CHEMICAL AND PHYSICAL CHANGES OF BLUEBERRY FRUIT ASSOCIATED WITH RIPENING AND DETERIORATION

By

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AN ABSTRACT

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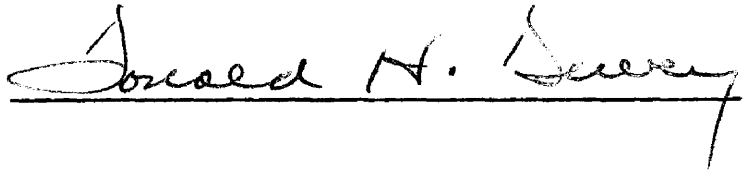
Approved 

About one half of the blueberries harvested in Michigan go to fresh market outlets. Frequently, considerable losses due to deterioration of the fruit in transit and in the markets are encountered and these losses often can be attributable to overripe berries within a package, therefore, a knowledge of the proper time to harvest the ripened fruit would be an important asset to the blueberry industry. Chemical changes and changes is physical characteristics due to chemical changes have been used as harvesting standards for other fruit so it would seem likely that one or more similar changes in blueberries could be adapted as a harvesting standard. For this reason, the initial step in this research was to determine the changes in organic and inorganic fruit constituents during the ripening phases of fruit development. The second step was to use this knowledge as a basis for devising a rapid test suitable for field application as a means of determining the proper time to harvest blueberries for optimum dessert and keeping quality.

During the first year of this study Jersey blueberry fruit on 18 uniform bushes of a commercial plantation were tagged at the time of red color development in the skin. These fruit were harvested at 3-4 day intervals for a period of 20 days after red coloration to provide fruit of known and varying degrees of ripeness. The harvested fruit were quickly frozen, held at -5° F. until all harvests were completed, and finally lyophillized in preparation for the determination

of chemical constituents on a dry weight basis.

Chemical analyses of the Jersey blueberry fruits of known and uniform physiological age showed changes with ripening as follows: (1) sugar content increased for 9 days after red color formation and then remained constant, (2) titratable acid content decreased continually and the pH increased continually as ripening progressed, (3) intensity of pigmentation increased the first six days following red coloration and then did not change, (4) soluble pectin contents decreased continually and, associated with this, the pectin methylesterase acitivity increases, (5) starch, acid hydrolyzable polysaccharides, ether soluble material, lignin, and cellulose did not change markedly, and (6) changes in mineral constituents were relatively small and inconclusive with ripening.

Sugar acid ratios increased with ripening and there was a positive linear correlation between this ratio and ripening of the fruit. This relationship was substantiated by repeating the test the following year for Jersey blueberries using the same bushes. Fruit of the Rubel variety was also harvested at known stages of ripening. The positive linear correlation of sugar-acid ratios to the degree of ripeness of the fruit held true for both varieties. The change of the sugar-acid ratios of the fruit with advancement of physiological age was outstanding and most likely of practical significance for a measurement of ripening.

Since the inital data indicated that the sugar-acid ratio was a promising index of ripening, five plots of 20 Jersey bushes were used to relate the sugar-acid ratios of the fruit to their shelf life after harvest. The five plots selected were in commercial plantations of varying ages in western Michigan near Bangor, Grand Junction, Lacota, Allegan, and Holland. The different locations which extended in a north-south direction for about 100 miles, provided a sequence of initial harvest dates. The harvests which started July 31 and continued to August 31, consisted of 5 pickings of each plot at intervals of four days.

Ripeness of the fruit was varied by harvesting one set of four bushes of each plot at each harvest date. No fruit were harvested from a set of bushes prior to the designated time of harvest. At this time all fruit which were blue in color were picked from clusters at random from the four bushes to fill eleven pint boxes. Ten of these pints were used for storage tests and one pint was frozen for chemical analysis. The sugar-acid ratios for the fruit harvested over a period of 20 days which initially contained fruit of variable degrees of ripeness and which contained wider ranges of ripeness as harvests progressed, were correlated with the percentage of breakdown of the fruit in storage. Increases in the accumulation of ripening were acompanied by increases in the sugar-acid ratios and the percentage breakdown in storage. It was found that the keeping quality of Jersey blueberry fruit

was dependent upon the degree of ripeness, which in turn could be measured by a sugar-acid ratio. A soluble solids-acid ratio was equally reliable as a measure of ripeness as the sugar-acid ratio.

It was found that pH gave a reliable estimate of the acid content of the fruit and that a hand refractometer measurement of soluble solids served to measure the percentage sugar content. Since soluble solids and pH can be measured quickly in the field, it would appear that a soluble solids-acid ratio could serve as an index for harvesting blueberries. Also it could be used to determine the lots of harvested fruit suitable for shipment, and possibly the period of time the fruit could be in transit and marketed without excessive deterioration.

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INTRODUCTION

Knowledge of the proper time to harvest the ripened fruit would be an important asset to the blueberry industry. Presently, each grower on the basis of his personal experience determines the time to pick his fruit according to fruit characteristics such as size of the berries, sweetness to taste, and firmness of the flesh. Individual variations of judgement and opinion of ripeness result in large differences in quality of the fruit harvested from different plantations.

About one half of the blueberries harvested in Michigan go to fresh market outlets. Frequently, considerable losses due to deterioration of the fruit in transit and in the markets are encountered and these losses often can be attributed to overripe berries within a package. The overripe berries are subject to breakdown which may cause the other berries in the container to become moistened with juice or they may decay so as to make the berries unattractive, off-flavored, and less marketable.

The presence of overripe fruit in fresh market packs can be attributed to the lack of standardization in determining the proper time of harvesting. Therefore, an objective test to measure the ideal stage of ripeness for optimum dessert quality and maximum market and storage life would be desirable. There are numerous fruit properties to consider in choosing

a suitable index of maturity or ripening. Many of these characteristics affect edible quality; they include flesh and skin texture, sweetness or tartness, and psychological considerations such as color, size, and freedom of defects. Frequently, the eating quality of fresh product must be partially sacrificed to provide a marketable product which may be handled without damage, stored for a reasonable period, and remain free of physiological or pathological disorders until the consumer has had an opportunity to utilize the product.

The maturing fruits of the highbush blueberry rapidly change in color from green to red and then to dark blue. Once the skin of the berries becomes completely blue in color it is impossible to observe if the berries have ripened adequately to be harvested. Since the position of the berries on the panicle is no indication of the degree of maturity there is no set pattern for harvest of the fully colored berries. All blue colored fruit are picked and, therefore, all degrees of ripeness are included in the yield. A harvesting standard would need to measure the degree of ripeness of blueberries which are quite lacking in uniformity of ripeness, and still provide a guide to avoid excessive quantities of overripe fruit.

The terms <u>mature</u> and <u>ripe</u> are not clearly definitive in common usage for describing fruit condition. With blueberries it would seem best to apply the term maturation to

all phases of development of the berry from fertilization to senescence. Fruit growth from fertilization to red color development of the skin may be considered as the immature stage of maturation, and red coloration to senescence may be considered the mature stage. Changes taking place during the latter stage may be considered as ripening. Within the mature stage, sour berries that lack blueberry flavor may be unripe, the fruit may be considered as ripe when maximum dessert quality has been attained, and overripe when the fruit becomes flat in taste or possesses an undesirable texture or appearance due to aging.

Chemical changes and changes in physical characteristics attributable to chemical changes have been used as harvesting standards for other fruit so it is probable that one or more similar changes in blueberries could be adapted as a harvesting standard. For this reason, the initial step in this research was to determine the development or degradation of organic and inorganic fruit constituents during the ripening phases of fruit development. The second step was to determine the possible use of this knowledge as a basis for devising a rapid test for determining the proper time to harvest blueberries for optimum dessert and keeping quality. Such a rapid test would be desirable for use under field conditions.

LITERATURE REVIEW

Numerous experiments designed to measure and define the best stage of maturity or ripeness for harvesting horticultural crops are described in the literature. Few, however, have dealt with the blueberry and relatively little information is available describing the quality factors and how they are affected by physical and chemical changes of the fruit as ripening progresses. Recommendations for harvest are limited and vague with respect to the condition of the fruit. Bailey et al. (1939) made the following statement regarding the harvesting of blueberries: "They must be neither too green nor too ripe. The stem end of ripe berries has a dark, rich, blue color. A reddish tinge there indicates immaturity. Underripe fruit is sour and lacks blueberry flavor. Picking should be done every six or seven days. If done more often than this, too many underripe berries are picked." Little was added by the recommendations of Slate and Collison (1942), except that overripe berries should be excluded from the harvests, but they made no suggestion as to the identifying characteristics of overripeness.

The commonly used maturity indices are summarized by Shoemaker (1955). They include subjective guides such as aroma, taste, changing of the color of the stems from green to brown, shriveling of the stems, ease with which the berries separate from their stems, freedom of the seeds from the pulp,

and color of seeds. Objective tests, where applicable, are more suitable for general use. Those listed as possible indices are size, sugar and acid content, the sugar-acid ratio, changes in viscosity of the juice, and changes in texture of the pulp. Objective indices discussed by Smock and Neubert (1950) as possibilities for apples are flesh pressure, the time interval from full bloom, and starch content of the fruit.

Uhe (1957) presented data showing a definite correlation between fruit size and sugar and acid content of the Jersey variety of blueberry. Sugar content increased with increased berry size, and acid content decreased with increased berry size. Various fertilizer treatments did not significantly influence the sugar or acid content of the berries. Berries picked at the end of the season were less acid than those picked at the beginning of the season and sugar content increased with later picking. Shutak et al. (1956), however, indicated that the soluble solids content of ripe berries of the Dixi, Pemberton, Atlantic, and Pioneer varieties decreased as the harvest season progressed. For a given variety, early ripening berries were sweeter than those ripening later. Bünemann (1956) found that the soluble solids content of blueberries increased as ripeness progressed. Ballinger, et al. (1953) reported that total yield in pounds per bush effects soluble solids content of the blueberry fruit with soluble solids content decreasing as yield increased.

Caldwell (1934) found in oranges, grapefruit, apples, strawberries, blackberries, raspberries, elderberries, pokeberries, and cherries that the total titratable acidity increased as the fruit matured, attained a maximum about the time ripening began, and then decreased as ripening proceeded. Hill (1958) found with raspberries that changes were generally uniform in titratable acid content and hydrogen ion concentration. They reached a maximum about the time visible fruit pigmentation occurred and then decreased as ripening proceeded. He suggested these changes may account for the increased palatability of berries between the time of fruit pigmentation to full ripeness.

