OBJECTIVE QUALITY TESTS IN EVALUATING FROZEN STRAWBERRIES

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INTRODUCTION

The strawberry is the most widely grown small fruit in the United States. It is grown on large scale for market in many localities and in home gardens throughout the country. Commercial and home crops have an annual value of about $85.5 million (44, p. 6). California, Oregon, and Washington produce over half the nation's strawberries and rank first, second, and third, respectively, in pounds of fresh fruit produced (29, p. 47). These three states produced about 66.8% of the total crop in 1957 (4, p. 5).

The great expansion in strawberry production has been aided by the technological advances in preserving foods by freezing. Prior to preservation by freezing, the short shelf-life of the fresh fruit was a major factor in limiting the commercial production of strawberries. Since the frozen food industry has made strawberries available throughout the year, they are no longer considered a seasonal delicacy.

The strawberry freezing industry has developed with exceptional rapidity and is now concentrated in the three Pacific Coast states of California, Oregon, and Washington. The 1946 output of this region represented only 48% of the national pack of frozen strawberries, while the 1956 output was about 82% (8, p. 1). The 1957 frozen strawberry pack was about 88.6% of the total (4, p. 5).

For the success and continued growth in consumption of most products it is necessary that they be highly acceptable to the consumer. The consumer is looking for good quality products and at the same time is not willing to pay high price for them. The processors, therefore, strive to produce products that will be of high quality as compared to price and meet acceptance by the consumer. Competition also forces the processors to improve or up-grade their products relative to costs and make them available to the consumer at low competitive prices.

The strawberry freezing industry is concerned with the problem of evaluating the quality of frozen strawberries they produce. They would like to pack and market only those berries which would please the consumer and assure repeat sales.

The only official method developed so far for evaluating frozen strawberries is the one under which the Agricultural Marketing Service (AMS) of the United States Department of Agriculture has established standards for grades of this product (43, p. 1-6). These standards are based on visual inspection of frozen strawberries. The AMS inspectors require a personal aptitude and many years of practical experience in order to become adept and skilled in their art. After this long training period, their visual judgments of frozen strawberries are nevertheless based on personal preferences and interpretations and are comparative and largely qualitative in nature.

The other somewhat more satisfactory but not officially recognized procedure employed by some large food processors is to present representative samples of a product to the taste panels and ask for their opinion of the product. However, in order that these evaluations be meaningful the judges are selected and trained, at great expense, for acuity and consistency. These newly developed taste test methods still possess the inherent defect of being subjective and, if not properly designed, fail to provide any useful information. These evaluations are difficult to conduct, expensive, and time consuming.

In view of the costs attending the use of trained taste panels, another possibility would be the application of objective measurement of various fruit quality attributes for evaluating frozen strawberries. It is possible that some physical and/or chemical attribute would correlate with the findings of the trained AMS inspectors and taste panels and would provide a quantitative basis for evaluating frozen strawberries. However, before one can correlate objective and subjective evaluations it is necessary to know which of the various objective determinations are capable of showing differences in frozen strawberries.

The study reported here was designed and conducted to obtain information as to which of the physical-chemical determinations could differentiate amongst frozen samples of five strawberry varieties as affected by date of harvest and length of storage. The information obtained from this work can be useful in later studies wherein correlation between the promising objective determinations and the subjective findings of trained panels may be used in evaluating the level of consumer acceptance and also for describing objectively the standards for grades of frozen strawberries.

REVIEW OF LITERATURE

The scope and importance of food quality evaluation are very great. Food quality and the methods of controlling it concern the food processor and all those in the field of food science and technology. It is also of increasing interest to the farmer as the primary producer and to the agricultural scientist, since the quality of a finished product can be no better than that of the raw material from which it is made.

Strawberries are frozen for the market for use as desserts, or for use in ice cream, sherbet, preserves, and other products. With the growing consumption of frozen strawberries in this country (33, p. 14) and the rapidly developing interest of the consuming public in this product, maintenance of uniform quality and improvement in quality have become matters of increasing importance to the berry packers in the states of California, Oregon, and Washington.

Quality is commonly thought of as a degree of perfection. Before quality can be evaluated and effectively controlled, there must be both definition of the particular attribute in question together with a reliable method for its assessment. The Taste Testing and Consumer Preference Committee (1958) of the Institute of Food Technologists (41, p. 736) has defined quality as: "The composite of those characteristics that differentiate among individual units of a product and have significance in determining the degree of acceptability of that unit by the user." Quality, then, is its conformance to specifications, which are nothing but ranges of acceptance.

It is generally recognized that the quality of any product is determined by its attributes. These attributes were until recently measured subjectively. The main difficulty encountered in the use of the subjective tests is their instability or tendency to drift in meaning with time and with judges. It is only recently that some objective methods have been developed to measure quantitatively some quality attributes such as color, flavor, and texture. Kramer and Twigg (23, p. 153-220) have reviewed the general principles and instrumentation for the physical measurement of food quality with special reference to fruits and vegetables.

Color

Some persons say that Americans eat with their eyes instead of with their palates. That is an overstatement, but certainly appearance is one of the bases of our judgment of excellence. The appearance of any object is of primary importance for its acceptance by the consumer. Color is one of the first properties of that object that the consumer notices. Color is such a good salesman that first sales in today's supermarket are made on the basis of eye-appeal.

The Agricultural Marketing Service of the United States Department of Agriculture has promulgated grades for many food products. These grades provide a common language among producers, processors, dealers, and retailers for trading purposes for a commodity. They can also serve as shoppers' aid to the consumers. Color is used as one of the main criteria for establishing standards for these grades.

In establishing the standards for grades of frozen strawberries, color is allotted 40 points out of a possible 100 (43, p. 2).

