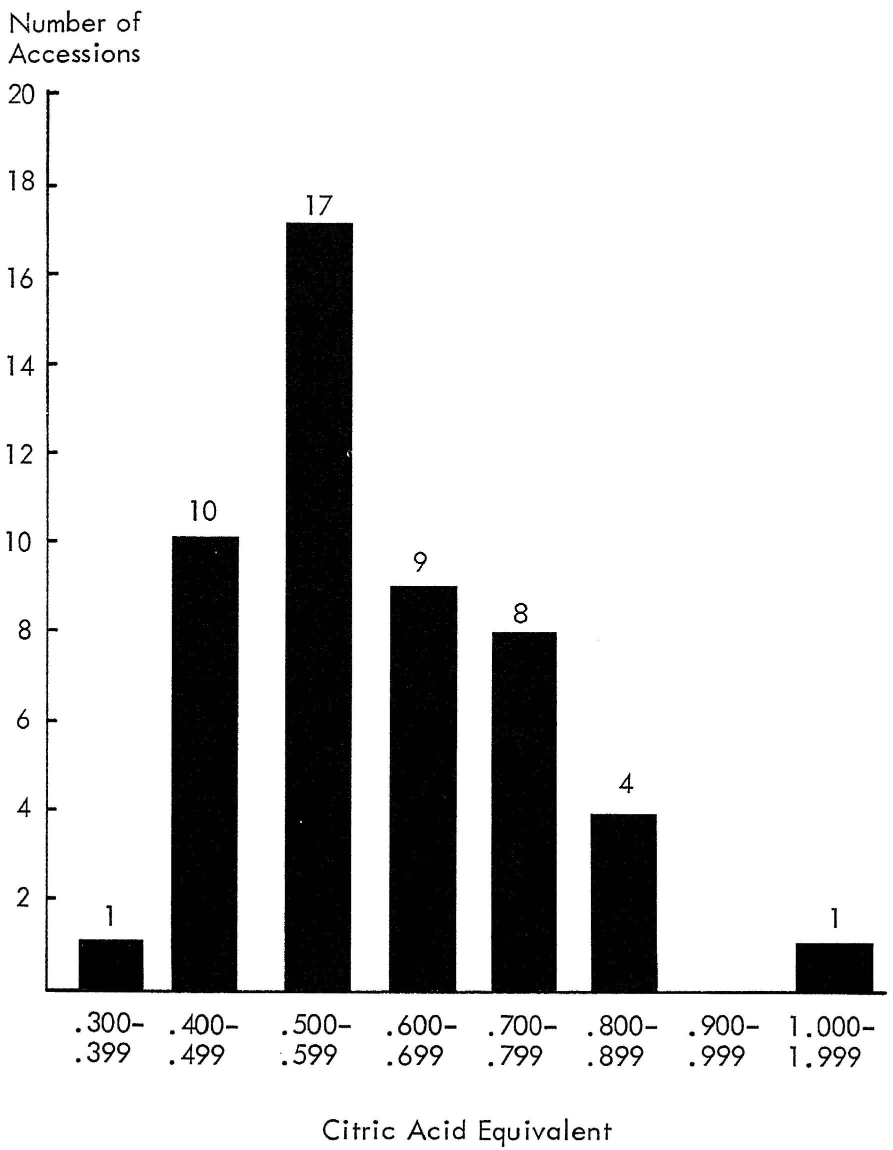


FIGURE 5
DISTRIBUTION OF 50 *L. ESCULENTUM* X *L. PIMPINELLIFOLIUM* LINES INTO CITRIC ACID EQUIVALENT CLASSES



pages 16). Likewise, accession 29, which exhibited the highest citric acid value of the hybrids (1.000), also had a low pH (4.28).

Accession 120 was the only line possessing a percent citric acid equivalent value below 0.400; its value was 0.392. Ten accessions, however, fell within the 0.400-0.499 class (Figure 5).

Minimum, Maximum, and Mean Citric Acid Equivalent Values of 25 L. pimpinellifolium Lines

The percent citric acid equivalent values of the 25 *L. pimpinellifolium* accessions ranged from a low of 0.422 to a high of 0.950 (Table 8).

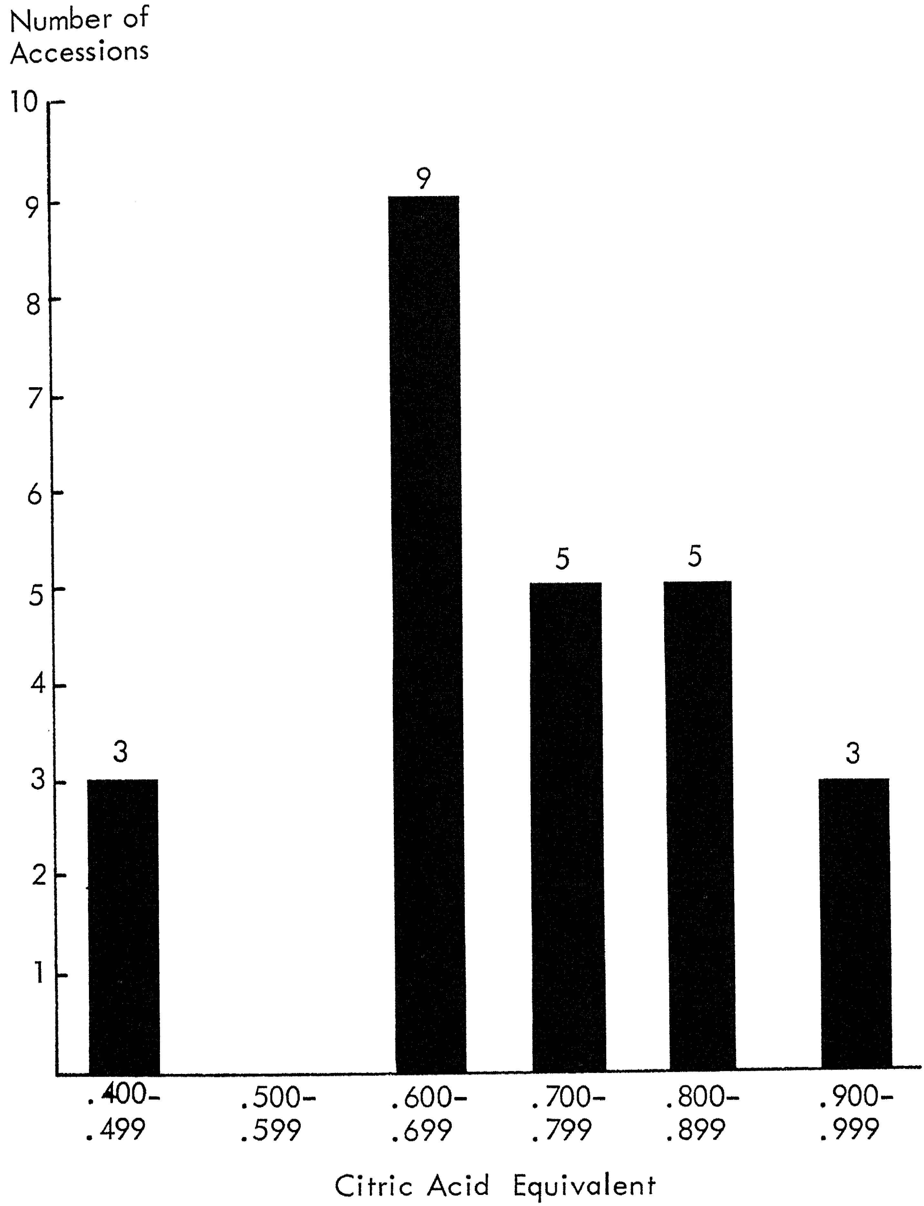
TABLE 8-EXTREME MEAN CITRIC ACID EQUIVAVLENT VALUES OF 25 *L. PIMPINELLIFOLIUM* LINES

	Percent Acid	Missouri No.
	0.950	56
	.918	88
	.906	58
	.894	82
	.826	72
	.817	69
High Acid Lines	.809	74
	.804	83
	.795	70
	.775	68
	.741	42
	.737	57
	0.736	73
	0.422	20
Low Acid Lines	.448	65
	0.467	59
Over-all Mean	0.720	

The high value of 0.950 was considerably higher than the 0.416, 0.498, and 0.50 values reported by Scott and Walls (35), Lambeth *et al.* (20), and Cameron (11), respectively, in their studies of *L. esculentum* varieties. Saywell and Cruess (34), however, reported a high of 0.810 percent citric acid equivalent. Two other lines possessed values above 0.900 as indicated in Table 8. Of the remaining accessions, the majority of the values fell closely around the mean value of 0.720 percent citric acid (Figure 6).