There is considerable evidence that sugar and acid changes can be used as measures of ripening for other fruits. Soluble solids content has been reported as a measure of harvest maturity for cherries by Marshall (1954) and for grapes by Shoemaker (1955). Soluble solids content of oranges, cantaloupes, melons, and pears are given as maturity standards in the Agricultural Code of California (1957). A maximum acid content of the juice serves as a maturity standard for pomegranates (Agricultural Code of California, 1957).

Sometimes a sugar-acid ratio gives a better measurement of eating quality than either sugar or acidity alone. Harding et al. (1940) reported that the ratio of total solids to total acid has been used as a maturity standard for oranges for many years. He suggested that a minimum total

solids as well as a minimum total acid content be used as a maturity standard for Valencia oranges. Rygg and Getty (1955) found that the best maturity standard for Marsh grapefruit was a ratio of total solids to total acid. They indicated, however, that discrepancies between this ratio and palatability made a better standard desirable. Winkler (1932) suggested that maturity related to palatability could be measured for table grapes using the degree Balling and the degree Balling-acid ratio. Amerine and Winkler (1941) concluded that the Balling-acid ratio was influenced by regional and seasonal conditions, the size of the crop and the variety. Variety was of marked influence and seemed more important than other variables studied. Haller (1952) stated that soluble solids-acid ratios have been used as a maturity index for cantaloupes.

Truscott and Wickson (1954) found that juice viscosity of the fruit showed promise as a measurement for predicting the proper harvest dates for apples, peaches, and pears.

Allen (1929) reported the results of studies of ripening changes for plums, pears, apricots, peaches, and apples. He concluded that softening of the flesh was one of the most important changes taking place in deciduous fruits. The knowledge that the flesh of fruits soften during ripening has stimulated the testing of various pressure devices for measuring fruit maturity. Haller (1952) concluded a pressure test was the best approach to a maturity standard for peaches.

Pressure tests have been the most reliable and practical maturity test for pears (Allen, 1932). The Bouyoucos-Marshall (1951) small fruit pressure tester was successfully used by Bünemann (1956) to measure differences in flesh firmness of blueberries. He obtained measurable differences in pressure readings with blueberries of different degrees of ripeness which had been stored eight weeks.

The time interval from full bloom has been recommended as a maturity index for apples by Haller and Smith (1950). However, an application of a period of time from full bloom to harvest would be difficult with the blueberry since the blossoming period lasts two to five weeks in commercially grown highbush varieties. Bailey (1947) reported that the time interval was too variable between seasons to be of practical use as a maturity standard for blueberries. Also Hindle et al. (1957) have reported that the time interval between blossom drop and fruit maturity was too variable to be used as a prediction of harvest time for blueberries. They also found no relationship between wood thickness and time to maturity. Young (1952) found that the development of the blueberry fruit took place in three stages: stage I, rapid growth; stage II, very little increase in size; and stage III, rapid growth and ripening. Stage II was quite variable even between berries on a single plant, thus rendering a time interval for harvest maturity unreliable. Hindle et al. (1957) also observed this growth pattern for

varieties of blueberries.

It is important that blueberries possess adequate market and storage life in addition to high dessert quality. The fruit should be left on the bush until it becomes ripe since the blueberry, like the grape, does not increase markedly in sugar content after harvest (Shutak et al., 1956). These researchers showed that berries when ripened on the bush averaged 3.6 percent higher in soluble solids than berries ripened off the bush.

Chandler (1944) found that blueberries could be kept four to six weeks at 35°F. in sealed jars provided they were firm, not overripe, and handled as little as possible. Bünemann et al. (1957) found that blueberries harvested at three stages of maturity defined as ripe, firm ripe, and hard ripe could be stored for two weeks without any marked changes from the original quality.

The limited information presently available for blueberries suggests that measurement of chemical changes associated with ripening may serve as a guide for harvesting this fruit. Also the favorable results obtained in adapting chemical changes to harvesting standards with other fruits indicate that they might be adaptable as a maturity index or standard for blueberries.

MATERIALS AND METHODS

The blueberry fruit obtained in the first year of this study came from a commercial plantation of 20-year old Jersey bushes near South Haven, Michigan. Fruit of known age in respect to ripening were assured by first removing all the berries which were blue in color from 18 uniform-sized bushes so that only fruit which were red or green in color remained. Since this was shortly prior to the time of a normal first commercial harvest, many fruit showed pigment development (red or blue) the following day. These were then tagged and subsequently harvested over a period of time to provide fruit of known maturity or degree of ripeness. The tagged fruit were picked at intervals of three or four days for a 20-day period. These harvests provided a range of fruit maturity of the fruit from unripe to overripe.

Four pints of berries were obtained at each harvest. The berries were picked into a container and randomly divided into four lots, and then sealed into separate plastic bags. Soluble solids readings were taken in the field at the time of harvest with a Zeiss-Opton hand refractometer. Three determinations were made of the juice extracted from about 20 berries crushed in a milk filter disk. The fruit in the plastic bags was placed in a home freezer cabinet at approximately -5° F. within one half hour after harvest.

At the conclusion of the harvest season the berries were ground in the frozen state in a Waring blendor and then lyophillized to prevent chemical and enzymatic changes during drying. This method of drying the fruit permitted enzymatic studies and prevented caramelization of the sugars. The lyophillized fruit was finally dried over phosphorous pentoxide at four millimeters pressure and room temperature in a Weber vacuum oven. The entire fruit was used for analysis without making a separation of seed, skin, and flesh.

A weighed ether soluble fraction was obtained from a one gram sample of dried blueberries extracted for 16 hours in a Soxlet extraction unit with absolute diethyl ether. After extraction the extractant was evaporated on a steam bath and then dried for four hours at 70° C. and four millimeters pressure over phosphorous pentoxide in a Weber vacuum oven.

The original dry residue was prepared for carbohydrate analyses and analyzed for reducing sugars, non-reducing sugars, starch, and acid hydrolyzable polysaccharides by the procedures outlined by Sell et al. (1946). Acid hydrolyzable polysaccharides were determined from the acid hydrolyzable residue from the starch determinations.

Approximately one gram of dried fruit was extracted with 50 milliliters of 80 percent ethyl alcohol for four hours on a Goldfisch apparatus and analyzed for cellulose by the method described by Phillips et al. (1943). The lignin

content was obtained according to the procedure of Williams and Olmstead (1935) using about two grams of dried fruit and extracting with 80 percent ethyl alcohol for four hours on a Goldfisch apparatus.

Soluble pectin content was determined by a slightly modified procedure from the one described by Lawrence and Groves (1954). Instead of repeated washing of the calcium pectate precipitate by alternate centrifuging and decanting, as recommended, the calcium pectate precipitate was transfered to a tared filter paper. The precipitate was washed with hot water until free of chloride ions. The paper and contents were then dried at 100° C. for 48 hours and weighed.

One gram of dried fruit was extracted with 30 milliliters of water at 38° C. for one hour, filtered, and the filtrate used for pectin methylesterase determinations (Kertesz, 1937).

A one gram sample of dried fruit was used to determine anthocyanin content. The procedure used for extraction was described by Anderson (1923). The filtrate containing the pigments was made to 100 milliliters with water and then diluted to 200 milliliters with 0.1 molar citric acid and 0.2 molar disodium phosphate buffer solution, the pH adjusted to 3.0 with 0.1 molar solution of sodium hydroxide, and then made to 100 milliliters with water. Transmission was measured in a Beckman W K-2 spectrophotometer at 500 millimicrons.

Titratable acidity was found by the procedure

described in A.O.A.C. (1955). Water was added to a one gram sample in an amount calculated to be equivalent to restore the berries to a fresh weight basis and thoroughly stirred. The pH was measured initially and then the juice was titrated with 0.1 normal sodium hydroxide to a pH of 8.1.

Some of the mineral constituents of the fruit, namely; calcium, magnesium, manganese, copper, iron, phosphorous, boron, and silicon, were determined by a modification of the method used by Perry et al. (1950), whereby a potassium sulfate-graphite buffer in powdered from was substituted for a 20 percent sodium nitrate solution.

The same procedures and bushes were used for obtaining blueberries of known degrees of ripeness in 1958 as in 1957. However, in 1958 two pints of tagged fruit were picked at each harvest. The harvests were spaced four days apart and made for a period of 20 days. In addition, 15 bushes of the variety Rubel grown in the same plantation and of the same age as the Jersey bushes were tagged and harvested in a like manner. All berries were transported to East Lansing the same day they were harvested in an insulated food jar on dry ice, and then transferred to a freezer room and held at -5° F. until chemically analyzed.

Since the 1957 data indicated that the sugar-acid ratio was a promising index of ripening, five plots of 20 Jersey bushes were used to relate the sugar-acid ratios of the fruit

to their shelf life after harvest. The five plots selected were in commercial plantings of varying ages in western Michigan near Bangor, Grand Junction, Laccta, Allegan, and Holland. The different locations, which extended in a north-south direction for about 100 miles, provided a sequence of initial harvest dates. The harvests, which started July 30 and continued to August 31, consisted of 5 pickings of each plot at intervals of four days.

Ripeness of the fruit was varied by harvesting one set of four bushes of each plot at each harvest date. No fruit was harvested from a set of bushes prior to the designated time of harvest. At this time fruit which was blue in color was picked from clusters at random from the four bushes to fill 11 pint boxes. Ten of these pints were used for storage tests and one pint was frozen for chemical analysis.

The storage samples were transported to East Lansing the same day they were harvested and placed in controlled temperature rooms regulated at 75 and 40° F. Four pints of fruit were held at 75° F. for six days and six pints of fruit were held at 40° F. for 18 days and then examined. Shelf-life was evaluated by the percentage of berries, on a fresh weight basis, that showed breakdown. Fruit that was shriveled was not classed as breakdown. Nearly all deterioration observed was stem scar decay, with only occasional "runny soft" berries being present. Stem scar decay appeared as a depression in the berry and sometimes browning at the

point of separation from the pedicel. The flesh of the fruit beneath the skin disintergrated and often juice exudations were observed. Mold growth was frequently associated with stem scar deterioration especially at 75° F. The mold growth present was observed to be an Alternaria. "Runny soft" berries were characterized by complete internal disintergration of the flesh and the collapse of the berry when subjected to slight pressure. No fungus mycelium could be observed in the berry tissue. Both these disorders wereconsidered to be physiological breakdown and the mold growth was believed to be secondary infection.

Determinations were made for pH, total sugar, and titratable acid content of the tagged fruit and fruit from maturity plots. Analyses were made on a fresh weight basis rather than on a dry weight basis as in the previous year. Three soluble solids readings were taken on all samples at the time of harvest with a hand refractometer for all samples using 20 berries for each determination.