Since color is one of the significant attributes of food quality, a great deal of effort has been expended in the study of the measurement of this characteristic, both as an index of change in the furtherance of research and as an index of quality in terms of consumer acceptance. The literature on the tools and technics of color measurement has been extensively reviewed by Judd (21, p. 80-296), Robinson _et al._ (35, p. 269), Shah (38, p. 6-12), and Kramer and Twigg (23, p. 158-175).

The objective indication of color differences in food has usually been attempted in a simplified, indirect way that involves a comparison of some physical characteristic of the sample or, more often, an extracted fraction that is assumed to be largely responsible for the associated color characteristics. Sondheimer and Kertesz (40, p. 246) described a method for determining the content of anthocyanin pigment in strawberries with the use of a spectrophotometer. This method is rather long and is not suitable for a production line or quality control type of analysis.

Another approach to the measurement of color of foods is to use a photoelectric tristimulus colorimeter. Robinson _et al._ (35, p. 269-275), Shah (38, p. 19-20), Hoover and Dennison (19, p. 195-198), Tinsley, Sidwell, and Cain (42, p. 340), and many others used Hunter Color and Color-Difference Meter for measuring the color of foods and food products.

The Hunter meter measures color on three scales ("R_d" or "L," "a," and "b") which give uniform measure of the visual perceptibility of differences between colors. The various scales (18, p. 2) specify different color attributes as follows:

"R_d"	luminous reflectance
or	
"L"	visual lightness
"a"	redness when plus gray when zero greenness when minus
"b"	yellowness when plus gray when zero blueness when minus

Their relationship to each other is shown graphically in Figure 1.

In comparing Hunter meter readings with readings from other instruments and visual scores, various ratios of "R_d" or "L," "a," and "b" values have been used. Little, Chichester, and Mackinney (28, p. 403-409) reported on the use of the function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ which shows perceptibility differences. Working with tomato juice, Robinson et al. (35, p. 273-274) showed that the ratio a/b correlated with dominant wavelength and that the function $(a^2 + b^2)^{\frac{1}{2}}$ represented saturation or chromaticity. They concluded that the ratio of "a" and "b" readings was a convenient and accurate method of expressing color of tomato juice. Birth, Norris, and Yeatman (1, p. 552-557) recently developed an instrument to obtain measurements of internal color of tomatoes without destroying them, and used Hunter a/b ratio to check the validity and accuracy of their instrument. Francis (13, p. 213-

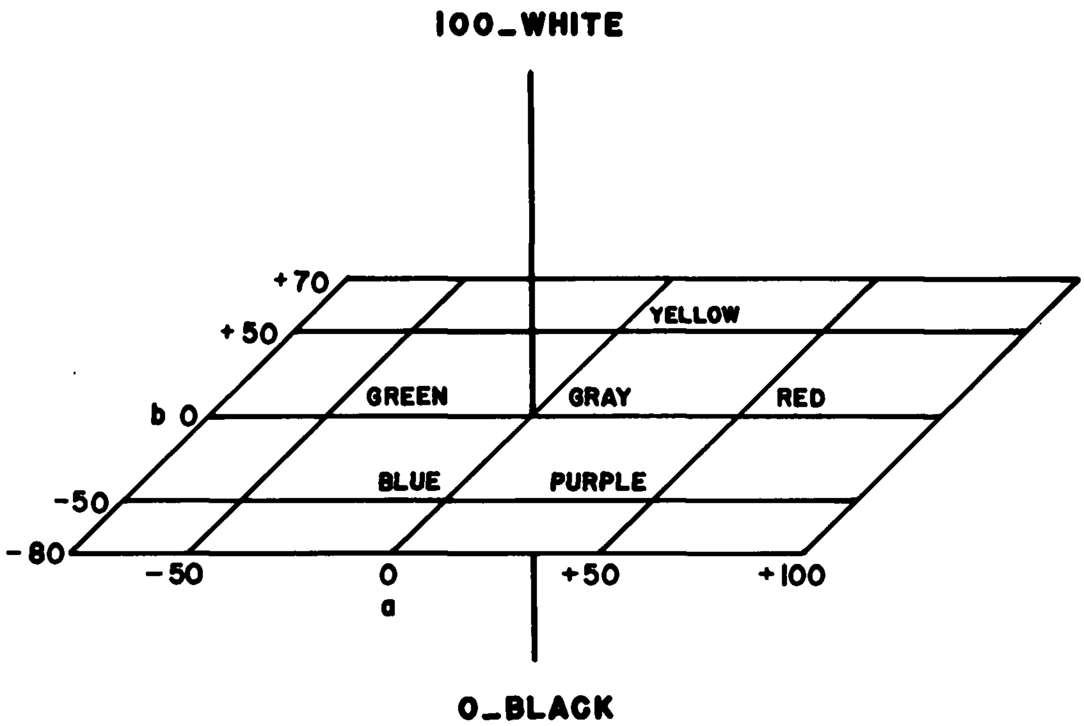

FIGURE 1.

DIAGRAM SHOWING DIMENSIONS OF THE HUNTER "L," "a," AND "b" COLOR SOLID.

220) observed that the a/b ratio was unsuitable for apples and used $\tan^{-1} a/b$ in his work.

According to Hoover and Dennison (19, p. 196-198) the "a" value was quite indicative of the amount of red pigment in strawberries and might be used for evaluation purposes, whereas "b" value was not affected by a change in the red pigment and, therefore, could be disregarded in the measurement of color in strawberries. They suggested that the formula

$$Y = \text{Antilog}\ (0.40239 + 0.03125\ X)$$

could be used for rating the color of strawberries where Y represented the p.p.m. Congo Red dye equivalents and X the "a" value of the Hunter meter.