Three lines exhibited acidity values within the 0.400-0.499 class; none, however, fell below the 0.400 value as was the case in the *L. esculentum* lines (Table 6). The lowest value of 0.422 reported herein is considerably higher than the 0.273 and 0.361 lows reported by Scott and Walls (35) and Lambeth *et al.* (20) in their studies of *L. esculentum* varieties. Two of these lines possessing low acidity values (numbers 59 and 65) also expressed high pH values.

FIGURE 6
DISTRIBUTION OF 25 *L. PIMPINELLIFOLIUM LINES* INTO CITRIC ACID EQUVIALENT CLASSES



Comparisons of Percent Citric Acid Equivalent Values of L. esculentum, L. esculentum X L. pimpinellifolium, and L. pimpinellifolium Lines

Even though each species expressed variable and extreme total acidity values, the compared ranges show relatively little difference among species (Table 9).

TABLE 9-COMPARISONS OF MINIMUM, MAXIMUM, AND MEAN PER CENT CITRIC ACID EQUIVALENT VALUES OF L. ESCULENTUM, L. ESCULENTUM X L. PIMPINELLIFOLIUM, AND L. PIMPINELLIFOLIUM LINES

Species	Percent Acid Low	High	Mean	Species Variation
L. esculentum	0.306	0.907	0.518	0.601
L. esculentum X L. pimpinellifolium	.392	1.000	.615	.608
L. pimpinellifolium	0.422	0.950	0.720	0.528

The data indicate, however, that the over-all mean acidity value of the *L. pimpinellifolium* group is definitely greater than that of the *L. esculentum* group. This would indicate that, collectively, the wild accessions are higher in titratable acidity than the *L. esculentum* lines. The work of Thompson *et al.* (40) in 1964 indicated that the locular percentage of small-fruited, high-acid lines was nearly twice that of larger-fruited selections. As a result, the acidity of small-fruited lines when expressed as a percentage of fresh fruit weight should exhibit a quantitative increase when compared to large-fruited lines, even when the genotypes for acidity may be identical.

Soluble Solids (Percent Brix)

Minimum, Maximum, and Mean Brix Values of 175 L. esculentum Lines

Table 10 indicates that the Brix values of the 175 *L. esculentum* lines ranged from a low of 4.05 to a high of 8.92 percent. The mean was 5.86. The extreme values are quite high when compared to the varieties reported by Scott and Walls (35), Cameron (11), and Lambeth *et.al.* (20).

As indicated in Table 10, eleven lines showed relatively high Brix values. Of this number, five fell in the 8.00-8.99 class while the remaining six fell in the 7.00-7.99 class (Figure 7). Stemless Penn Orange (number 197), with a Brix value of 7.52 percent, was the only named variety having a value above 7.00. It should be noted that this same variety possessed one of the lower pH and higher titratable acidity values as well (Table 2 and Table 7).

Seventeen lines fell into the lowest Brix class of 4.00-4.99 percent (Figure 7). The majority of the values were grouped in the upper portion of the class; however, accession 156 from Turkey had a Brix value of 4.05 percent, which was considerably lower than that of the remaining low sugar lines (Table 10).

FIGURE 7
DISTRIBUTION OF 175 *L. ESCULENTUM* LINES INTO PERCENT BRIX CLASSES

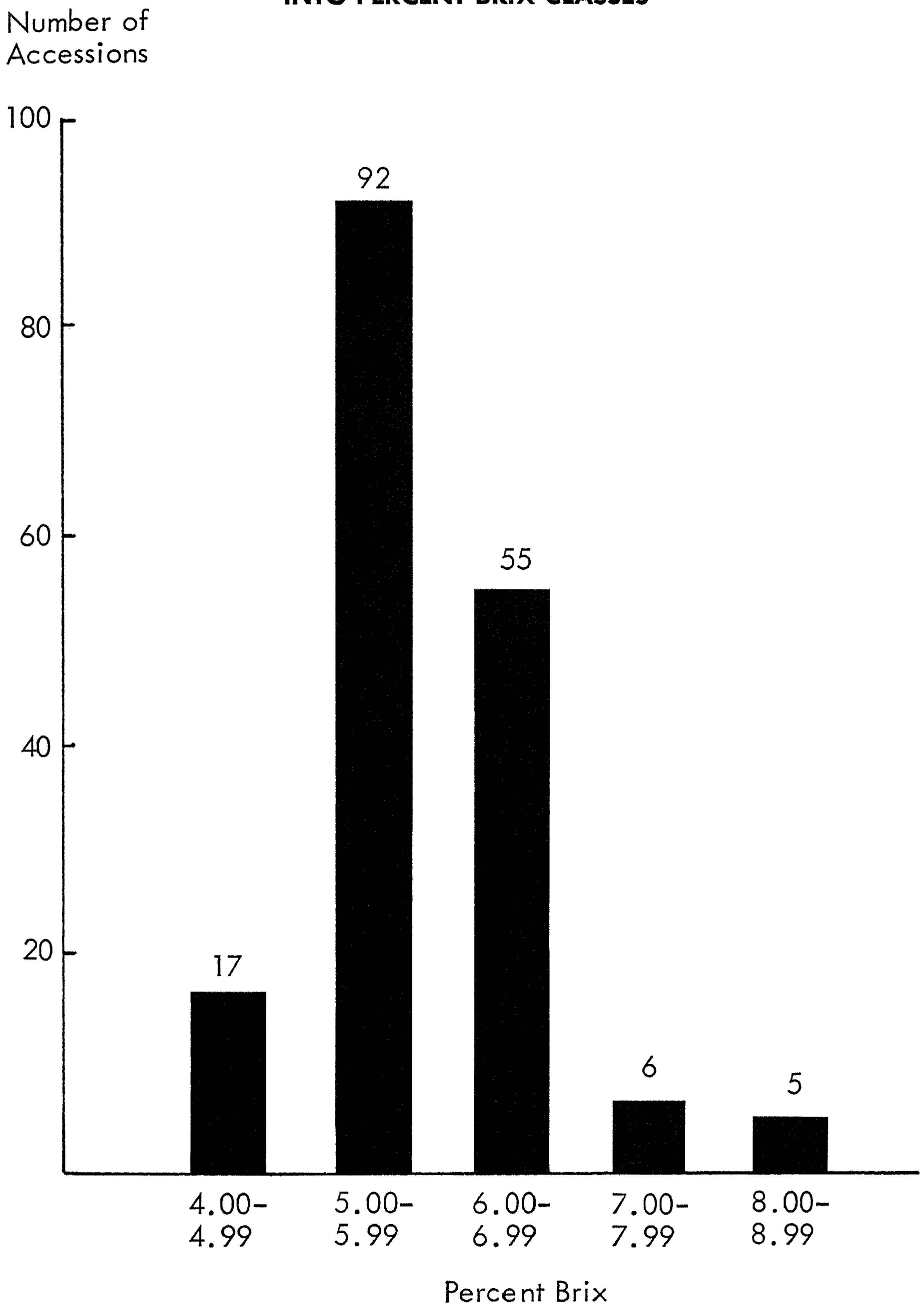


TABLE 10-EXTREME MEAN PER CENT BRIX VALUES OF 175 L. ESCULENTUM LINES

	Percent Brix	Missouri No.	Name
High Brix Lines	8.92	214	
	8.58	208	
	8.56	210	
	8.25	205	
	8.16	212	
	7.61	213	
	7.56	211	
	7.52	197	Stemless Penn Orange
	7.22	209	
	7.20	207	
	7.17	215	
Low Brix Lines	4.05	156	
	4.37	39	Aurore
	4.44	63	
	4.47	19	Plerette
	4.47	131	
	4.57	186	
	4.63	27	
	4.72	48	
	4.72	220	
	4.73	44	
	4.75	37	
	4.77	155	
	4.83	225	
	4.90	40	
	4.91	239	
	4.92	64	
	4.98	11	
Over-all Mean	5.86		