Total sugars were determined for all samples using the Lane-Eynon (1923) method. A 50 gram sample of frozen berries was blended in a Waring blendor with 100 milliliters of water, two grams of calcium carbonate was added, and then the sample was boiled for 30 minutes. The sample was transferred to a 500 milliliter volumetric flask, cooled, and then made to volume. A 100 milliliter aliquot was transferred to a 200 milliliter flask, three milliliters of

saturated neutral lead acetate added, and the solution allowed to stand 15 minutes after shaking. The solution was then made to volume and filtered into a beaker containing one gram of dry sodium oxalate and refiltered to remove the excess lead.

A 50 milliliter aliquot was hydrolyzed overnight at room temperature with five milliliters of concentrated hydrochloric acid. The solution was neutralized to a methyl orange end point using 3 N sodium carbonate and made to 100 milliliters. Total sugar was determined from a 20 milliliter aliquot by titrating to a methylene blue end point by using a 0.5 percent dextrose solution. All determinations were made in duplicate.

Total acid was determined on a 50 gram sample. The frozen berries were blended with 100 milliliters of water, strained through two thicknesses of cheesecloth, and a 100 milliliter aliquot taken. Initial pH measurements were recorded and then the solution was titrated to a pH of 8.1 with 0.1 normal sodium hydroxide. All samples were analyzed in duplicate.

RESULTS

The quantities of the organic constituents determined for the Jersey blueberry fruits harvested at known stages of ripeness in 1957 are summarized in Table 1. These contents, expressed as percentage of the dry weight of the berries, are averages of four lots of fruit separated at harvest. An exception is soluble pectin, which was determined from three lots of fruit as necessitated by the shortage of sample for measurement of this constituent. These data were analyzed by the multiple range and multiple F test descriped by Duncan (1955). Since the data are expressed as percentages, arc sine transformations are applied to constituents with contents of less than 20 percent for statistical analysis (Snedecor, 1950). Statistically significant changes occurred in all fractions during ripening.

Figure 1 shows the changes in percentage sugars from the time of red color formation to overripeness. The changes in non-reducing sugars, although statistically significant at the 5 percent level (Table 1), were gradual and relatively small. The percentage content of non-reducing sugar at the first harvest was significantly less than the content of berries harvested at 16 and 20 days after red coloration, and the amount of non-reducing sugar in berries harvested at 6 days after red coloration was less than that of berries harvested 20 days

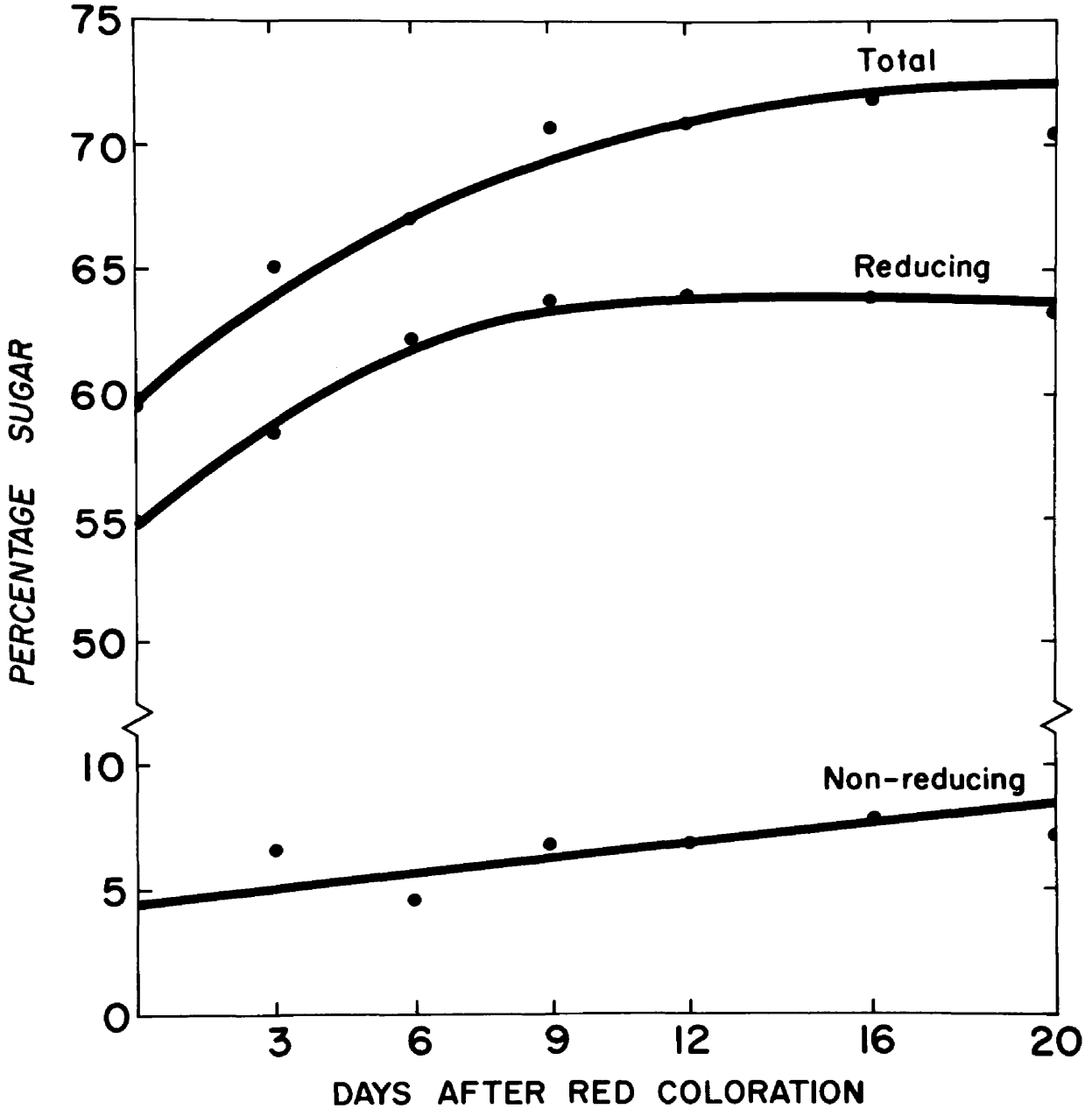
TABLE 1

ANALYSIS OF BLUEBERRY FRUIT FOR CERTAIN ORGANIC CONSTITUENTS.
JERSEY VARIETY. (PERCENT DRY WEIGHT).

Constituent	Days After Red Coloration							
	0	3	6	9	12	16	20	F value
Titratable Acid (as citric)	9.03	4.40	2.59	1.98	1.63	1.29	1.15	687.6**
Reducing Sugar	54.94	58.48	62.24	63.78	64.00	63.96	63.12	16.9**
Non-reducing Sugar	4.56	6.69	4.77	6.92	6.90	7.84	7.24	3.6*
Total Sugar	59.50	65.17	67.01	70.70	70.90	71.80	70.36	20.4**
Ether Soluble Fraction	5.4	3.8	3.6	3.5	3.7	3.6	3.6	6.5**
Starch	6.57	6.77	6.20	6.87	6.77	6.80	7.08	3.3*
Acid Hydrolyzable Polysaccharides	4.15	3.48	3.40	3.00	4.33	4.18	4.55	8.3**
Cellulose	4.53	3.82	4.13	3.45	3.69	3.51	3.51	3.0*
Lignin	6.84	5.43	4.59	4.21	4.26	5.44	4.90	10.3*
Soluble Pectin	1.09	0.98	1.00	0.89	0.88	0.64	0.66	4.7*

* Indicates significance of F at the 5% level.
** Indicates significance of F at the 1% level.

Fig. 1. The changes in reducing sugars, non-reducing sugars, and total sugars of Jersey blueberry fruit during ripening on a dry weight basis.


75
70
65
60
55
50
10
5
0
PERCENTAGE SUGAR
Total
Reducing
Non-reducing
3
6
9
12
16
20
DAYS AFTER RED COLORATION

after red coloration.

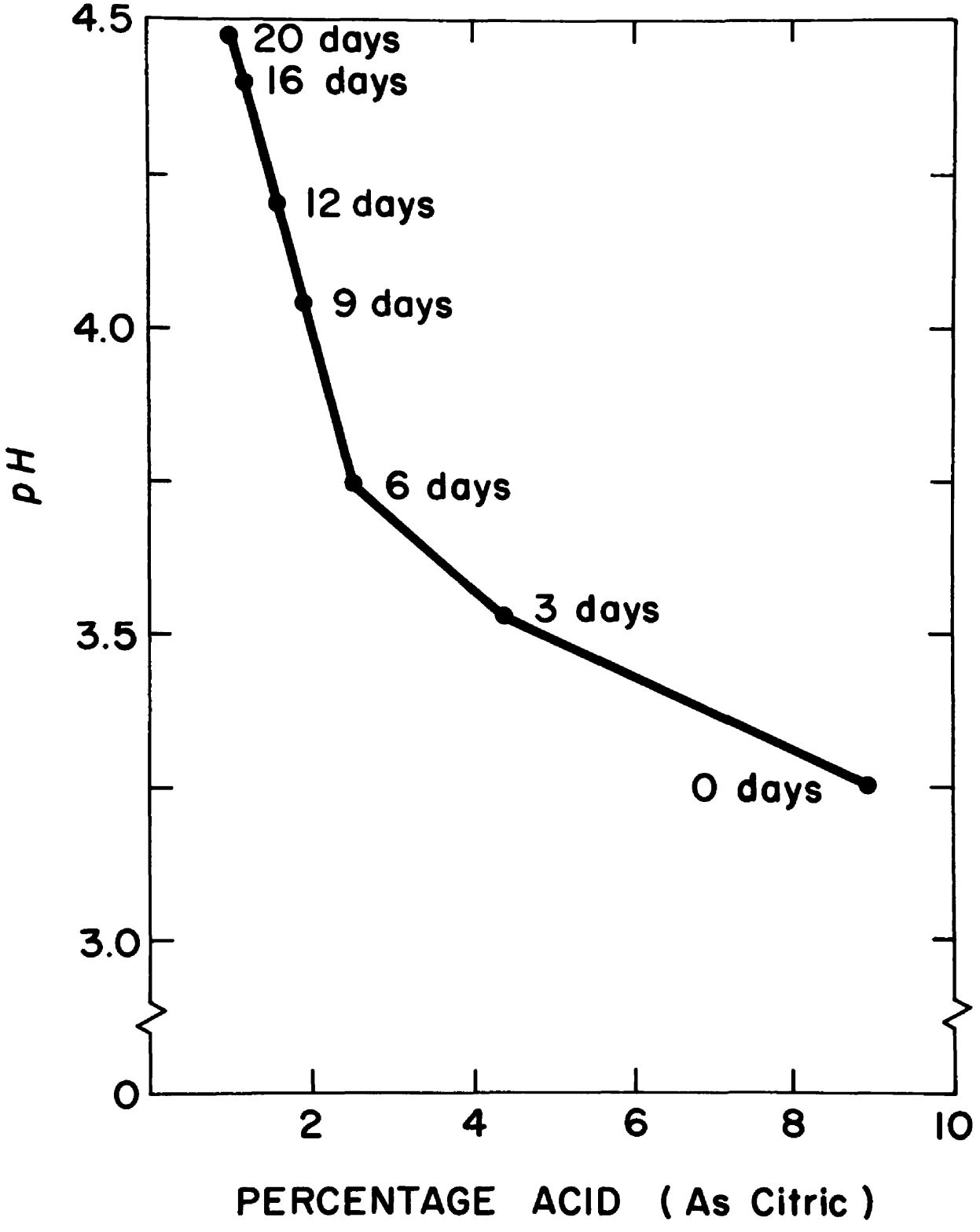
There was a significant increase in the percentage of reducing sugar between 0 days after red coloration and all other harvests, and between 3 days after red color formation and all other harvests. There was no significant change in reducing sugar thereafter.