Shah (38, p. 36) demonstrated that the use of Hunter "L" value alone was sufficient for describing the color of frozen strawberries, because "a" and "b" values did not have a significant effect on the "L" readings. He reported (38, p. 52) that the Hunter "L" values for commercially frozen (4:1) strawberries ranged from 14.8 to 20.6.

Volatile Reducing Substances (VRS)

The step between good and deteriorating food was never great in the primitive food industry, and lacking chemical procedures, men relied on sensory tests to detect differences. However, the aesthetic experience was also an early aspect of food appraisal. Next to color, odor played the major role in deciding if a particular food was fit and sound for consumption. In our advanced technical society, odor plays an important part in development of new products, maintaining and even enhancing the quality of foods. Color stimulates the consumer to purchase an item the first time, but odor and taste stimulate him to purchase the product again.

The volatile organic substances in foods and food products, although present in minute amounts, are of great importance since some of them impart the characteristic aroma to the food and, to a large extent, determine its quality. An organic chemist may be interested in characterizing these substances and other non-volatile materials (precursors) which may be converted into volatile compounds by using the conventional or special laboratory technics, such as distillation and chromatographic methods.

Coppens and Hoejenbos (6, p. 690) reported the presence of some twenty volatile constituents in the strawberry juice. McGlumphy (30, p. 354) confirmed the existence of certain compounds as reported by Coppens and Hoejenbos in strawberry juice and, in addition, identified three other compounds in strawberries. He also reviewed the literature on fruit flavors, and his survey showed that apple, banana, black currant buds, cherry, grape, peach, pear, raspberry, and strawberry all contain volatile flavoring compounds.

Dimick and Makower (9, p. 73-75) reviewed the literature on chemistry of flavoring compounds in strawberries and also reported the presence of fourteen compounds in the strawberry essence. Various flavor and essence manufacturers have used this knowledge and compounded synthetic strawberry flavors. Jacobs (20, p. 61-62) listed seventy-eight compounds which are normally used for the preparation of synthetic strawberry flavors.

The objective measurement of odor has been thus far largely an attempt to identify, isolate, and measure quantitatively the specific substances responsible for certain odors. Since these volatile substances occur in extremely minute quantities, their identification and quantitative estimation by the classical methods is extremely difficult, and certainly impracticable for use in quality evaluation work. There is need for the development of valid, reliable, quick, and cheap methods which may be easily carried out for evaluating the odor of foods and food products.

Lang _et al._ (24, p. 491) as well as others suggested that most types of volatile organic odoriferous compounds which conceivably might be present or formed in a food were oxidizable. This information was made use of by Lang _et al._ (24, p. 491-494), Leonard _et al._ (26, p. 479), and Farber and Ferro (12, p. 303) in developing procedures for measuring odors objectively.

The methods of Lang _et al._ and of Farber and Ferro are based on the principle of aeration of the sample at ambient temperatures, since these are the temperatures at which one usually encounters the volatile odoriferous compounds. The method of Leonard _et al._ embodies the principle of steam distillation of the volatile organic constituents of the foods. All these methods, however, employ potassium permanganate as the receiving agent.

Lang and associates (24, p. 490-494; 12, p. 303-304) and Moorjani _et al._ (31, p. 386) successfully used the VRS method for evaluating the quality of fish and also in following the changes brought about during spoilage of it.

Farber (11, p. 300-304) found the VRS method very versatile. He used this method with good results in evaluating the quality of a large variety of food products and other commodities such as apple, allspice, acacia, black pepper, bread, coffee, corn, cotton seed, garlic, red grape, large green grape, horseradish, lemon, marjoram, mustard seed powder (yellow and red), onion, orange, mock orange blossom, prune, raisin, rose, tangerine, and vinegar. He found the VRS method very sensitive, since gradations in samples, which were not easily evaluated organoleptically, could be readily measured by this method. On the basis of this and other studies he concluded that the VRS method could be regarded as a chemical means of evaluating odor intensity or, in other words, as a useful tool for odorimetry.

Leonard *et al.* (26, p. 478-482) and Claypool *et al.* (5, p. 375-380) used steam VRS determinations with work on maturity studies of Bartlett pears for canning. They found that the canned pears which were judged best for flavor and aroma had the highest VRS content. Leonard and associates, on the basis of their work with Bartlett pears, suggested that the steam VRS estimations provided an objective method for evaluating aroma of canned pears.

Other Physical and Chemical Determinations

Taste is an important component of flavor attribute of foods and food products. It is one of the senses, the receptors for which are located in the mouth and are activated by a large variety of different compounds in solution. Most of our knowledge of taste has come from studies on the reactions of humans to various foods. This method, however, is not a very accurate quantitative measurement. Information regarding taste reactions has been obtained objectively by using neural response of the sense receptors by employing electrophysiological technics. To use such complex technics in routine quality evaluation or inspection work with foods is impracticable.

In the absence of suitable direct methods for determining the taste of foods, advantage has been taken of the coincidental relationships between certain measurements and taste. The degree of sweetness can be approximated by a sugar determination or, where possible, more readily by a refractometer. Sourness may be measured by total acid determination or by the use of a pH meter. The ratio of sugar (per cent) or soluble solids (Brix°) to the acid (per cent), designated as the sugar/acid or Brix°/acid ratio, is widely accepted as a useful index of palatability in many foods. The horticulturists and others working with fruits refer to this ratio as "maturity ratio."