Minimum, Maximum, and Mean Brix Values of 50 L. esculentum X L. pimpinellifolium Lines

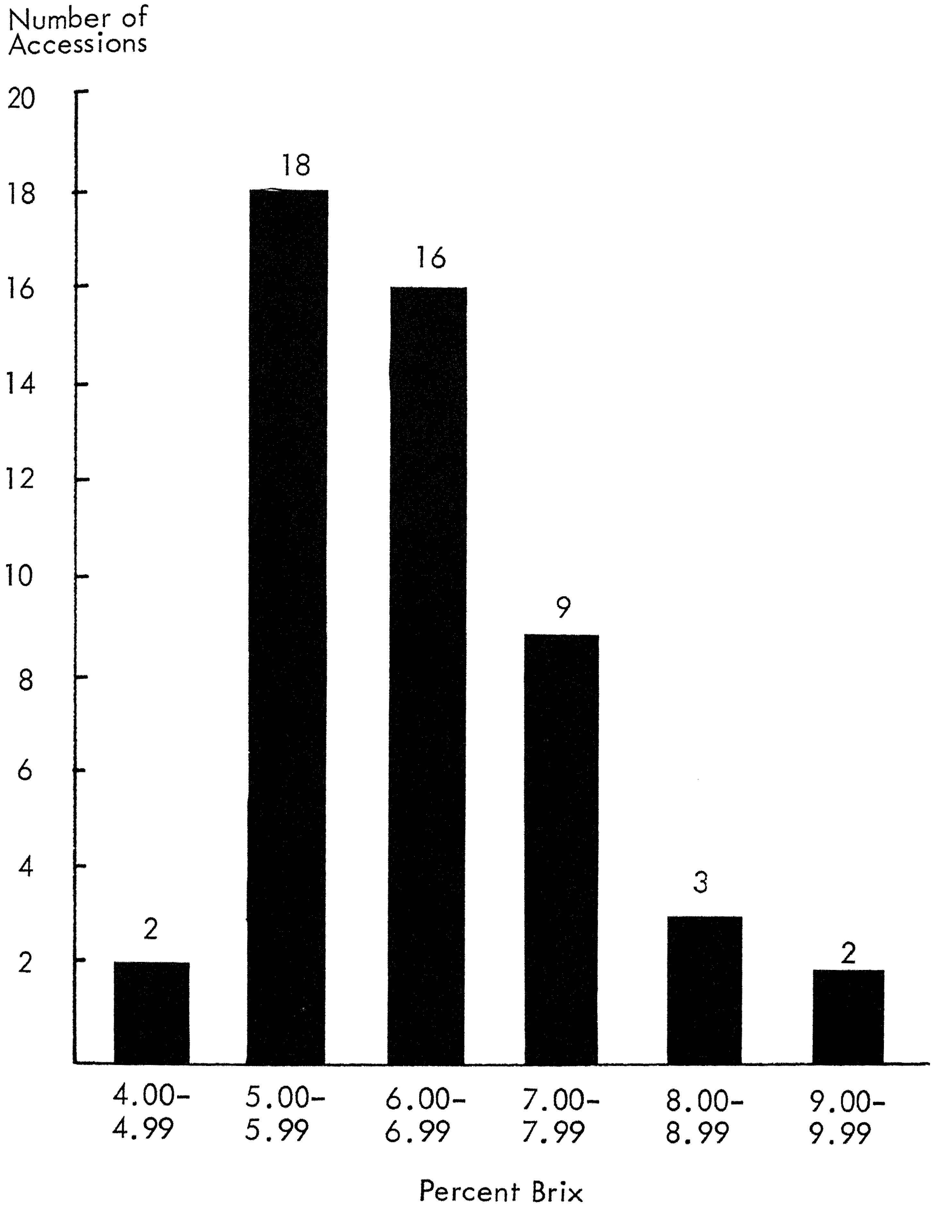
Five interspecific hybrid accessions expressed relatively high Brix values (Table 11). Accession 162 of Mexico showed the highest value (9.16 percent) while accession 122 of Columbia had the second highest value (9.06 percent).

As indicated in Table 11, two accessions expressed Brix values below 5.00 percent. Eighteen accessions, however, fell within the 5.00-5.99 class (Figure 8).

TABLE 11-EXTREME MEAN BRIX VALUES OF 50 L. ESCULENTUM X L. PIMPINELLIFOLIUM LINES

	Percent Brix	Missouri No.
High Brix Lines	9.16	162
	9.06	122
	8.96	163
	8.34	81
	8.26	84
Low Brix Lines	4.93	148
	4.94	138
Over-all Mean	6.54	

FIGURE 8
DISTRIBUTION OF 50 *L. ESCULENTUM* X *L. PIMPINELLIFOLIUM* LINES INTO PERCENT BRIX CLASSES



Minimum, Maximum, and Mean Brix Values of 25 L. pimpinellifolium Lines

The Brix range of the 25 *L. pimpinellifolium* lines varied from 6.02 to 9.86 percent with a mean value of 7.65 (Table 12). It should be noted that the lowest

TABLE 12-EXTREME MEAN BRIX VALUES OF 25 L. PIMPINELLIFOLIUM LINES

	Percent Brix	Missouri No.
High Brix Lines	9.86	59
	9.82	92
	9.13	65
	8.23	66
	8.12	73
	8.11	56
	8.09	58
	8.01	88
Low Brix Lines	6.02	79
	6.42	20
	6.45	71
	6.56	70
	6.61	67
	6.91	87
	6.96	74
Over-all Mean	7.65	

value of 6.02 percent exceeds all of the high Brix values reported in the literature review (11, 20, 34, 35). Lambeth *et.al.* (20) reported the highest Brix reading of all previous workers with a 5.12 percent value for the *L. esculentum* commercial variety, Orange Jubilee. The high Brix value of 9.86 percent reported herein is nearly twice that of the 5.12 value.

The over-all range in Brix readings is relatively small as indicated in Figure 9. Twenty-two of the lines possessed Brix values between 6.00 and 8.99 while the remaining three lines exhibited values above 9.00 percent. Two of these lines (numbers 59 and 65) also expressed high pH (Table 4) as well as relatively low titratable acidity values.

Comparisons of the Minimum, Maximum, and Mean Brix Values of L. esculentum, L. esculentum x L. pimpinellifolium, and L. pimpinellifolium Lines

Table 13 indicates the extreme variation in percent Brix values within each species. The *L. pimpinellifolium* group showed a 3.84 difference while the variation in the *L. esculentum* group was 4.87. The variation in the *L. esculentum* x *L. pimpinellifolium* lines fell between that for the *L. pimpinellifolium* and the *L. esculentum* lines with a 4.23 percent Brix difference.