Fruit from all other harvests had a significantly higher total sugar content than berries at the first harvest. Fruit harvested at 9, 12, 16, and 20 days after red color formation had a higher total sugar content than fruit harvested at 3 and 6 days after red coloration.

The pH and acidity changes of the berries with ripening are shown in Fig. 2. Acids are expressed as citric since Nelson (1927) found that most of the acid present in blueberries is citric with the remaining acids being mainly malic. There was a sharp decline in the percentage titratable acids during the first 6 days after red coloration followed by a less rapid decline to the last harvest. As the acid content decreased there was a corresponding measurable increase in pH.

Statistical analysis showed the acid contents of the fruit significantly decreased as harvesting progressed except between the last two harvests which occurred 16 and 20 days after red coloration. Significantly different values for all harvests except between 12, 16, and 20 days after red color formation were evident by pH measurements. The pH values were converted to hydrogen ion concentration for statistical analysis and calculation of averages.

Fig. 2. The changes in titratable acid content and pH of Jersey blueberry fruit during ripening on a dry weight basis.


4.5
4.0
3.5
3.0
0
pH
20 days
16 days
12 days
9 days
6 days
3 days
0 days
2
4
6
8
10
PERCENTAGE ACID (As Citric)

The changes in the ether soluble fraction, acid hydrolyzable polysaccharides, and starch contents of the fruit with ripening are shown in Fig. 3.

There was a significant decline in the ether soluble material of the fruit between the initial and second harvests (0 and 3 days after red coloration). Thereafter, it remained constant and the downward trend between the harvests at 12, 16, and 20 days after red color formation as shown in Fig. 3 was not statistically significant.

There were slight decreases in acid hydrolyzable polysaccharides for the first four harvests and increases thereafter. Statistically the acid hydrolyzable polysaccharide contents of the berries harvested at 3, 6, and 9 days after red color formation were similar and significantly less than the contents of fruit of all other harvests.

Although the starch content appeared relatively constant during the ripening period in Fig. 3, the percentage starch content of fruit harvested at 6 days after red coloration was significantly less than the percentage starch content of fruit harvested at all other times except at 0 days.

Fig. 4 shows that the cellulose content decreased slightly with progression of ripening during the first 9 days then held constant for the remainder of the harvesting period. The content at 9, 12, 16, and 20 days was significantly lower than at 0 days after red coloration.

Marked changes in lignin content occurred with ripening, (Fig. 4). Lignin content of the first harvest was significantly

Fig. 3. The changes in starch and acid hydrolyzable polysaccharides contents, and ether soluble material of Jersey blueberry fruit during ripening on a dry weight basis.

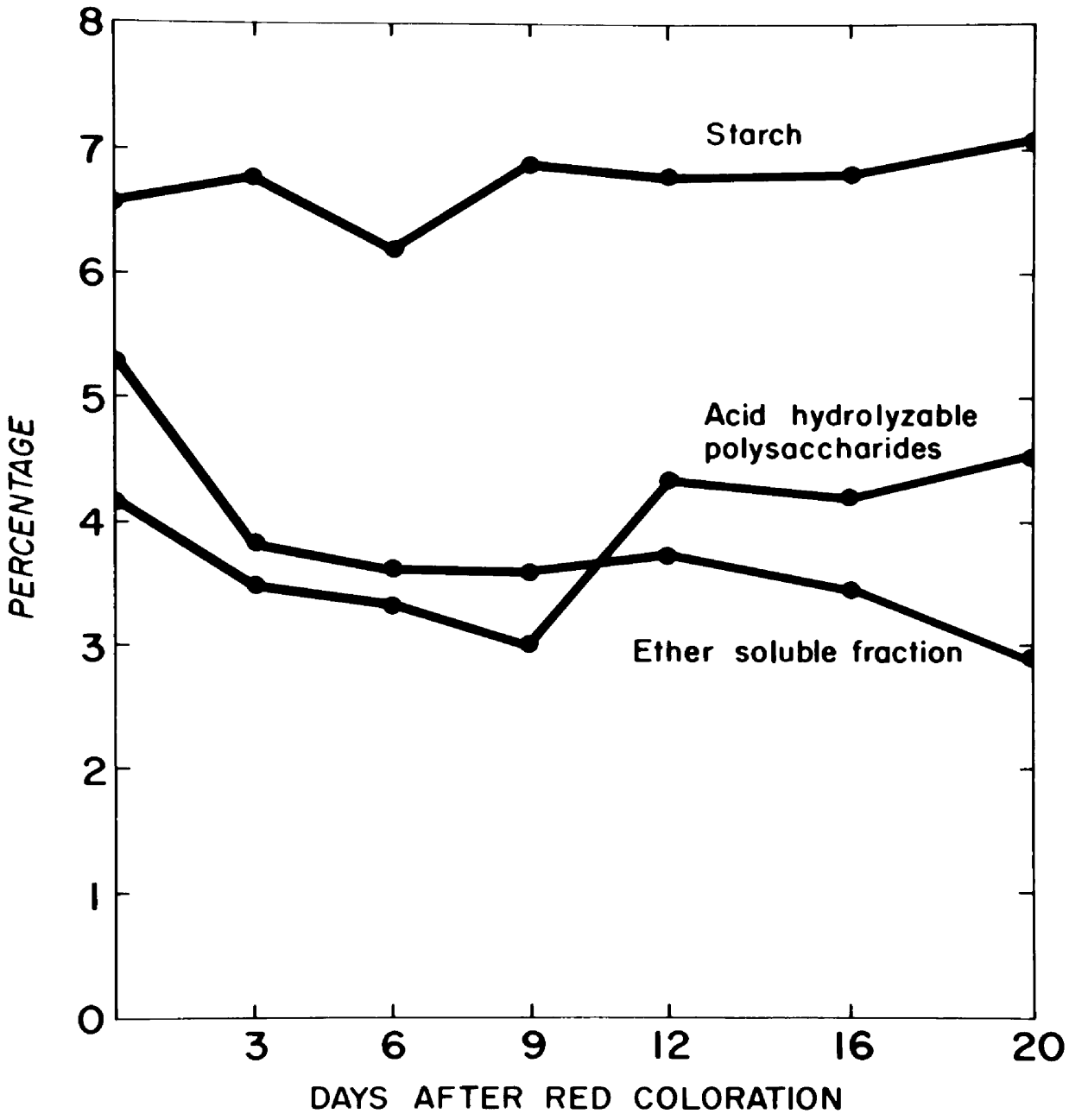
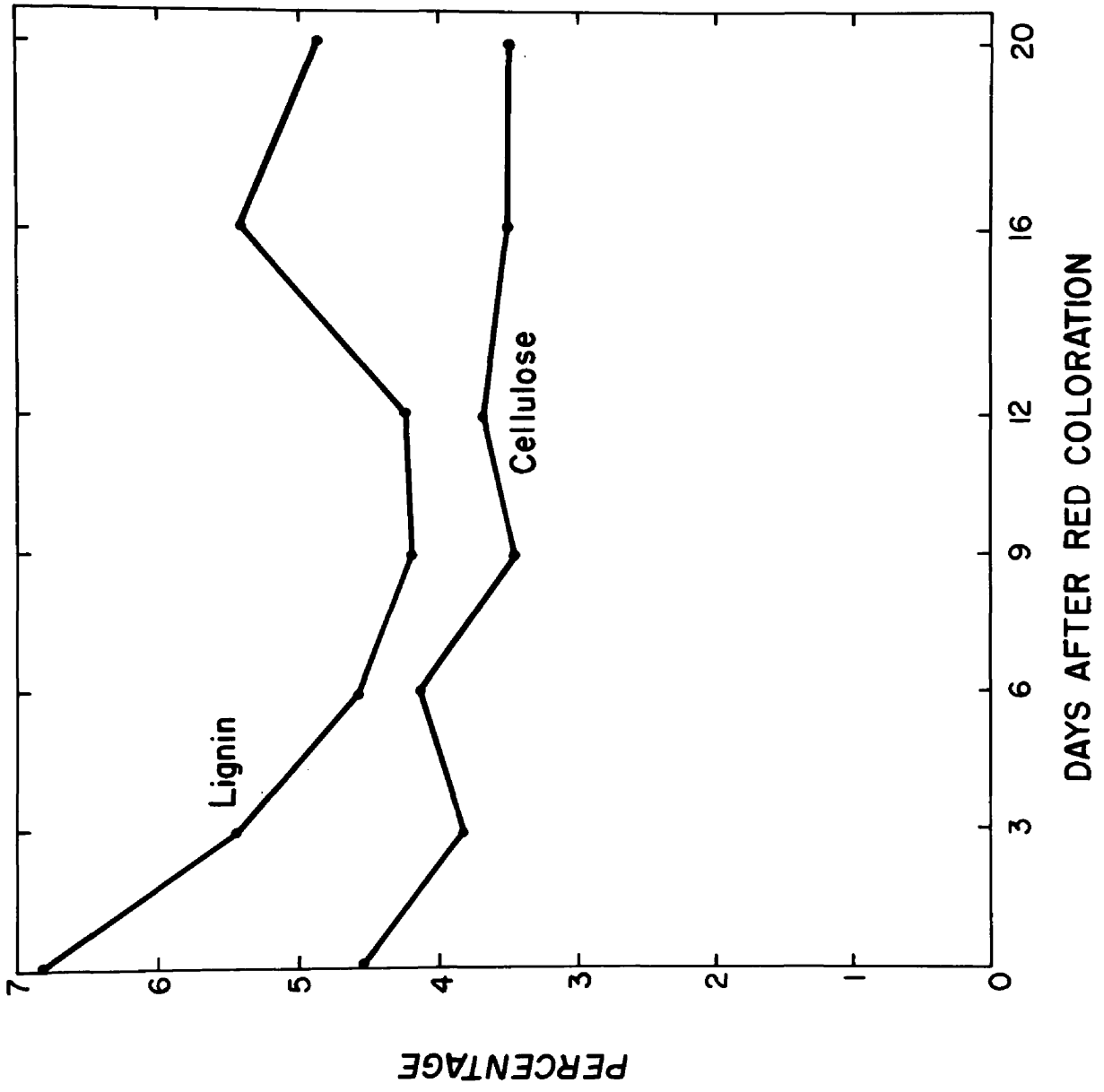

8
7
6
5
4
3
2
1
0
PERCENTAGE
Starch
Acid hydrolyzable
polysaccharides
Ether soluble fraction
3
6
9
12
16
20
DAYS AFTER RED COLORATION

Fig. 4. The changes in lignin and cellulose content of Jersey blueberry fruit during ripening on a dry weight basis.