Reducing and Total Sugars

Culpepper, Caldwell, and Moon (7, p. 661-664) noticed that the content of total sugar in strawberry varied with different stages of maturity. They observed that the total sugar content was relatively low in young fruit. Free reducing sugar in most cases made up 60% to 90% of the total sugar content. At the stage of whitening, total sugar increased gradually, and the reducing sugar comprised 80% to 90% of the total sugar present. Yao (46, p. 22-23) found that the total sugar content of Marshall strawberry during the harvesting period (May 30-June 25) ranged from 5.36% to 9.78%. Smith and Heinze (39, p. 207-209) studied the composition of strawberries picked at various stages of maturity. Their work showed that the total sugar content of berries increased gradually as the fruit passed from quarter-colored to fully-colored stage. Rohrer and Luh (36, p. 647) observed that in boysenberries the amount of reducing sugars was greater than that of non-reducing sugars during all stages of maturity.

Soluble Solids (Brix°)

Gerhardt, English, and Smith (15, p. 247-252) reported that Italian prunes picked when their per cent soluble solids content reached 14 to 16 possessed the best quality. Wiley (45, p. 70) noticed that the soluble solids content of Italian prunes was 11.7% at the beginning of the harvest season and gradually increased to 16.5% toward the end of the season. Rood (37, p. 109) observed that the amount of soluble solids changed slightly and very irregularly as the peaches matured and varied significantly between the years. Leonard, Luh, and Hinreiner (25, p. 482) found that the soluble solids content of peaches ranged from 13.4% to 15.1%.

The soluble solids content of fruits like any other constituent is affected by the location where the fruits are grown. Robinson *et al.* (34, p. 6) reported that Marshall strawberries grown in New

York state contained 6.4% soluble solids. Yao (46, p. 22-23), working with the same variety grown in Oregon state, found that the soluble solids content of the berries was 7.9% during early harvest and 11.8% toward the end of the season.

Hartman (17, p. 19) determined the amount of soluble solids of canned prunes and found that it ranged from 26.0% to 28.9%. The prunes containing 28.6% soluble solids had the most desirable taste. Wiley (45, p. 92) reported that the canned Italian prunes from the first harvest contained 22.9% soluble solids as compared to 25.6% for the prunes from the last harvest. Leonard, Luh, and Hinreiner (25, p. 484) noticed that the soluble solids content of canned peaches ranged from 19.2% to 21.6%.

pH

Wiley (45, p. 130) determined the pH value of prunes from different trees during nine harvest dates and found that it ranged from 3.10 to 3.58 as the fruit matured. Leonard, Luh, and Hinreiner (25, p. 482), working with peaches, observed that the pH of the maturing fruit increased and reached its peak when the fruit was fully ripe.

The chemical composition of 43 strawberry varieties reported by Robinson *et al.* (34, p. 6) show that the pH values for these varieties ranged from 3.37 to 3.88. Yao (46, p. 22-23) found that the pH value of Marshall strawberries was 3.20 at the beginning of the harvest season, but increased to 3.62 toward the end of the season.

Wiley (45, p. 105) showed that the pH values of the canned prunes from nine harvest dates ranged from 3.19 to 3.45. He did not find any consistent pattern of change in pH of the canned prunes. Leonard, Luh, and Hinreiner (25, p. 484) found that the pH of canned peaches ranged from 3.90 to 4.07.

Titratable Acidity

The studies conducted by Culpepper, Caldwell, and Moon (7, p. 663-664) showed that the titratable acidity decreased rapidly as the strawberry fruit matured. Yao (46, p. 22-23), working with Marshall strawberry found that the titratable acidity ranged from 1.16% to 0.74% during the harvesting season. Smith and Heinze (39, p. 209) studied subsequent color development and composition of strawberries picked at various stages of maturity and observed that quarter-colored berries on an average contained two-tenths of one per cent more titratable acidity than fully-colored berries. Robinson *et al.* (34, p. 6) reported the acid values for 43 strawberry varieties. These values ranged from 1.49% for *Fragaria virginiana* 27 to 0.52% for Sparkle.

Working with Italian prunes, Wiley (45, p. 78) observed that the total acid in the fruit from the early harvest was 1.04% and dropped to 0.68% in the fruit from the last harvest.

Hartman (17, p. 19) noticed that the titratable acidity of the canned prunes from different harvests ranged from 0.99% to 0.59%. He concluded that canned prunes containing about 0.6% acid had the best flavor characteristics. Wiley (45, p. 143, 157) presented data for canned prunes from different harvests and showed that the fruit with 0.42% acid was judged the best. Dryden and Hills (10, p. 590) studied the consumer preference of applesauce and noted that the sauce containing about 0.45% acid was preferred by most tasters. Leonard, Luh, and Hinreiner (25, p. 484) observed that the acid content of canned peaches ranged from 0.25% to 0.37%.

Soluble Solids/Acid Ratio

Gerhardt, English, and Smith (15, p. 247-252) reported that the ratio of soluble solids to acid offered the most practical guide to prune quality. Fruits picked with soluble solids/acid ratio of 14.5 were best for fresh fruit shipments. During the three-week period of harvesting, the soluble solids/acid ratio of the fruits ranged from 10.5 for the first harvest to 17.2 for the last harvest. Working with Italian prunes, Wiley (45, p. 78, 81) found that the average soluble solids/acid ratio of the fresh fruits ranged from 11.33 in the beginning of the harvest season to 24.15 toward the end of the season. On the basis of statistical analysis of the taste panel scores, he suggested that the use of soluble solids/acid ratio was satisfactorily precise in predicting the canned fruit flavor.

The soluble solids/acid ratio is customarily accepted in the citrus industry as the standard of maturity. This ratio is considered the best single chemical criterion of quality of oranges and grapefruits. Braverman (3, p. 173) reported that the California regulations concerning citrus industry standards required a minimum ratio of 8.0 for oranges and 7.0 for grapefruits, whereas the South African standards were 5.0 for seedling oranges, 5.5 for Valencias, and 6.0 for navels. In Palestine, the ratio of 8.0 was adhered to.