The *L. pimpinellifolium* lines showed the highest over-all mean Brix value (7.65 percent). The *L. esculentum* lines ranked lowest with a mean of 5.86 per-

FIGURE 9
DISTRIBUTION OF 25 *L. PIMPINELLIFOLIUM* LINES INTO PERCENT BRIX VALUES

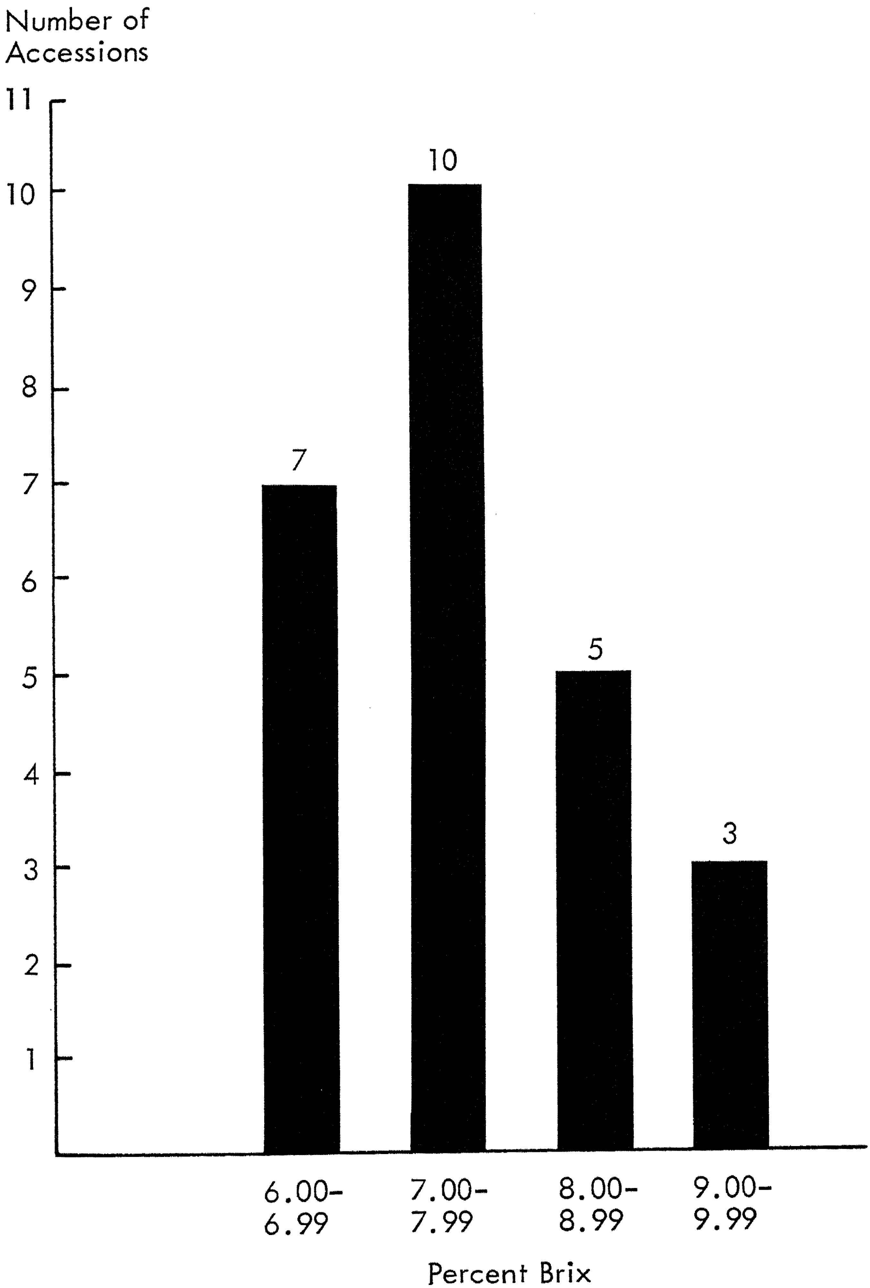


TABLE 13-COMPARISONS OF MINIMUM, MAXIMUM, AND MEAN BRIX VALUES OF 175 L. ESCULENTUM, 50 L. ESCULENTUM X L. PIMPINELLIFOLIUM, AND 25 L. PIMPINELLIFOLIUM LINES

Species	Percent Brix Low	Percent Brix High	Percent Brix Mean	Species Variation
L. esculentum	4.05	8.92	5.86	4.87
L. esculentum X L. pimpinellifolium	4.93	9.16	6.54	4.23
L. pimpinellifolium	6.02	9.86	7.65	3.84

cent while the interspecific hybrid group mean was intermediate with a 6.54 percent value. It is interesting to note that the over-all mean Brix values of the three species fell into the identical order as their mean percent citric acid values, discussed in the previous section.

Sugar-Acid Ratio

Minimum, Maximum and Mean Sugar-Acid Ratios of 175 L. esculentum Lines

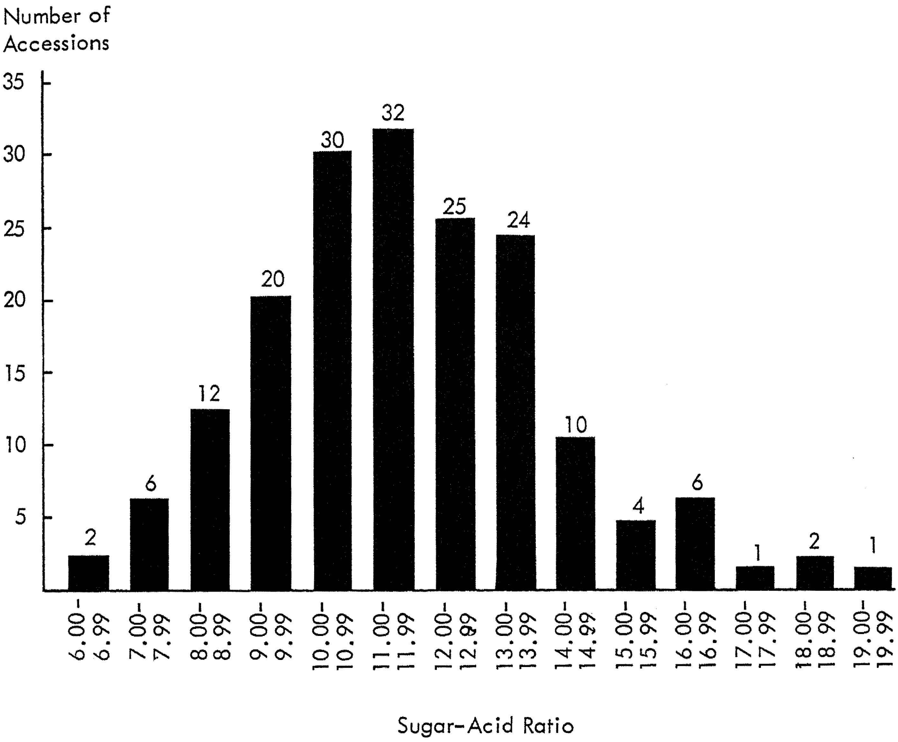
Table 14 indicates a sugar-acid ratio range from 6.72 to 19.02 and a mean value of 12.07 for the 175 *L. esculentum* lines. The low ratio of 6.72 is in close

TABLE 14-EXTREME MEAN SUGAR-ACID RATIOS OF 175 L. ESCULENTUM LINES

	Sugar-Acid Ratio	Missouri No.	Name
High Sugar-Acid Lines	19.02	117	Merveille des Marches
	18.40	214	
	18.02	90	
	17.71	205	
Low Sugar-Acid Lines	6.72	63	
	6.95	89	
	7.16	31	
	7.51	64	
	7.71	223	
	7.72	202	
	7.98	49	
	7.99	98	
Over-all Mean	12.07		

agreement with the 6.9 and 7.28 low ratios reported by Scott and Walls (35) and Lambeth *et.al.* (20), respectively; however, the highest ratio of 19.02 reported herein was considerably higher than the 10.8 and 13.11 high values reported by these same workers. As indicated in Figure 10, the remaining lines not possessing extreme sugar-acid ratio values were grouped about the 12.07 mean value, thus resembling a normal distribution.