Lignin
Cellulose
PERCENTAGE
DAYS AFTER RED COLORATION
0
1
2
3
4
5
6
7
3
6
9
12
16
20

greater than all other harvests. Lignin content of berries harvested 3 and 16 days after red color formation was significantly greater than berries harvested at 9 and 12 days after red coloration.

The soluble pectin content and the pectin methylesterase activity of Jersey blueberry fruit during ripening are shown graphically in Fig. 5. There was a marked decrease in soluble pectin of the fruit on the bushes between the harvests made at 6 and 9 days. Corresponding to this was an increase in the pectin methylesterase activity between these harvests and a continued increase in activity thereafter. Soluble pectins decreased throughout the harvest period, but the sharp decrease followed the break in pectin methylesterase activity by at least 6 days.

Blueberries harvested 0, 3, and 6 days after red coloration had significantly greater soluble pectin content than berries harvested 16 and 20 days after red coloration. Pectin methylesterase activity at 9, 12, 16, and 20 days after red coloration was greater than the activity in berries harvested at 0, 3, and 6 days after red coloration. Activity was greater in berries harvested at 16 and 20 days after red coloration than berries harvested at 9 days and greater in berries harvested at 20 days than those at 12 and 16 days after red color formation.

The relationship of pigmentation changes with ripening is illustrated in Fig. 6. The changes in percentage transmission of light, due to changes in concentrations of anthocyanin

Fig. 5. The changes in soluble pectin content and pectin methylesterase activity of Jersey blueberry fruit during ripening on a dry weight basis.

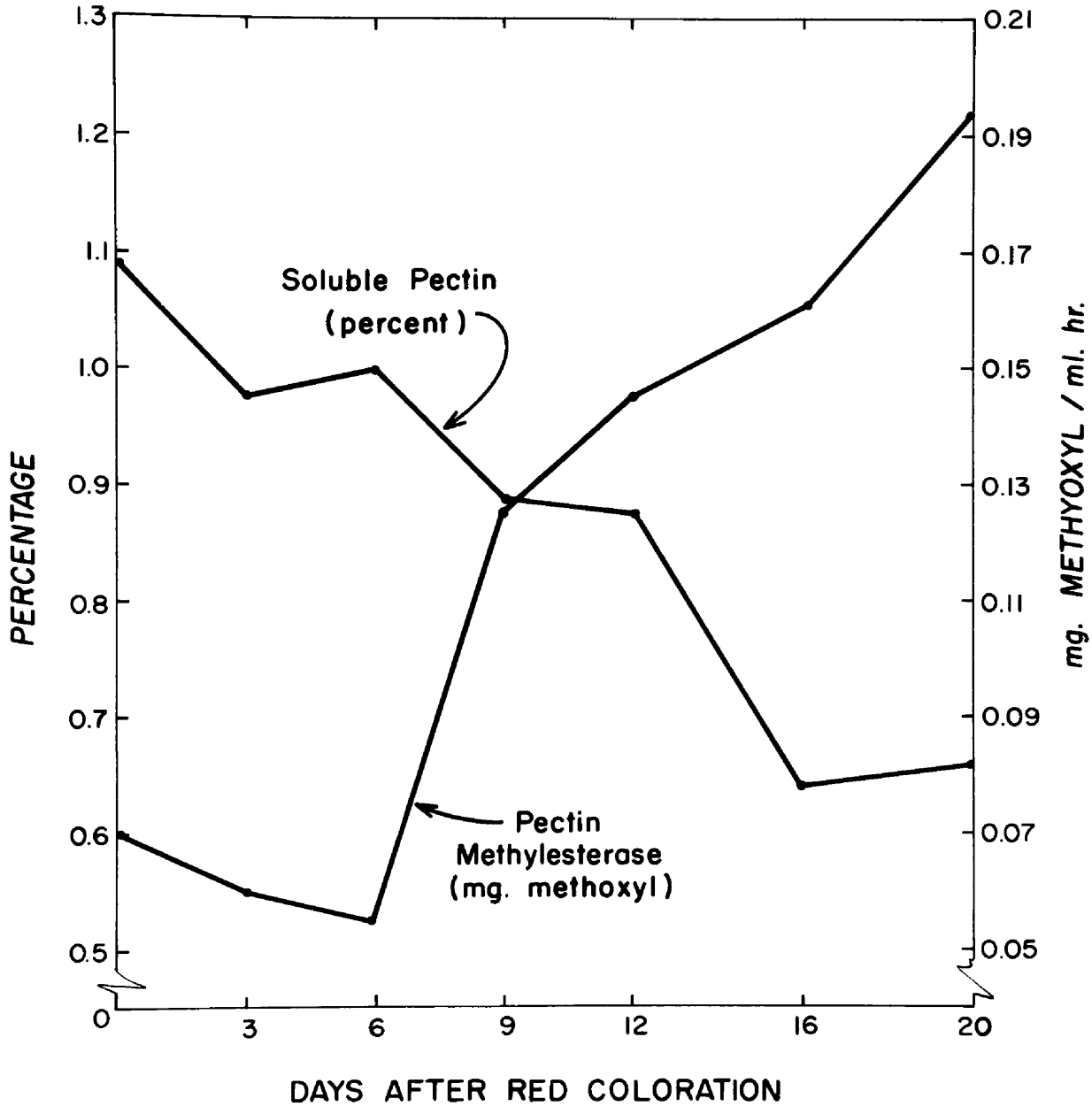
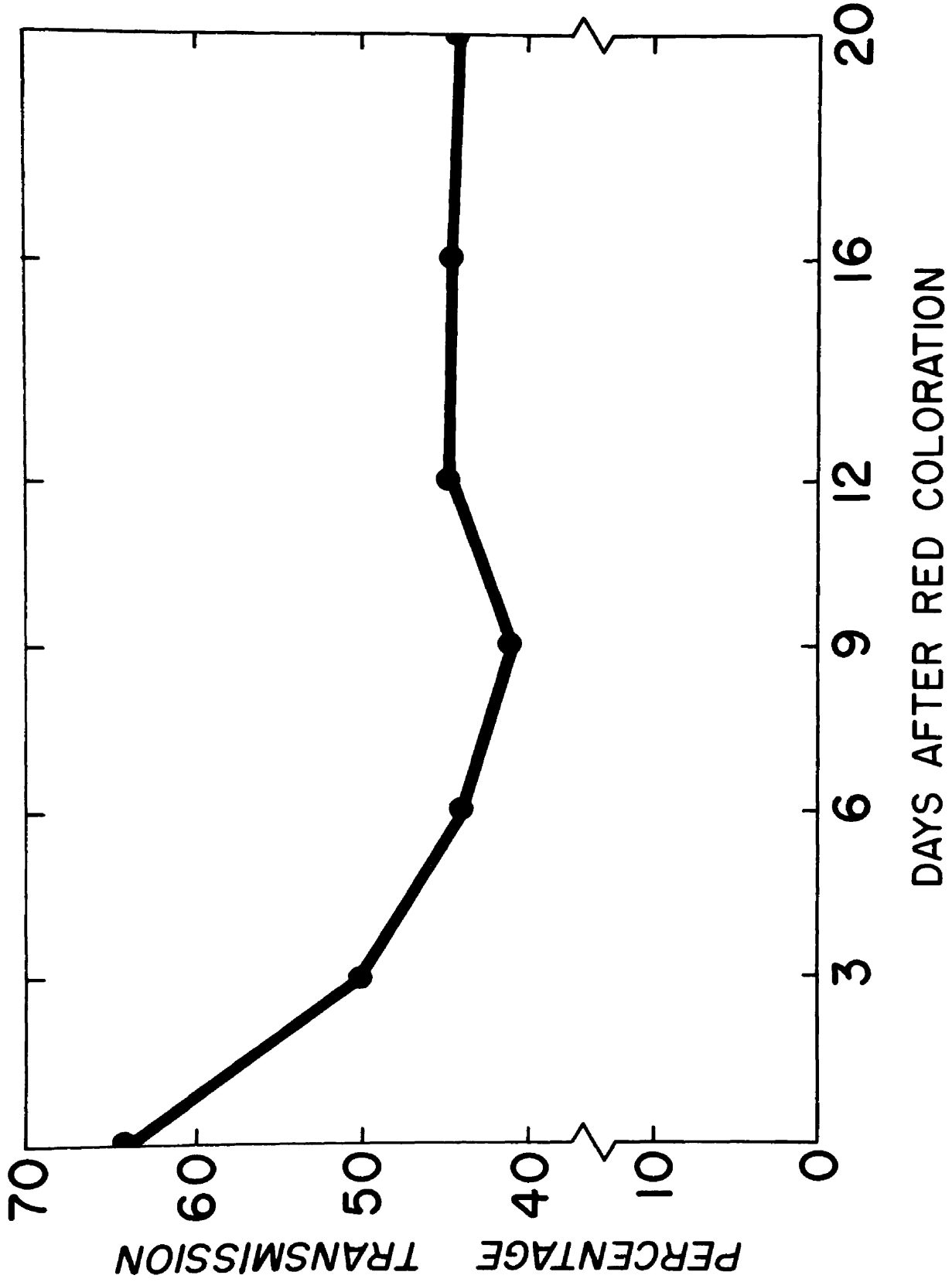

1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0
0.21
0.19
0.17
0.15
0.13
0.11
0.09
0.07
0.05
PERCENTAGE
mg. METHYOXYL / ml. hr.
Soluble Pectin
(percent)
Pectin
Methylesterase
(mg. methoxyl)
3
6
9
12
16
20
DAYS AFTER RED COLORATION

Fig. 6. The changes in percentage transmission of light attributable to anthocyanin content in Jersey blueberry fruit during ripening.