Smith and Heinze (39, p. 209) presented data on soluble solids and total acid for strawberries picked at various stages of maturity. The soluble solids/acid ratios calculated from these data show that they ranged from 4.92 to 11.51. Robinson et al. (34, p. 6) determined the soluble solids and titratable acidity values of 43 varieties of strawberries. The calculated soluble solids/acid ratios for these varieties ranged from 4.95 to 12.33.

Leonard, Luh, and Hinreiner (25, p. 482) found the ratio of soluble solids to total acid a good index of the maturity changes in cling peaches. Rood (37, p. 109), who conducted his studies on California freestone peaches, noticed that the soluble solids/acid ratio was better than titratable acidity alone for judging the maturity of peaches.

Hartman (17, p. 19) observed that canned prunes with 28.7% soluble solids and 0.6% total acid were considered to possess the best flavor. These values show that canned prunes with soluble solids/acid ratio of 47.83 were liked by most tasters. The data presented by Wiley (45, p. 143, 154, 157) indicate that canned Italian prunes having 55.5 soluble solids/acid ratio obtained the highest flavor score.

Working with peaches Leonard, Luh, and Hinreiner (25, p. 483) found that the fruit which had a soluble solids/acid ratio of 57.0 was liked the best. Dryden and Hills (10, p. 590), who studied consumer preference for applesauce, noticed that sauce having soluble solids/ acid ratio of 48.8 was preferred by most tasters. Rohrer and Luh (36, p. 648) observed that when the filling used in boysenberry pie had a soluble solids/acid ratio of 25.7 the flavor rating was poor, whereas when the filling had a soluble solids/acid ratio of 30.7 to 31.2 it was considered of superior quality.

Total Solids

Texture is intimately associated with the structural make-up of the fruit or vegetable matter whether raw or processed. Variations in texture can be usefully employed in differentiating the different varieties of a particular fruit. Various instrumental methods have been developed for measuring this quality attribute of foods. Kramer and Twigg (23, p. 197-209) described many instruments and procedures for this purpose.

Moisture or inversely total solids determination is probably one of the important and widely used analytical measurements in the processing and testing of foods and food products. Moisture content of sweet corn has been established as a reliable index of maturity in the canning stage. Geise, Homeyer, and Tischer (14, p. 250) reviewed the literature on this subject. Kramer (22, p. 410-413) found that moisture determination of sweet corn along with the determinations for pericarp and kernal size was useful in predicting processed quality accurately.

Culpepper, Caldwell, and Moon (7, p. 668) did not find any correlation between firmness and the amount of total solids present in strawberries at different stages of maturity. Haller, Harding, and Rose (16, p. 334), however, noticed that a direct correlation existed between the per cent dry weight and the firmness of different strawberry varieties.

MATERIALS AND METHODS

A large number of strawberry varieties are grown in the Pacific Coast states for the fresh fruit market and for the frozen-pack. In Oregon, Marshall and Northwest are the primary commercial varieties, followed by Siletz and Puget Beauty. Lassen is a California variety and is grown to a certain extent in Oregon. These five varieties were included in the studies reported here.

Source of Material

Fruit was obtained from two harvests fifteen days apart. During the early harvest the samples of fruit of Marshall, Northwest, and Puget Beauty varieties were collected from the Stayton Canning Company, Stayton, Oregon, that of Lassen from a farm near Salem, Oregon, and that of Siletz from a farm near Corvallis, Oregon. The samples of fruit of all the five varieties of the late harvest were obtained from the Stayton Canning Company. The fruit had been picked in the usual manner for commercial handling, i.e., some berries had their caps on whereas others were without caps.

Handling of Material

Fruit of all varieties from a harvest was processed within eight hours of harvest. Fruit of each variety was washed separately in a small McLauchlan berry washer, and the caps removed. During the washing operation all blemished, moldy, crushed, green or otherwise unfit fruit was removed. The berries were sliced in a McLauchlan centrifugal slicer set to a thickness of one-quarter inch.

Packaging and Storage Procedures

Cane sugar (sucrose) was added to the sliced and weighed strawberries to obtain a 4 plus 1 fruit to sugar ratio on weight basis. The sliced berries and sugar were mixed by hand. The mixture was then filled into 303 x 406 fruit enamel cans at the rate of 15 ozs. per can. The cans were sealed by an American Can Company, Model 6, automatic double seaming machine. They were coded with random numbers, quick frozen at -18° F. for 24 hours in a blast freezer, and then held in storage at 0° F. until evaluated. Twenty cans of each variety from each harvest were prepared in this manner.

Preparation of Strawberries for Objective Tests

Two cans of each variety from each harvest were removed from storage and placed in a room maintained at 34° F. Thawing of the contents of the cans occurred during the succeeding 24-hour period. The cans were then opened and the contents mixed in a stainless steel bowl. A suitable uniform sample of berries and sirup was immediately removed for color measurements, and the remaining sample was pureed in a Waring Blender for 30 seconds. This pureed sample was used for other objective determinations.

In order to avoid any appreciable loss of flavoring constituents a portion of the pureed sample was immediately transferred to a

250-ml. centrifugal bottle, and the sample centrifuged at 4,000 r.p.m. for one hour. The supernatant sirup was used for the estimation of the volatile reducing substances.

Objective Tests

Duplicate samples of frozen strawberries were quantitatively examined and analyzed for color (Hunter "L," "a," and "b"), volatile reducing substances, reducing and total sugars, soluble solids (Brix$^{\circ}$), pH, titratable acidity, and total solids (dry matter).

The Hunter "L," "a," and "b" readings were used to calculate values such as L + a, L + b, a + b, L + a + b, a/b, $(a^2 + b^2)^{\frac{1}{2}}$, and $(L^2 + a^2 + b^2)^{\frac{1}{2}}$. The reducing sugars/acid, total sugars/acid, and soluble solids/acid ratios were also calculated.