FIGURE 10
DISTRIBUTION OF 175 *L. ESCULENTUM* LINES INTO SUGAR-ACID RATIO CLASSES



Minimum, Maximum, and Mean Sugar-Acid Ratios of 50 L. esculentum x L. pimpinellifolium Lines

Figure 11 shows that six classes had five or more frequencies and six classes had three or less frequencies which indicated wide and inconsistent variation among the lines for the sugar-acid ratio quality.

As indicated in Table 15, six lines possessed sugar-acid ratios that fell into the lowest class range of 7.00-7.99. Three lines, meanwhile exhibited sugar-acid ratios above 17.00. Accession 122 of Columbia possessed the highest mean sugar-acid ratio (19.33); accession 163 of New Caledonia ranked second with a value of 18.34. Line 34 from Venezuela had a 17.24 value and ranked third.

It should be noted that the lines possessing the highest sugar-acid ratios (lines 122 and 163) had high pH values as well (Table 3). Likewise, these same two lines ranked second and third high, respectively, in Brix values (Table 11).

FIGURE 11
DISTRIBUTION OF 50 *L. ESCULENTUM* X *L. PIMPINELLIFOLIUM* LINES INTO SUGAR-ACID RATIO CLASSES

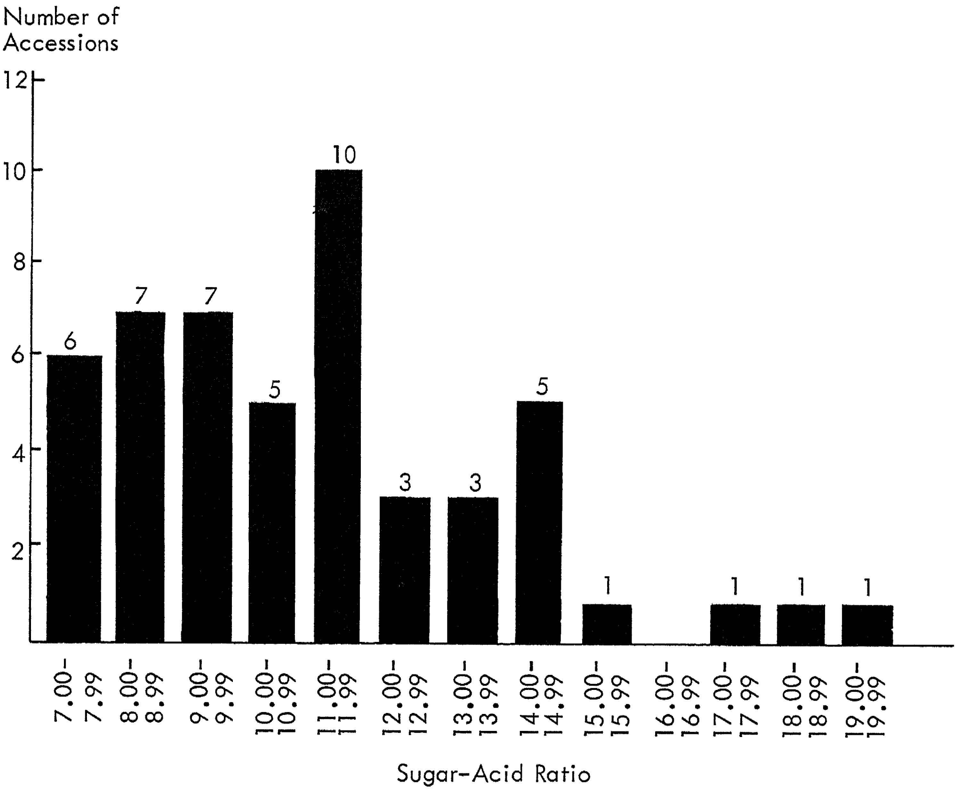


TABLE 15-EXTREME MEAN SUGAR-ACID RATIOS OF 50 L. ESCULENTUM X L. PIMPINELLIFOLIUM LINES

	Sugar-Acid Ratio	Missouri No.
High Sugar-Acid Lines	19.33	122
	18.34	163
	17.24	34
Low Sugar-Acid Lines	7.24	29
	7.25	16
	7.39	28
	7.62	135
	7.69	134
	7.77	166
Over-all Mean	11.20	

Minimum, Maximum, and Mean Sugar-Acid Ratios of 25 L. pimpinellifolium Lines

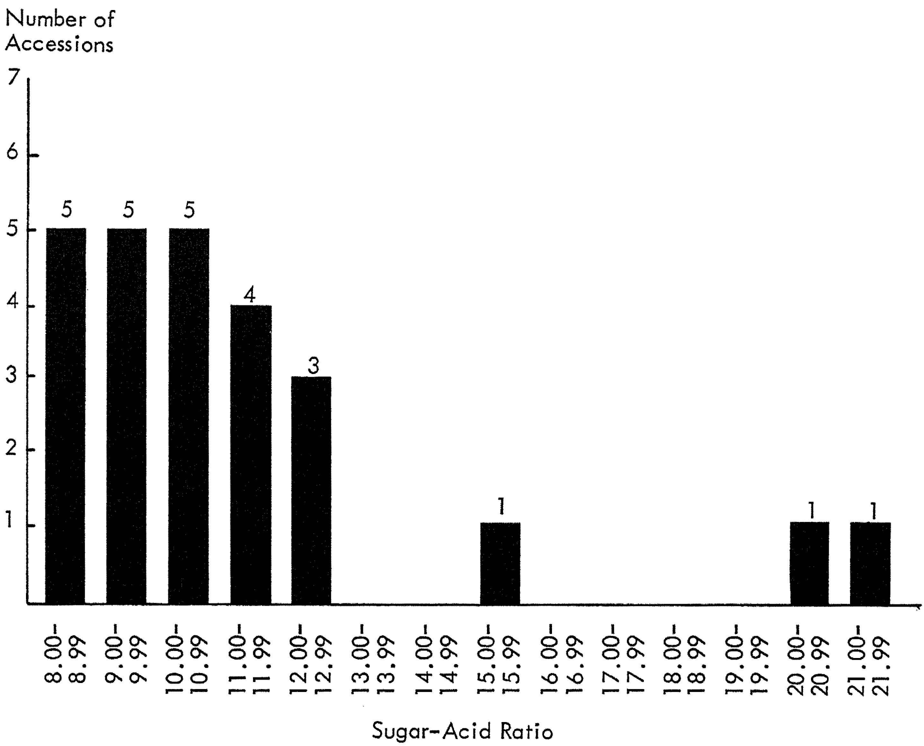
As indicated in Table 16, the sugar-acid ratios of the 25 wild accessions ranged from a low of 8.33 to a high of 21.80. The mean sugar-acid ratio was 11.25.

TABLE 16–EXTREME SUGAR-ACID RATIOS OF 25 L. PIMPINELLIFOLIUM LINES

	Sugar-Acid Ratio	Missouri No.
High Sugar-Acid Lines	21.80	59
	20.36	65
	15.08	20
Low Sugar-Acid Lines	8.33	70
	8.78	88
	8.85	79
	8.87	74
	8.92	58
Over-all Mean	11.25	

The low value of 8.33 was within reasonable agreement of Scott and Walls (35) and Lambeth *et.al.* (20) who reported on *L. esculentum* lines. The high value of 21.80 reported herein, however, is much higher than the values reported for commercial varieties. Twenty-two of the 25 accessions fell within the relatively small range of 8.00 to 12.99 while the remaining three lines expressed marked deviations from the mean (Figure 12). Accession 59, which has the highest sugar-acid ratio, also possessed the highest pH, the highest sugar content; and the third lowest total acidity value (Table 4, Table 8, and Table 12). This suggests a possible inverse correlation between the sugar content and titratable acidity. As stated previously, Scott and Walls (35) found the sugar content to be inversely correlated with total acidity. As a result, the expected sugar-acid ratios would have wider variations than either the acidity or sugar concentrations alone.