PERCENTAGE TRANSMISSION
70
60
50
40
10
0
3
6
9
12
16
20
DAYS AFTER RED COLORATION

pigments, during ripening indicated that considerable amounts of anthocyanin pigments were formed in the fruit during the first 6 days following the development of red color. Practically no change occurred after the first 6 days. Fruit harvested at 0 and 3 days were significantly lower in transmission values than fruit harvested 6 to 20 days after attaining red color.

The ash constituents determined spectrographically for blueberry fruit of varying degrees of ripeness are given in Table 2. These data were analyzed statistically by the multiple range and multiple F test described by Duncan (1955). The values given are averages for three determinations.

The percentages of calcium, magnesium, manganese, and phosphorous on a dry weight basis showed a significant decline as the fruit ripened. The calcium, magnesium, and manganese contents of the fruit declined rather consistently for the first 6 days after red coloration and then remained fairly constant. Phosphorous content was more erratic showing a decline after the first harvest, but an increase 12 days after red coloration which was large enough to be significantly greater than harvests at 6, 9, and 16 days after red color formation.

Tests in 1958 were designed to furnish additional information regarding a sugar-acid ratio of blueberries of uniform ripeness. The resultant data for the Jersey and Rubel varieties are summarized in Table 3 and the sugar-acid ratios are compared with the ratios obtained for Jersey analyzed on a dry weight basis in the previous year, see Fig. 7. The straight

TABLE 2

COMPOSITION OF BLUEBERRY FRUIT FOR CERTAIN ASH CONSTITUENTS AS ASSOCIATED WITH RIPENING. JERSEY VARIETY.

Ash Constituent (% dry wt.)	Days After Red Coloration						
	0	3	6	9	12	16	20
Calcium [a]	.053	.044	.046	.040	.036	.038	.041
Magnesium [b]	.045	.039	.032	.033	.033	.031	.032
Manganese [c]	.0038	.0036	.0028	.0028	.0029	.0025	.0029
Phosphorous [d]	.123	.103	.093	.097	.110	.097	.103
Iron	.0051	.0041	.0061	.0045	.0078	.0046	.0043
Boron	.00041	.00031	.00036	.00037	.00025	.00049	.00034
Copper	.00053	.00047	.00043	.00043	.00047	.00047	.00053
Silicon	.015	.015	.013	.017	.013	.016	.014

a/ 0 days greater than 9, 12, 16, and 20 days at p=.01; 0 days greater than 3, 9, 12, 16, and 20 days at p=.05; 6 days greater than 16 and 20 days at p=.05.

b/ 0 days greater than 6, 9, 12, 16, and 20 days at p=.01; 3 days greater than 16 days at p=.01; 0 days greater than 3 days at p=.05; 3 days greater than 6, 9, 12, 16, and 20 days at p=.05.

c/ 0 days greater than 16 days at p=.01; 0 days greater than 6, 9, 12, 16, and 20 days at p=.05.

d/ 0 days greater than 3, 6, 9, 16, and 20 days at p=.01; 12 days greater than 6 days at p=.01; 0 days greater than 3, 6, 9, 12, 16, and 20 days at p=.05; 12 days greater than 6, 9, and 16 days at p=.05.

TABLE 3

SUGAR, ACID, AND SUGAR-ACID RATIOS OF JERSEY AND RUBEL BLUEBERRY FRUIT AT DIFFERENT STAGES OF RIPENING IN 1958 ON A FRESH WEIGHT BASIS

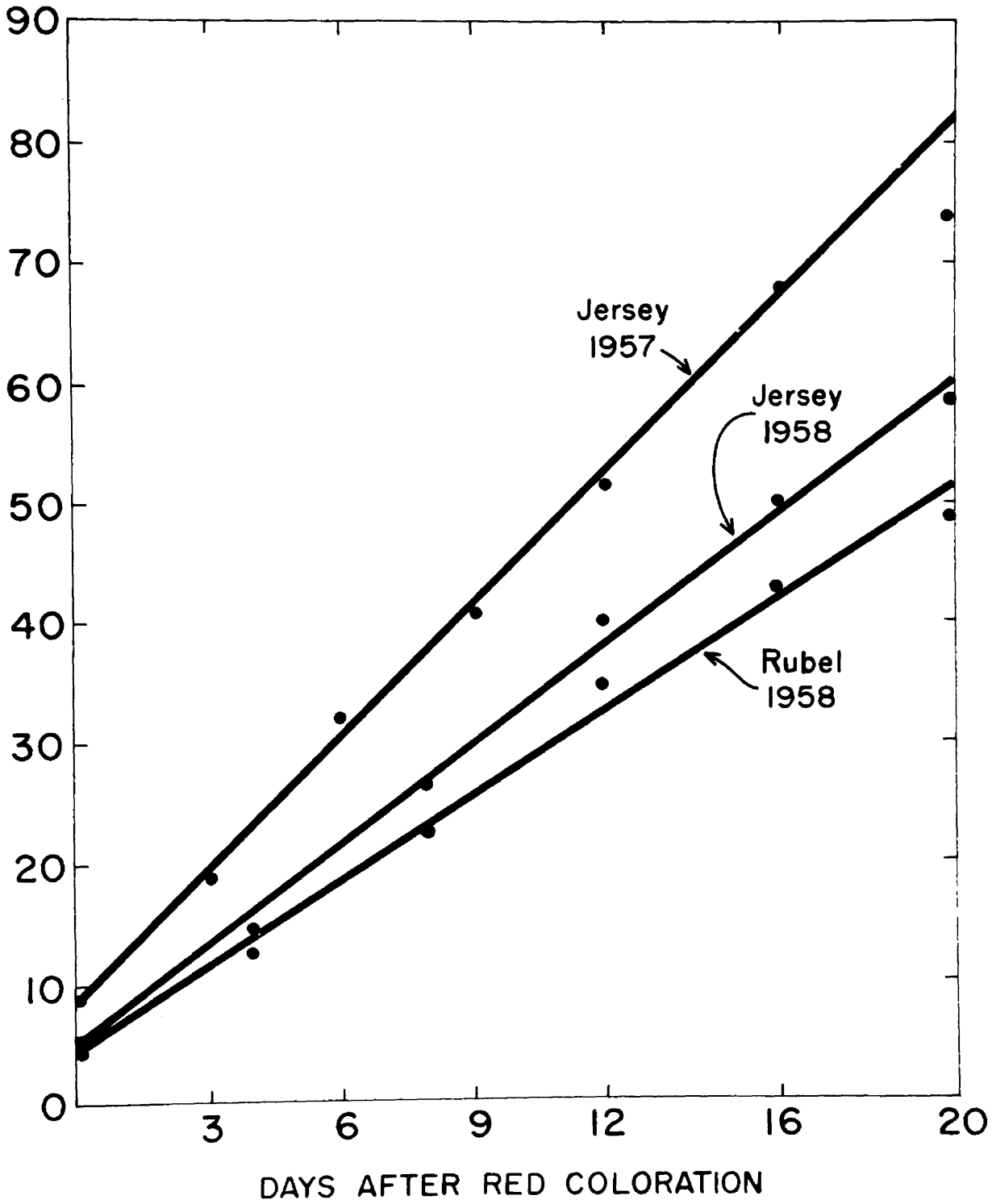
Days After Red Coloration	Variety					
	Jersey			Rubel		
	% Total Sugar	% Titratable Acid	Sugar: Acid	% Total Sugar	% Titratable Acid	Sugar: Acid
0	8.0	1.76	4.5	7.2	1.81	3.9
4	11.3	0.79	14.4	10.8	0.87	12.5
8	12.1	0.46	26.4	11.7	0.52	22.6
12	13.0	0.33	40.0	12.8	0.37	34.9
16	12.9	0.26	50.0	12.9	0.30	43.0
20	12.7	0.22	58.5	12.8	0.26	48.9

line relationship existed for both varieties when the ratios were calculated from the contents determined with fresh fruit. The slope of both lines was lower for Jersey of the previous year.

Quality characteristics of the fruit observed at the time of harvested suggested that the best harvest time would be 6 to 16 days after red color formation. Berries at 0 to 3 days after red coloration were tart and some of the berries which had been blue in color for 20 days had deteriorated on the bushes.

The ratios presented above are for fruit of known and uniform ripeness for a given harvest. The sugar and acid data obtained from the five maturity plots provides a more realistic

Fig. 7. Sugar-acid ratio changes of Jersey and Rubel blueberry fruit during ripening. The values on the vertical axis are sugar-acid ratios and degrees of ripening are represented as days after red coloration on the horizontal axis.


90
80
70
60
50
40
30
20
10
0
3
6
9
12
16
20
Jersey
1957
Jersey
1958
Rubel
1958
DAYS AFTER RED COLORATION

evaluation of the ratio as a measure of ripeness since the fruits of each harvest were of all stages of ripening consistent with the time of harvest. For example, berries harvested at the third interval contained fruit that had turned blue in color just prior to harvest as well as fruit that ripened initially and throughout the period up to harvest time. The ratios for these fruit (Table 4) are, therefore, averages for all degrees of fruit ripeness when picked at a given harvest time. The sugar-acid ratios for fruit from all five localities for the first two harvests fall between the ratios obtained for Jersey blueberries of 0 to 8 days after red coloration, (Table 3). Most of the initially harvested fruit from the maturity plots had a ratio similar to Jersey berries harvested four days after development of red coloration. This would suggest that the bulk of the fruit contained in these harvests had ripened 4-6 days after attaining red color.

Deterioration of the harvested fruit by plot locations and times of harvest are given by the percentage of fruit with breakdown after storage for 6 days at 75° F. and 18 days at 40° F. in Table 4. There was a marked effect of temperature upon the shelf life of the berries. Fruit held at 40° F. had much less breakdown even though held in storage three times as long as fruit held at 75° F.