The physical-chemical analyses of the frozen strawberries were conducted at the end of three- and six-month storage periods at 0° F.

Color Measurements

The color was measured by using a Hunter Color and Color-Difference Meter. The method of Tinsley, Sidwell, and Cain (42, p. 340) as modified by Bockian and Hirzel (2, p. 49) was used in presenting the samples of frozen strawberries to the Hunter meter for color measurements.

The procedure as outlined in the printed instructions (18, p. 5) provided by manufacturers of the Hunter meter was followed in standardizing the instrument. The Hunter "L" color scale was used (38, p. 22). The instrument was standardized against a National Bureau of Standards red enamel plaque SKC 70 having the following "L" color scale values: "L" = 27.0, "a" = + 48.8, and "b" = +16.4.

A sample of non-experimental sliced and sugared (4:1) strawberries was put in a circular 9-inch dish of clear plastic, and the dish placed in position (Figure 2) for rotating. The dish was rotated at various speeds to arrive at a rate at which the galvanometer would give a constant reading, and also that which would not affect the position of the fruit in the dish due to centrifugal force. Speeds between 30 and 80 r.p.m. were found to give a steady reading on the galvanometer. This indicated that the instrument was "seeing" an apparently uniform object. Any individual reading ("L," "a," or "b") taken from the Hunter meter, when the sample was rotating, was found to be mathematically equal to the arithmetic mean of a large number of individual readings taken at random spots on the surface of the sample at rest. A speed of 50 r.p.m. was consequently selected for the experimental work.

Volatile Reducing Substances (VRS)

The VRS method of Lang *et al.* (24, p. 490-494), as modified by Farber and Ferro (12, p. 303), was used for determining the volatile reducing substances of the frozen strawberries. The various reagents used were as follows:

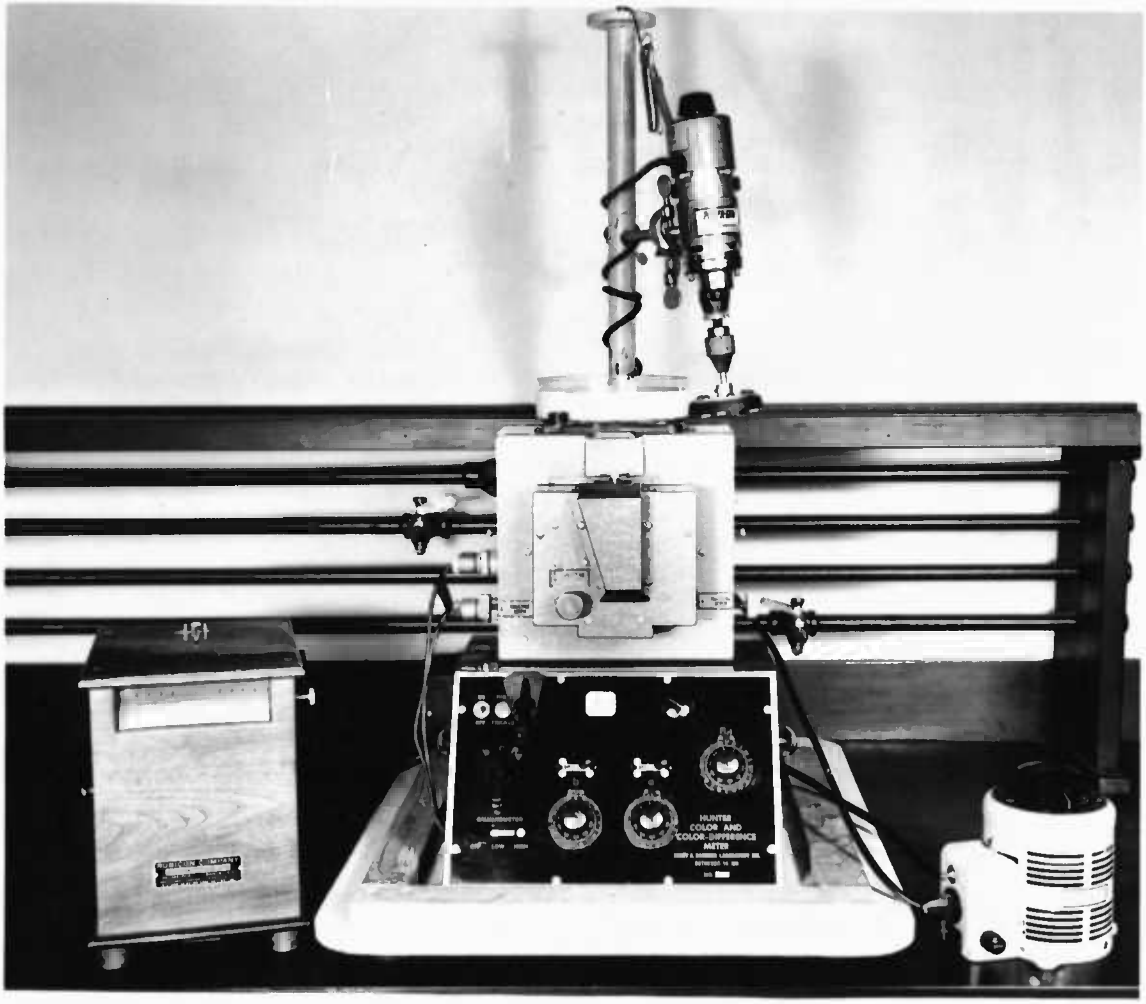

FIGURE 2.

THE HUNTER COLOR AND COLOR-DIFFERENCE METER

WITH SPINNING ATTACHMENT

0.02 N potassium permanganate in N sodium hydroxide solution.

6 N sulfuric acid.

20% potassium iodide in 0.1% sodium carbonate solution.