FIGURE 12
DISTRIBUTION OF 25 *L. PIMPINELLIFOLIUM* LINES INTO SUGAR-ACID RATIO CLASSES



Comparisons of Sugar-Acid Ratios of L. esculentum, L. esculentum x L. pimpinellifolium, and L. pimpinellifolium Lines

As indicated in Table 17, the *L. pimpinellifolium* group contained the highest sugar-acid ratio line and the *L. esculentum* group had the lowest sugar-acid ratio line. The interspecific hybrid group had sugar-acid ratio extremes which were intermediate between the wild accession and common tomato groups.

Even though considerable variation in sugar-acid ratios exists within a species, there is little difference in mean values of the ratios among the species when considered collectively. This would again suggest that selection for particular sugar-acid ratio values should be on an individual line basis rather than by species. The *L. esculentum* group would probably offer the best lines for further breeding work due to their superior horticultural characteristics.

Little research has been conducted regarding the ideal sugar-acid ratio for either fresh market or canning lines. Scott and Walls (35) found lines possessing

TABLE 17–COMPARISONS OF MINIMUM, MAXIMUM, AND MEAN SUGAR-ACID RATIOS OF *L. ESCULENTUM*, *L. ESCULENTUM* X *L. PIMPINELLIFOLIUM*, AND *L. PIMPINELLIFOLIUM* LINES

Species	Sugar-Acid Ratio Low	High	Mean	Species Variation
L. esculentum	6.72	19.02	12.07	12.30
L. esculentum X *L. pimpinellifolium*	7.24	19.33	11.20	12.09
L. pimpinellifolium	8.33	21.80	11.25	13.47

high sugar-acid ratios to be mild and bland in taste and low sugar-acid ratios to be acid and tart; thus, lines expressing medium to high sugar-acid values would probably be suited for fresh market consumption while lines expressing relatively low sugar acid ratios would be desirable for canning and processing.

L. Esculentum Lines Exhibiting Potential Use in Canning and Processing

Since acidity is so important in the production of high quality processed tomato products, the following tables have been constructed to indicate lines possessing desirable acidity characteristics for possible use in the processing industry. Accession 197, a yellow-pigmented variety, is included in Table 18 even though its citric acid equivalent value of 0.697 percent is probably not significantly lower than 0.700 percent. Besides having a low pH and a moderately high

TABLE 18–*L. ESCULENTUM* LINES POSSESSING pH VALUES BELOW 4.40 AND PERCENT CITRIC ACID VALUES ABOVE 0.700

Missouri No.	pH	Citric Acid (%)	Soluble Solids (% Brix)	Sugar-Acid Ratio
98	4.26	0.710	5.67	7.99
97	4.31	.706	6.22	8.82
31	4.34	.747	5.36	7.16
235	4.35	.713	5.65	8.07
197*	4.38	.697	7.52	10.78
223	4.38	0.809	6.12	7.71

*Named variety (Stemless Penn Orange)

total acidity value, the variety had a sugar content (7.52) that exceeded that of the other lines under consideration. In considering lines for processing, however, low pH and high total acidity are more important than the sugar content as sucrose can be readily added during the canning process.

No attempt will be made to discuss lines possessing desirable qualities for the fresh market. For customers demanding the acid or tart-like fruit, lines having low pH, high titratable acidity, and low sugar content would be recommended; for those preferring the bland and sweet-like fruit, lines possessing high pH, low total acidity, and high sugar would be most desirable. Further work needs to be done to determine the proper proportions of sugar and acidity preferred by the majority of consumers of fresh fruit.

L. Esculentum x L. Pimpinellifolium Lines Exhibiting Potential for Breeding Improved Canning Varieties

Table 19 contains the interspecific hybrid lines possessing both pH values below 4.40 and percent citric acid values above 0.700. Other lines meeting only one of the qualities listed above should probably be considered for future use in breeding programs.

TABLE 19–L. ESCULENTUM X L. PIMPINELLIFOLIUM LINES POSSESSING pH VALUES BELOW 4.40 AND CITRIC ACID EQUIVALENT VALUES ABOVE 0.700 PERCENT

Missouri No.	pH	Citric Acid (%)	Soluble Solids (% Brix)	Sugar-Acid Ratio
28	4.27	0.839	6.20	7.39
29	4.28	1.000	7.11	7.24
135	4.34	.709	5.40	7.62
129	4.36	.869	6.52	8.42
134	4.36	.726	5.54	7.69
171	4.36	.824	6.80	8.28
16	4.39	.888	6.33	7.25

The fruit size of the hybrid lines, ranging from one-half to 1.5 inches in diameter, limits their value as commercial lines; however, they could be used in breeding programs to incorporate genes for specific quality factors into commercial varieties.

L. Pimpinellifolium Lines Possessing Quality Factors Desired in Canning Varieties

As indicated in Table 20, the three *L. pimpinellifolium* lines possessing pH values below 4.40 also had relatively high total acidity values. The three lines, as well as the entire group of wild accessions, possessed moderately high sugar contents when compared to the *L. esculentum* and interspecific hybrid groups. As indicated previously, the over-all mean percent Brix value of the *L pimpinellifolium* group was 7.65 while the *L. esculentum* and the interspecific hybrid group possessed 5.86 and 6.54 percent Brix values, respectively. This may indicate that the high-acid wild accessions when considered collectively possess more sugar than the *L. esculentum* and *L. esculentum* X *L. pimpinellifolium* lines.

The *L. pimpinellifolium* lines are limited in use due to their extremely small fruit size. Many, however, have been and are presently being used in breeding for disease resistance. The lines possessing desirable quality characteristics, such as those listed in Table 20, may also be useful in breeding better canning varieties.

TABLE 20-L. PIMPINELLIFOLIUM LINES EXHIBITING pH VALUES BELOW 4.40 AND CITRIC ACID VALUES ABOVE 0.700 PERCENT

Missouri No.	pH	Citric Acid (%)	Soluble Solids (% Brix)	Sugar-Acid Ratio
82	4.33	0.894	9.82	11.00
88	4.35	.918	8.01	8.78
83	4.36	0.804	7.76	9.67

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APPENDIX

TABLE 21-FRUIT QUALITY ATTRIBUTES OF 250 TOMATO ACCESSIONS
MEAN VALUES

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
79532	1	Peru		4.51	0.697	7.78	11.43
91458	2	India	Primrose Gage	4.70	.361	5.92	16.41
91907	3	Bulgaria		4.54	.561	5.96	10.64
91912	4	Bulgaria		4.75	.349	5.57	16.05
92853	5	China		4.53	.526	5.94	11.29
92864	6	China		4.61	.370	5.10	13.74
92866	7	China		4.50	.516	5.72	11.12
95586	8	Manchuria		4.50	.503	5.20	10.36
95588	9	Manchuria		4.45	.576	5.77	10.08
95591	10	Manchuria		4.42	.573	5.72	9.96
99782	11	Peru		4.40	.600	4.98	8.35
102713	12	U.S.S.R.	Tshudorynka	4.60	.511	6.00	11.74
102717	13	U.S.S.R.		4.61	.466	5.21	11.36
102721	14	U.S.S.R.		4.64	.458	6.03	13.42
103055	15	China		4.42	.619	5.71	9.28
108245	16	Germany		4.39	.888	6.33	7.25
109315	17	Turkey		4.62	.531	6.52	12.31
109833	18	Morocco	Joffre	4.65	.387	5.24	13.38
109835	19	Morocco	Plerette	4.52	.417	4.47	10.72
110595	20	England		4.62	.422	6.42	15.08