TABLE 4

THE RELATIONSHIP BETWEEN SUGAR-ACID RATIOS AND BREAKDOWN IN STORAGE OF JERSEY BLUEBERRIES

Plantation	Harvest Date	Sugar:Acid	Percentage Breakdown	
			75° F.	40° F.
Holland	Aug. 11	13.4	21.5	3.9
	" 15	16.5	27.4	8.4
	" 19	24.6	29.9	13.6
	" 23	28.7	37.0	17.0
	" 27	19.4	30.0	19.2
Bangor	Aug. 3	15.4	22.7	8.4
	" 7	13.7	32.4	7.7
	" 11	22.6	58.5	20.4
	" 15	26.5	50.5	24.7
	" 19	30.6	70.5	37.3
Grand Junction	Aug. 7	12.4	20.3	5.3
	" 11	17.3	44.2	12.7
	" 15	21.8	34.2	15.4
	" 19	36.3	37.0	20.4
	" 23	33.9	55.3	35.0
Lacota	Aug. 7	10.3	13.8	2.9
	" 11	13.4	38.0	5.4
	" 15	27.3	35.0	14.0
	" 19	27.2	43.7	22.1
	" 23	33.9	46.0	27.0
Allegan	July 31	14.7	----	10.1
	Aug. 3	18.5	19.4	7.3
	" 7	25.5	38.0	18.0
	" 11	40.4	55.0	23.3
	" 15	38.8	61.8	58.5

DISCUSSION

The increase in total sugars between 0 and 9 days after red coloration was about 11 percentage points or almost one-fifth on a dry weight basis (Fig. 1). On a fresh weight basis, however, the change in total sugars would appear much smaller (about 1.7 percent) so as to be of minor value as a measure of ripening by a field test. Furthermore, total sugar changes are relatively small once the fruit turns red in color and would have little application alone as a maturity index.

Changes in acidity and pH (Fig. 2) of the fruit during ripening were the largest and might possibly be used alone as a harvesting standard.

Some of the constituents which showed changes but which probably have little practical application as a field test for ripeness were ether soluble material, acid hydrolyzable polysaccharides, and starch. The ether soluble fraction, which was the residue in the ether extract after extraction of the sample for sugar determinations, was composed mainly of the lipids; fats and oils, waxes, and phospholipids. Possible non-lipid constituents contained in the ether fraction would be the resins, terpenes, sterols, and free fatty acids (Bonner, 1950). The Jersey blueberry fruit had a relatively high starch content (Fig. 3) which was probably associated with the many seeds in the fruit. Also, most of the acid hydrolyzable polysaccharides and ether

soluble fractions were probably in the seeds. Winton and Winton (1935) reported the percentage composition of air dry blueberry seeds as: water, 6.75; protein, 17.87; fat, 31.00; nitrogen free extract plus fiber, 42.72; and ash, 1.66.

To ascertain if the constituents of the cell walls were possibly related to the softening and breakdown of blueberry fruit with overripeness cellulose and lignin were determined. Although changes of these materials could not be easily adaptable to field measurements, they might account for the collapse of the tissues at the late stages of maturity. Changes in cellulose(Fig. 4) were slight and probably would not account for the softening of the flesh of the blueberry during ripening. Lignin changes (Fig. 4) were more marked,however, it is likely that the seeds contained most of the lignin in the blueberry fruit (Winton and Winton, 1935).

Normally the pectin materials of cell walls rapidly change into soluble pectins with ripening. Apparently with blueberries these soluble pectins were rapidly broken down into pectic acids and other degradation products of pectin during the later stages of ripening. This would account, at least in part, for the softening and deterioration of the overripe fruit (Bonner, 1950).

Changes in pigment content were rapid during the early stages of ripening (Fig. 6). With pigment formation being rapid and of short duration,it offers possibilities as a test for maturity provided a simple and rapid test for its presence could be devised.

A comparison of the values in Table 2 to those Amling (1958) reported for average mineral content values for Jersey blueberry fruit collected the same year show that manganese contents are nearly equal, calcium and magnesium contents are lower and phosphorous, boron, iron, and copper contents are higher in Table 2. Magnesium content of fruit given in Table 2 correspond to the average values for magnesium in blueberry fruit reported by Ballinger (1958). However, calcium, phosphorous, manganese, and iron values were higher and copper and boron values are lower than the mean values he reported. The values for ash constituents in Table 2 are within the coefficient of variation values given by Ballinger.

The four minerals which changed significantly during ripening may have been translocated from the fruit as the fruit matured or the decline may have been due to a dilution from increased dry matter content. Since the moisture content of the berries was not determined the decline in mineral content cannot be definitely attributed to increased dry matter. It may be noted, however, that most of the minerals declined, especially after the first and second harvests, when the largest increase in sugars occurred. The percentage change in mineral content of the fruit during ripening from the initial harvest will show that the mineral content decreases most markedly during the 6 days after red coloration and then remains relatively constant.

Evidence to support the conclusion that there was an increase in dry matter content of the berries and thus perhaps a dilution in percentage mineral content during ripening was

given by Shutak et al. (1956). They found that berries ripened on the bush were about 3.6 percent higher in soluble solids than berries ripened off the bush, indicating that sugar was being translocated into the fruit from the leaves during the ripening process. They also presented data showing that soluble solids increased in five varieties by an average of 2.4 percent between red coloration and blue coloration of the berries. Their results, however, seem inconclusive since in the same paper they reported the average moisture content of berries was around 86 percent regardless of the stage of ripening. It would seem that the percentage moisture content should decrease with increases in the percentage soluble solids content. The fact that only 25 berries were used in their moisture determinations may account for the inconsistency of the data.

Four of the ash constituents determined spectrographically showed a significant decline with ripening. Of these four, only one, phosphorous is adaptable to a quick field test. Unfortunately, phosphorous did not follow a logical pattern so it probably could not be used as a test of maturity.

The value of a sugar-acid ratio as an index of ripening for other fruits (Agricultural Code of California, 1957) suggested its adaptation for blueberries. The ratio calculated from the data presented on percentage total sugars and the percentage titratable acids has been plotted in Fig. 7. Its suitability as an index of ripening is strongly indicated by the nearly linear relationship of the ratio to days from red

color development of the fruit. Further evidence for its application was needed, however, in respect to measurement of sugars and acids in the field on a fresh weight basis and for varieties other than Jersey.

The reason for the lower sugar-acid ratios for Jersey fruit in 1958 than in 1957 is not known. The most probable reason is the fruit differences associated with seasonal variations and other possible reasons are the differences in preparation of the sample for analysis and the different procedures of analyses. The sugar-acid ratios of the variety Rubel were smaller than for Jersey blueberries because of the higher total acid content of the Rubel fruit than of the Jersey fruit at all harvests, coupled with lower sugar contents at the first four harvests (Table 3).

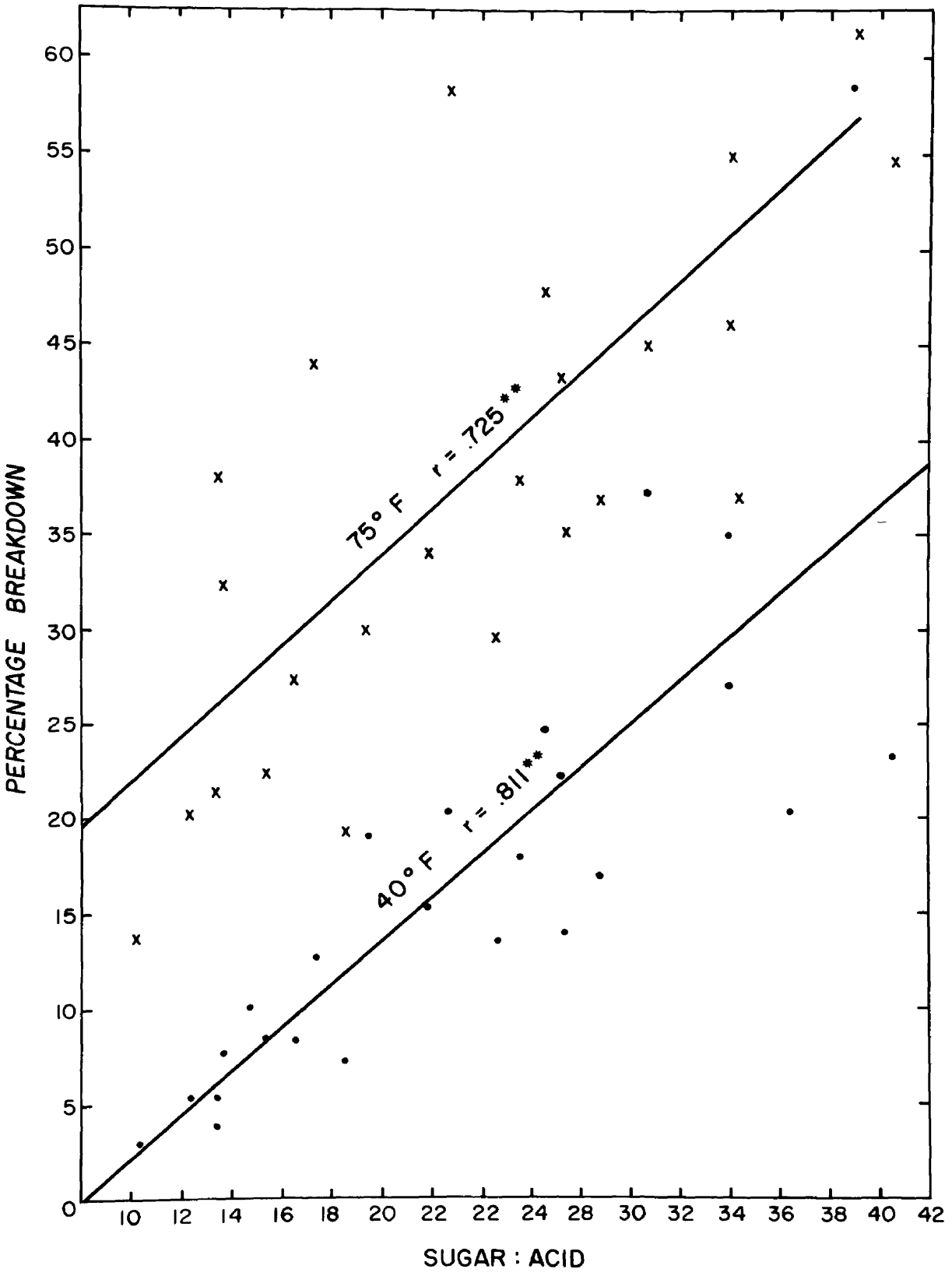
The admixture of berries of all degrees of ripeness accounts for the lower sugar-acid ratios of the final harvests of the maturity plots (Table 4) than for the final harvest of the tagged fruit of known ripeness at 20 days (Table 3). The highest ratio obtained for fruit of mixed degrees of ripeness was similar to the ratio obtained for tagged fruit 12 days after red coloration. The decrease in ratios between the fourth and fifth harvests in the plantations near Holland, Grand Junction, and Allegan may have been caused by the abscission of ripe berries of the first ripening flush during this interval or it may have been due to a normal change of the ratio in overripe fruit as shown in Fig. 7. There was a tend-

ency for the straight line relationship of sugar-acid ratios to ripeness to fail when the fruit was extremely overripe. This occurred for the last pickings of Jersey fruit in 1957 and 1958 and Rubel in 1958 and came about as the decline in acid content became smaller and as sugars began to decrease.