0.02 N sodium thiosulfate ($Na_2S_2O_3 \cdot 5\ H_2O$) in 0.2% sodium carbonate - 0.1% sodium tetraborate ($Na_2B_4O_7 \cdot 10\ H_2O$) solution.

1% soluble starch in saturated sodium chloride solution.

A 10-ml. sample of previously centrifuged and clarified sirup was put in aeration flask A (Figure 3), and 10 ml. of the potassium permanganate solution were put in reaction flask B (Figure 3). The VRS of the sirup were aspirated in 40 minutes into the potassium permanganate solution.

The excess potassium permanganate was determined as follows: Contents of flask B were acidified by adding 5 ml. of sulfuric acid. Three milliliters (an excess) of potassium iodide solution were then added to this flask, and the liberated iodine titrated against sodium thiosulfate solution, using five drops of starch solution as inside indicator.

A control was run, every day the experimental determinations were conducted, by using 10 ml. of distilled water instead of the strawberry sirup and treating the potassium permanganate as in the test determinations. The difference between the control and the test titrations represented the amount of potassium permanganate reduced.

Two units of the VRS apparatus were set up at a time for any one sample to obtain duplicate readings. The average amount of potassium permanganate reduced multiplied by 1000 times the normality of the sodium thiosulfate solution yielded the amount of microequivalents

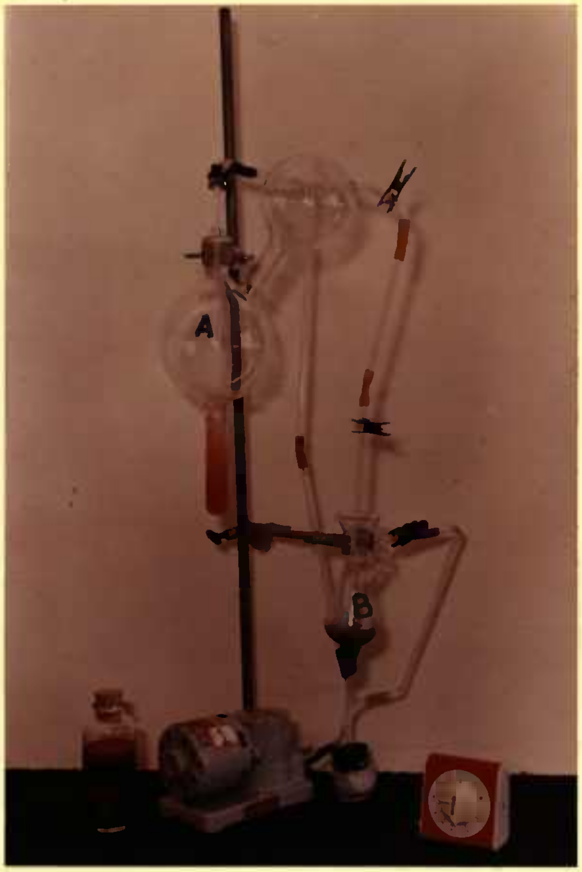

FIGURE 3.

A SINGLE UNIT OF APPARATUS FOR THE DETERMINATION

OF VOLATILE REDUCING SUBSTANCES

reduced by the volatile reducing substances of the 10-ml. sample. A sample calculation is as follows:

Titration	Ml. of 0.02 N sodium thiosulfate solution: First Vessel	Second Vessel
Control	9.8	9.9
Test	7.3	7.5
Difference	2.5	2.4
Average Difference	2.45	

Microequivalents of reduction = 2.45 x 1000 x 0.02

= 49/10-ml. sample

Reducing and Total Sugars

The colorimetric ferricyanide method of Morell (32, p. 249) was used for estimation of reducing and total sugars in the frozen strawberries. The various reagents used were:

Stock solution A	40.00 g. of reagent grade potassium ferricyanide and 40 g. of sodium carbonate monohydrate dissolved in distilled water, and the volume made up to 2000 ml.
Stock solution B	40% sodium carbonate monohydrate solution.
Molar	neutral lead acetate solution.
20%	disodium phosphate solution.
1 N	hydrochloric acid.
1 N	sodium hydroxide.

A fresh solution of the alkaline ferricyanide, exactly 0.05% in potassium ferricyanide and approximately 1% in sodium carbonate concentration, was prepared each time it was used, by pipetting 50 ml.

of each of stock solutions A and B into a 2000-ml. volumetric flask and diluting to volume with distilled water.

A Coleman Combined Nepho-Colorimeter, Model 9, and 25 x 105 mm. PH Coleman cuvettes were used. The colorimeter was standardized at 100% transmittance using distilled water and the PH Coleman No. 8-203 blue (430 mmu) filter.

A standard sugar curve was prepared by using a dozen 2-ml. aliquots of sugar solution containing 0.1 to 1.2 mg. of total dextrose per tube and reading per cent transmittance, after allowing the dextrose to react with 25 ml. of alkaline ferricyanide. The per cent transmittance data from acid-inverted sucrose produced an identical curve. For convenience in calculation, a sugar table was prepared from the standard curve by means of which any observed reading could be readily converted to milligrams of glucose or invert sugar.

The details of the experimental procedure were as follows: A 5-g. sample of pureed strawberries was diluted to 160 ml. with distilled water and filtered through a Whatman No. 1 paper. A 5-ml. aliquot of the filtrate was pipetted into a 50-ml. volumetric flask, 2 ml. of neutral lead acetate solution added and the contents thoroughly mixed. After 5 minutes, 5 ml. of sodium phosphate solution were added and the volume made up to mark with distilled water, and filtered. A 2-ml. aliquot was transferred to a 25 x 190 mm. test tube to which 25 ml. of the alkaline ferricyanide reagent were added. Blanks were included using 2 ml. of distilled water and 25 ml. of the alkaline ferricyanide reagent.