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
114967	21	India		4.50	.656	5.92	9.03
115201	22	U.S.S.R.	First Early	4.43	.571	5.13	8.98
115219	23	U.S.S.R.	Reine des Hatives	4.57	.459	5.16	11.24
115872	24	U.S.S.R.	Chudo Rinka	4.57	.515	5.91	11.45
116526	25	India		4.65	.406	5.70	14.11
118325	26	Brazil		4.66	.391	5.24	13.72
118328	27	Brazil		4.55	.446	4.63	10.34
118405	28	Venezuela		4.27	.839	6.20	7.39
118407	29	Venezuela		4.28	1.000	7.11	7.24
118782	30	Venezuela		4.49	.560	5.45	9.72
118785	31	Venezuela		4.34	.747	5.36	7.16
119104	32	Brazil		4.47	.577	5.60	10.00
119105	33	Brazil		4.55	.492	5.11	10.46
119214	34	Venezuela		4.66	.408	7.01	17.24
119778	35	Argentina		4.52	.557	5.86	10.83
120263	36	Turkey		4.51	.612	5.57	9.11
120278	37	Turkey		4.53	.523	4.75	9.55
121664	38	Canada	Bestal	4.61	.480	5.78	12.14
123433	39	Morocco	Aurore	4.54	.458	4.37	9.91
124036	40	Argentina		4.60	.372	4.90	13.32
124038	41	Peru		4.58	.512	5.64	11.26
124039	42	Peru		4.52	.741	7.64	10.94

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
124132	43	India		4.50	.503	5.86	11.79
124133	44	India		4.47	.449	4.73	10.72
124165	45	Venezuela		4.59	.431	5.62	13.10
124581	46	India		4.63	.468	5.37	11.41
126407	47	Panama		4.44	.520	5.08	9.80
126408	48	Panama		4.51	.531	4.72	8.86
126409	49	Peru		4.44	.648	5.18	7.98
126411	50	Peru		4.45	.630	5.80	9.20
126413	51	Peru		4.56	.585	5.70	9.90
126419	52	Peru		4.60	.621	6.61	10.65
126423	53	Peru		4.45	.662	6.03	9.22
126424	54	Peru		4.59	.456	6.47	14.19
126425	55	Peru		4.44	.612	6.32	10.43
126430	56	Peru		4.52	.950	8.11	9.10
126432	57	Peru		4.52	.737	7.19	10.00
126433	58	Peru		4.47	.906	8.09	8.92
126436	59	Peru		4.95	.467	9.86	21.80
126908	60	Peru		4.61	.603	5.52	9.21
126916	61	Peru		4.45	.510	5.30	10.42
126920	62	Peru		4.43	.555	5.00	9.03
126921	63	Peru		4.34	.665	4.44	6.72

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
126922	64	Peru		4.30	.666	4.92	7.51
126924	65	Peru		4.93	.448	9.13	20.36
126925	66	Peru		4.46	.678	8.23	12.18
126927	67	Peru		4.67	.664	6.61	10.34
126931	68	Peru		4.61	.775	7.41	9.58
126932	69	Peru		4.53	.817	7.52	9.21
126933	70	Peru		4.42	.795	6.56	8.33
126934	71	Peru		4.64	.629	6.45	10.27
126937	72	Peru		4.60	.826	7.84	9.51
126938	73	Peru		4.57	.736	8.12	11.05
126939	74	Peru		4.54	.809	6.96	8.87
126940	75	Peru		4.52	.620	7.56	12.21
126941	76	Peru		4.62	.650	7.96	12.31
126942	77	Peru		4.48	.562	6.32	11.24
126947	78	Peru		4.55	.643	7.37	11.51
126949	79	Peru		4.52	.697	6.02	8.85
126950	80	Peru		4.49	.546	5.56	10.31
126951	81	Peru		4.56	.558	8.34	15.08
126952	82	Peru		4.33	.894	9.82	11.00
126953	83	Peru		4.36	.804	7.76	9.67

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
127799	84	Peru		4.62	.579	8.26	14.28
127803	85	Peru		4.31	.649	5.82	8.97
127804	86	Peru		4.37	.540	5.76	10.63
127805	87	Peru		4.49	.684	6.91	10.08
127806	88	Peru		4.35	.918	8.01	8.78
127808	89	Peru		4.41	.907	6.14	6.95
127810	90	Peru		4.82	.324	5.76	18.02
127819	91	Peru (Bol.)		4.40	.648	5.87	9.06
127821	92	Peru (Bol.)		4.52	.524	5.86	11.66
127824	93	Peru (Bol.)		4.46	.611	5.00	8.17
128219	94	Bolivia		4.48	.567	5.83	10.36
128220	95	Bolivia		4.34	.689	5.70	8.30
128221	96	Bolivia		4.38	.616	5.74	9.34
128222	97	Bolivia		4.31	.706	6.22	8.82
128223	98	Bolivia		4.26	.710	5.67	7.99
128227	99	Bolivia		4.37	.608	5.95	9.82
128229	100	Bolivia		4.33	.521	5.28	10.33
128232	101	Bolivia		4.60	.482	6.84	14.59
128234	102	Bolivia		4.54	.543	6.97	12.84

TABLE 21 (continued)

Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
128250	103	Bolivia		4.58	.418	5.73	13.75
128253	104	Bolivia		4.50	.468	6.06	13.04
272751	105	El Salvador		4.49	.505	6.66	13.18
128256	106	Bolivia		4.46	.658	6.09	9.30
128265	107	Bolivia		4.62	.458	5.79	12.84
128267	108	Bolivia		4.57	.457	5.81	12.73
128268	109	Bolivia		4.47	.466	5.72	12.33
128269	110	Bolivia		4.54	.471	6.27	13.43
128291	111	Argentina		4.39	.530	6.18	11.67
128597	112	Chile		4.57	.500	6.97	14.06
128605	113	Chile		4.51	.597	6.50	10.98
128639	114	Peru		4.43	.685	7.36	10.82
128664	115	Peru		4.50	.464	5.48	11.82
128884	116	France	de Marmande	4.41	.680	6.24	9.18
128886	117	France	Merveille de Marches	4.72	.306	5.83	19.02
128887	118	France	Perfection	4.64	.522	6.78	13.00
128890	119	France	Rouge Grosse	4.59	.565	6.26	11.11
129028	120	Ecuador		4.56	.392	5.06	12.93
129030	121	Ecuador		4.40	.506	5.59	11.21
129074	122	Colombia		4.73	.469	9.06	19.33
129090	123	Colombia		4.65	.551	7.80	14.36

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
129101	124	Colombia		4.64	.392	6.23	16.19
129138	125	Argentina		4.46	.511	5.47	10.69
129143	126	Peru		4.72	.496	6.38	13.00
129148	127	Ecuador		4.58	.469	6.36	13.58
129154	128	Ecuador		4.44	.681	5.74	8.44
129155	129	Ecuador		4.36	.869	6.52	8.42
129156	130	Ecuador		4.58	.716	6.70	9.53
135909	131	Baluchistan		4.48	.447	4.47	9.97
140050	131	Brazil		4.54	.513	5.31	9.88
146094	133	Iran		4.56	.491	5.47	11.99
147609	134	Brazil		4.36	.726	5.54	7.69
14735	135	Ecuador		4.34	.709	5.40	7.62
148656	136	Iran		4.64	.473	6.13	13.06
155368	137	Peru		4.41	.593	5.34	9.01
155369	138	Peru		4.30	.602	4.94	8.19
155371	139	Peru		4.64	.517	5.88	11.63
155375	140	Peru		4.51	.563	6.38	11.40
155378	141	Peru		4.61	.472	5.43	12.13
155379	142	Peru		4.42	.537	5.60	10.45
157193	143	Australia	Tatura Dwarf Globe	4.58	.467	6.13	13.09
157993	144	Italy	Prospero	4.58	.438	5.09	11.63