Fruit deterioration following harvest (Table 4) was related to the sugar-acid ratio (Fig. 8) and the linear correlation coefficient of these properties at both temperatures was highly significant. The correlation at 40° F. was higher than at 75° F. probably because of greater mold growth at 75° F. which developed as secondary infection following breakdown. Mold growth was considerably inhibited on berries held at 40° F. for the 18 days in which they were kept in storage. The parallelism of the regression lines at the two temperatures indicates therewas a marked dependence of keeping quality or shelf life upon the degree of ripeness regardless of the temperature at which the fruit was stored. A temperature of 32° F. would further decrease deterioration of blueberries according to the studies of Bünemann et al. (1957).

Shutak et al. (1957) suggested the importance, in Rhode Island, of delaying harvest as long as practical after blue coloration to obtain maximum fruit size, however, the danger of delaying harvest too long in Michigan is evident from the marked dependence of shelf life upon the degree of ripeness of the blueberries at harvest. Their suggestion was probably based upon the observation that the berries from the varieties

Fig. 8. The linear correlation of sugar-acid ratios of Jersey blueberry fruit with the percentage breakdown in storage for 6 days at 75° F. and 18 days at 40° F.


PERCENTAGE BREAKDOWN
SUGAR : ACID
75° F r = .725**
40° F r = .811**
0
5
10
15
20
25
30
35
40
45
50
55
60
10
12
14
16
18
20
22
22
24
28
30
32
34
36
38
40
42

Pioneer, Pemberton, and Dixi, in Rhode Island, drop off 3-4 days after blue coloration as reported by Hindle et al. (1957). However, Young (1952) reported that berries remained on the bushes 10-12 days after reaching "maturity" in Michigan. The latter report is in agreement with the observations during this experiment in 1957 and 1958. Few of the tagged berries of the varieties Jersey and Rubel abscissed when left on the bushes 20 and 24 days, respectively, after red coloration.

Comparisons of the use of sugars or acids alone, or the sugar-acid ratio were made for deriving a practical index for time of harvest. Table 5 shows the reliability of the three

TABLE 5

A COMPARISON OF THE LINEAR CORRELATION COEFFICIENTS AND STANDARD ERRORS FOR SUGAR-ACID RATIOS, SUGAR CONTENT, AND ACID CONTENT WITH THE PERCENTAGE BREAKDOWN OF JERSEY BLUEBERRY FRUIT HELD 18 DAYS AT 40° F. AND 6 DAYS AT 75° F.

Index	Fruit Deterioration			
	18 Days at 40° F.		6 Days at 75° F.	
	Correlation Coefficient	Standard Error(%)	Correlation Coefficient	Standard Error(%)
Sugar:Acid	0.811**	7.5	0.725**	10.4
Sugar	0.565**	10.6	0.537**	12.7
Acid	0.738**	8.6	0.696**	10.8

methods as an index for determining the percentage breakdown of fruit held at the two temperatures. The lowest standard errors and the highest linear correlation coefficients for

the sugar-acid ratio show it to be the most accurate of the three as a measurement of keeping quality of blueberries for storage or shipment.

The determination of sugars and acids had to be simplified in order to use the sugar-acid ratio as a quick test of ripening. Possibilities included soluble solids as a measure of sugar and pH for acid content. Therefore, soluble solids readings, sugar determinations, pH measurements, and titratable acid contents of the berries were made for fruit from the maturity plots. Many samples of Rubel and Jersey berries from a soil fertilization project were also utilized.

Total sugar content of blueberries averaged about two percent lower than the soluble solids content. This is consistent with the findings of Strachan et al. (1951) for apples, pears, apricots, cherries, peaches, and Italian prunes in which differences ranged from two percent (apple) to 7.6 percent (cherries) greater for soluble solids content than total sugar content. They noted a consistent relationship between the actual total sugar content and the soluble solids content for each kind of fruit and only slight variations for different varieties of the same fruit. Some variation occurred with the degree of maturity and ripeness with sugar making up a slightly greater percentage of the soluble solids in more mature fruit of any one variety.

A linear correlation calculated for soluble solids content and total sugar content of blueberries was highly significant with a correlation coefficient of 0.62 and a standard error of

estimate of ± 1.12 percent. This indicated that soluble solids readings obtained by a hand refractometer would be a reliable measure of sugar content of blueberries.

There was a positive linear correlation between pH measurements and titratable acid content with a high correlation coefficient of 0.916 and a small standard error of estimate of ± 0.074 percent. Obviously, pH measurements would be an adequately precise means of determining the total acid content of blueberries.

Ratios calculated from the soluble solids and acid contents of other fruits are used as harvesting standards (Agricultural Code of California, 1957). It seemed feasible that the measured soluble solids content would serve as well as the total sugar content as estimated by soluble solids readings for obtaining a ratio for blueberries. Its reliability was ascertained by correlating fruit deterioration (Table 4) with the ratio of estimated sugar content from soluble solids readings to acid content as estimated from pH, and a correlation of deterioration with the ratio of soluble solids to estimated acid content. These linear correlations are summarized in Table 6.

The similarities of the two coefficients of correlation and standard errors at each temperature are good evidence that

TABLE 6

A COMPARISON OF THE LINEAR CORRELATION COEFFICIENTS AND STANDARD ERRORS FOR ESTIMATED SUGAR-ACID RATIOS AND SOLUBLE SOLIDS-ESTIMATED ACID RATIOS WITH THE PERCENTAGE BREAKDOWN OF JERSEY BLUEBERRY FRUIT HELD 18 DAYS AT 40° F. AND 6 DAYS AT 75° F.

Ratios of Fruit Constituents	Fruit Deterioration			
	18 Days at 40° F.		6 Days at 75° F.	
	Correlation Coefficient	Standard Error	Correlation Coefficient	Standard Error
Estimated Sugar: Estimated Acid	0.715**	8.94	0.609**	11.90
Soluble Solids: Estimated Acid	0.718**	8.91	0.613**	11.87

the soluble solids-acid ratio was equally reliable as a ratio of the estimated sugar and acid, for predicting the shelf life of Jersey blueberries.

CONCLUSIONS

Chemical analyses of Jersey blueberry fruits of known and uniform physiological age showed marked changes with ripening as follows: (1) increased total sugars, (2) decreased titratable acid content, (3) increased ratio of sugars and acids, (4) increased pH, (5) increased pectin methylesterase activity and decreased soluble pectin content, and (6) increased intensity of pigmentation. Insignificant changes in chemical content with ripening were found for: (1) starch, (2) acid hydrolyzable polysaccharides, (3) ether soluble material, (4) cellulose, and (5) lignin. Statistically significant decrease were found to occur for calcium, magnesium, manganese, and phosphorous contents with ripening. The change of the sugar-acid ratios of the fruit with advancement of physiological age was outstanding and most likely of practical significance for measurement of ripening. It was found that pH gave a reliable measure of the acid content of the fruit and that a hand refractometer measurement of soluble solids served to measure the percentage sugar content.

The sugar-acid ratio, for fruit harvested over a period of 20 days which initially contained fruit with variable degrees of ripeness and which contained a wider range of fruit ripeness as harvests progressed, were correlated with the percentage breakdown of the fruit in storage. Increases in the accumulation of ripening were

accompanied by increases in the sugar-acid ratios and the percentage breakdown in storage. It was found that the keeping quality of Jersey blueberry fruit was dependent upon the degree of ripeness, which in turn could be measured by a sugar-acid ratio. Since soluble solids and pH can be measured quickly in the field and soluble solids-acid ratios were equally reliable as a measure of ripeness as the sugar-acid ratios, their ratio could possibly serve as an index for harvesting blueberries.

SUMMARY

Jersey blueberry fruit on 18 uniform bushes of a commercial plantation near South Haven, Michigan, were tagged at the time of red color development in the skin. These fruit were harvested at 3 to 4 day intervals for a period of 20 days after red coloration to provide fruit of known and varying degrees of ripeness. The harvested fruit were quickly frozen, held at -5° F. until all harvests were completed and finally lyophillized in preparation for determination of their chemical constituents on a dry weight basis.

Extensive analyses of the fruit showed the following chemical changes occurred between red color formation and overripeness of the fruit:

1. The sugar content increased for 9 days and then remained constant.

2. The titratable acid content decreased continually and the pH increased continually as ripening progressed.

3. The intensity of pigmentation increased the first 6 days following red coloration and then did not change.

4. Soluble pectin contents decreased continually and, associated with this, the pectin methylesterase activity increased.

5. Other organic constituents, namely, starch, acid hydrolyzable polysaccharides, ether soluble matereal, lignin,

and cellulose did not change markedly.

6. Changes in mineral constituents were relatively small and inconclusive with ripening.

There was a linear relationship between the sugar-acid ratios of the fruit and ripening of the fruit. As the degree of ripeness increased the sugar-acid ratios increased.

To substantiate this relationship, the test was repeated the following year for Jersey blueberries using the same bushes. Fruit of the Rubel variety were also harvested at known stages of ripening. Both varieties were analyzed for total sugars and titratable acid contents of the fresh fruit for calculation of sugar-acid ratios. The linear relationship of sugar-acid ratios to the degree of ripeness of the fruit held true for both varieties.

To determine if sugar-acid ratios are applicable to field testing the degree of ripeness of blueberry fruit, five plots of 20 Jersey bushes each were used from commercial plantations at five different locations in western Michigan. Varying degrees of ripeness of the fruit were provided by harvesting one set of four bushes of each plot at each of five harvests. No fruit were harvested from a set of bushes prior to the designated time of harvest. Fruit from these plots were held at 75° F. for six days and at 40° F. for 18 days and then examined for breakdown. Shelf life of the blueberries was highly correlated with the sugar-acid ratios of the fruit at harvest time. As the sugar-acid ratio

increased the shelf life of the fruit decreased.

Since soluble solids can be determined with a hand refractometer and acid content can be estimated by pH measurements, the use of a soluble solids-acid ratio may possibly be used to determine the proper harvest time for blueberries.

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