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
158161	145	Venezuela		4.49	.611	6.78	11.14
158164	146	Venezuela		4.47	.540	5.99	11.12
158166	147	Venezuela		4.52	.490	5.76	11.83
158167	148	Venezuela		4.46	.510	4.93	9.92
158171	149	Venezuela		4.55	.573	6.68	11.61
159199	150	Peru		4.57	.399	5.03	12.73
163245	151	India		4.45	.630	6.63	10.54
163246	152	India-2		4.44	.773	7.84	10.22
163248	153	India-2		4.56	.519	6.62	12.83
166365	154	India-6		4.41	.786	7.43	9.58
175776	155	Turkey-15		4.38	.565	4.77	8.45
175781	156	Turkey-15		4.47	.500	4.05	8.63
181778	157	Turkey-15		4.47	.468	5.68	12.30
183692	158	Turkey-22	Scarletawen	4.67	.418	5.34	13.14
183693	159	Turkey-22	Stokerdale	4.62	.469	5.30	11.39
187002	160	Guatemala-24		4.47	.644	7.95	12.32
188567	161	Italy-26		4.53	.480	5.73	11.92
190288	162	Mexico-27		4.61	.772	9.16	11.88
190256	163	New Caledonia-27		4.78	.490	8.96	18.34
190858	164	Argentina-28	Rey de- los Tempranos	4.46	.536	6.09	11.42
193357	165	Australia-30	Tainter	4.66	.441	5.24	11.88
195003	166	Ethiopia-31		4.44	.677	5.27	7.77

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
195006	167	Ethiopia-31		4.48	.569	7.46	13.20
204975	168	Puerto Rico-37		4.42	.588	5.20	8.86
204982	169	W. Va.#126-1-37		4.71	.520	7.33	14.58
204997	170	W. Va.#701-37		4.52	.663	6.72	10.23
204998	171	W. Va.#702-37		4.36	.824	6.80	8.28
205014	172	New Caledonia-37		4.41	.789	6.93	8.89
205016	173	W. Va.#819-2-37		4.38	.681	5.96	8.74
205017	174	W. Va.#828-1-37		4.54	.497	6.08	12.37
205018	175	W. Va.#828-2-37		4.50	.700	6.43	9.19
205028	176	W. Va.#889-1-37		4.51	.478	5.50	11.54
205040	177	P.A. Young	Yellow Peach	4.67	.438	6.36	14.59
205642	178	Italy-37	Ladino di Pannocchia	4.54	.475	5.92	12.45
212410	179	Venezuela		4.62	.528	7.63	14.56
212411	180	Morocco		4.63	.455	6.63	14.59
212412	181	N. Dakota	Cavalier	4.66	.451	6.01	12.29
212413	182	N. Dakota	Doublerich	4.69	.392	5.70	15.05
212415	183	N. Jersey	Campbell Soup 54 Reynard 54	4.52	.504	6.06	12.10
213188	184	Greece	Sel. T-62 Scarlet Globe	4.42	.546	6.32	11.60
213189	185	Greece	Sel. T-1385 Early Chatham	4.46	.527	5.32	10.06
229809	186	N. Hampshire		4.67	.382	4.57	12.14

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
229810	187	N. Hampshire		4.62	.384	5.21	13.60
234254	188	Michigan		4.55	.522	6.33	12.15
245760	189	Rhode Island		4.45	.563	5.92	10.56
260397	190	Bolivia		4.67	.416	6.17	14.99
260398	191	Bolivia		4.54	.468	6.30	13.46
260399	192	Bolivia		4.44	.527	6.38	12.11
260401	193	Bolivia		4.59	.444	5.41	12.24
260403	194	Bolivia		4.55	.510	5.49	10.81
262935	195	U.S.S.R.		4.55	.414	6.70	16.29
270230	196	Texas	Golden Sphere	4.42	.560	6.75	12.08
270246	197	S. Carolina	Stemless Penn Orange	4.38	.697	7.52	10.78
270260	198	Michigan	Burgess Lemon	4.69	.374	5.70	15.38
272627	199	El Salvador		4.57	.472	5.52	11.78
272628	200	El Salvador		4.55	.436	5.54	12.86
272629	201	El Salvador		4.60	.488	6.06	12.37
272635	202	Costa Rica		4.45	.714	5.50	7.72
272636	203	Costa Rica		4.54	.597	6.02	10.06
272640	204	El Salvador		4.40	.724	6.37	8.93
272645	205	Guatemala		4.68	.468	8.25	17.71
272647	206	Guatemala		4.55	.562	6.10	10.90
272648	207	Guatemala		4.46	.600	7.20	11.99

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
272649	208	Guatemala		4.64	.542	8.58	15.81
272652	209	Guatemala		4.48	.606	7.22	11.94
272655	210	Guatemala		4.61	.658	8.56	13.03
272656	211	Guatemala		4.60	.658	7.56	11.86
272658	212	Guatemala		4.65	.592	8.16	14.38
272660	213	Guatemala		4.64	.524	7.61	14.63
272662	214	Guatemala		4.77	.485	8.92	18.40
272663	215	Guatemala		4.49	.600	7.17	11.97
272665	216	El Salvador		4.68	.395	6.35	16.46
272668	217	El Salvador		4.62	.492	5.73	11.77
272669	218	El Salvador		4.70	.454	6.47	14.66
272670	219	El Salvador		4.49	.492	5.27	10.69
272672	220	El Salvador		4.47	.487	4.72	9.78
272685	221	El Salvador		4.61	.443	5.31	12.10
272687	222	El Salvador		4.66	.408	5.34	13.09
272689	223	El Salvador		4.38	.809	6.12	7.71
272690	224	El Salvador		4.63	.391	5.87	15.17
272691	225	El Salvador		4.45	.445	4.83	10.90
272692	226	El Salvador		4.63	.391	5.62	14.48
272693	227	El Salvador		4.53	.411	5.73	13.97
272697	228	El Salvador		4.56	.446	5.77	12.91
272700	229	El Salvador		4.54	.504	5.84	11.65

TABLE 21 (continued)

Plant Introduction Number	Missouri Number	Origin	Name	pH	Citric Acid Equivalent	Percent Brix	Sugar-Acid Ratio
272704	230	Guatemala		4.69	.390	5.04	13.53
272705	231	Guatemala		4.49	.474	5.37	11.32
272706	232	Guatemala		4.48	.541	5.82	10.76
272707	233	Guatemala		4.44	.606	6.57	10.85
272708	234	Guatemala		4.51	.585	6.31	10.86
272709	235	Guatemala		4.35	.713	5.65	8.07
272710	236	Guatemala		4.45	.770	6.37	8.45
272711	237	Guatemala		4.50	.566	5.77	10.22
272715	238	Guatemala		4.60	.459	5.74	12.68
272716	239	Guatemala		4.58	.411	4.91	12.35
272723	240	Guatemala		4.66	.460	5.87	12.79
272726	241	Guatemala		4.55	.475	6.38	13.58
272727	242	El Salvador		4.78	.442	6.11	13.88
272734	243	El Salvador		4.58	.526	5.72	11.04
272745	244	El Salvador		4.47	.537	6.14	11.52
272746	245	El Salvador		4.55	.518	6.34	11.89
272749	246	El Salvador		4.59	.502	6.93	13.82
272753	247	El Salvador		4.66	.377	6.12	16.30
272758	248	El Salvador		4.51	.543	6.50	12.01
--	249	Ohio	Marmanda	4.65	.426	5.60	13.18
--	250	Ohio	Utah 665	4.48	.497	5.76	11.80

TABLE 22-TOTAL RAINFALL FOR TWO-WEEK PERIODS FOR THE GROWING SEASON OF 1964 AT NEW FRANKLIN, MISSOURI

Period		Amount (Inches)
May	1-15	1.32
	16-31	3.73
June	1-15	3.02
	16-30	1.39
July	1-15	1.11
	16-31	0.00
August	1-15	0.00
	16-31	1.05

TABLE 23-AVERAGE MAXIMUM AND MINIMUM TEMPERATURES BY TWO-WEEK PERIODS FOR THE GROWING SEASON OF 1964 AT NEW FRANKLIN, MISSOURI

		Maximum °F	Minimum °F	Dry-bulb
May	1-15	77.66	56.46	74.13
	16-31	82.75	59.19	77.37
June	1-15	78.87	59.66	75.00
	16-30	87.14	64.64	84.14
July	1-15	87.06	65.86	83.26
	16-31	93.43	69.75	89.75
August	1-15	91.06	60.93	85.40
	16-31	86.56	63.43	83.06