For total sugars, a 10-ml. portion of the clarified sample was transferred to a 25-ml. volumetric flask, 5 ml. of hydrochloric acid added, and the inversion conducted by immersion in a boiling water bath for 10 minutes. The flask was cooled in running water, 5 ml. of sodium hydroxide added to completely neutralize the acid, and the volume made up with distilled water. A 2-ml. aliquot was pipetted into a 25 x 190 mm. test tube to which 25 ml. of the alkaline ferricyanide were added.

The test tubes from both sets were gently shaken to mix the contents, put in a wire basket and immersed in a gently boiling water bath. The wire basket was held in the water bath in such a manner that the contents of the tubes were immersed to approximately two-thirds of their depth. Heating was continued for exactly 10 minutes and the basket then taken out and quickly immersed in a container of cold water. The tubes were cooled exactly 10 minutes by continuously running a stream of cold water in the container. The tubes were then taken out of the water and wiped from the outside. The colorimetric readings were taken by transferring the contents of the test tubes to clean, dry 25 x 105 mm. cuvettes and measuring the per cent transmittance in the colorimeter.

The per cent reducing sugar values were obtained directly by referring to the sugar table. However, in case of invert sugars the values obtained were divided by the factor 0.95 to derive the values for per cent total sugars (as invert sugars).

Soluble Solids (Brix^{o})

One tablespoon of pureed strawberry sample was squeezed in a 4-fold thickness of muslin to obtain clear sirup. A few drops of this sirup were placed on the clean and dry lens of a Toko Hand Refractometer (range 0-32%) and the per cent soluble solids of the sample read from the interval scale. This reading was then corrected for temperature and recorded. Duplicate readings were obtained by examining a second portion of the sirup.

pH

Approximately 100-g. sample of pureed strawberries was placed in contact with the electrodes of a Beckman, Model H-2 line operated pH meter, and the pH of the sample recorded. Duplicate readings were taken by using another sample of the same material. The pH meter had previously been standardized against a buffer of pH 4.0.

Titratable Acidity

The titratable acidity was determined by electrometric titrations. The same pH meter that was used for pH measurements was used for titratable acidity determinations. The meter in this case was, however, standardized against a buffer of pH 9.0.

A 10-g. sample of pureed strawberries was weighed into a 150-ml. beaker and diluted with 100 ml. distilled water. The sample was titrated to pH 8.0 using 0.1 N sodium hydroxide solution. Duplicate readings were obtained by using a second aliquot. The titratable acidity was calculated as per cent citric acid by the following formula:

$$\frac{\text{Ml. NaOH x Normality of NaOH x } 0.064^{*}}{\text{Weight of Sample (g.)}} \times 100 = \text{per cent citric acid}$$

* 0.064 = millequivalent weight for citric acid.

Physical and Chemical Ratios

Individual values of Hunter "L," "a," and "b," and those of reducing sugars, total sugars, soluble solids, and titratable acidity were used to calculate the various ratios as mentioned earlier.

Total Solids

Approximately 10-g. samples of pureed strawberries were evenly spread into tared aluminum pans and accurately weighed. The pans were then placed in a vacuum oven maintained at 70° C. temperature and 25-28 inches of vacuum for 24 hours. They were removed from the oven at the end of this period, cooled in a desiccator and reweighed. The weight of the dry matter after proper calculations was reported as the per cent total solids.

Statistical Methods

The analysis of variance calculations were performed for the various objective determinations and their derived ratios and functions according to Li (27, p. 167-169). The least significant difference (27, p. 233-238) and the new multiple range test (27, p. 238-241) were also worked out where necessary.

RESULTS AND DISCUSSION

The results will be presented and discussed under three general headings which will cover color, volatile reducing substances, and other physical and chemical determinations of frozen (4:1) samples of five strawberry varieties as affected by date of harvest and length of storage at 0° F.

It is appropriate to point out here that the figures given in the tables of mean values represent the averages of readings obtained from two replications analyzed at each storage period. Secondly, the value for the interaction term, variety x harvest x storage, was used as the divisor in deriving the various F values in all the analysis of variance calculations.

Results of Color Determinations

Hunter "L"

The Hunter "L" values are given in Table 1. These values ranged from 16.5 to 25.7.

These data were subjected to analysis of variance calculations, the results of which are shown in Table 2.

It may be seen from Table 2 that differences in Hunter "L" values due to variety, harvest, and interaction of variety with harvest were significant at the 5% level. The differences due to storage and also those due to its interactions with variety and harvest were not significant.

TABLE 1.
Mean Hunter "L" Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	20.80	22.15	21.50	20.55	21.25
Marshall	18.90	19.65	19.25	18.05	18.96
Siletz	23.95	25.70	23.45	23.40	24.13
Northwest	21.00	19.70	17.70	16.50	18.73
Puget Beauty	20.75	21.25	21.95	21.55	21.38
Storage Means	21.08	21.69	20.77	20.01	

TABLE 2.
Analysis of Variance for Hunter "L" Values Of Five Frozen (4:1) Strawberry Varieties as Affected By Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	38.4650	81.6667	S.
Harvest	1	9.9002	21.0195	S.
Storage	1	.0562	.1193	N.S.
Variety x Harvest	4	4.3640	9.2654	S.
Variety x Storage	4	1.1750	2.4947	N.S.
Harvest x Storage	1	1.1731	2.4907	N.S.
Variety x Harvest x Storage	4	.4710		
Error	20	.1148		

In order to determine which of the variety means were significantly different from others, the new multiple range test (27, p. 238-241) was applied. The result of this test is shown in Table 3.

TABLE 3.
New Multiple Range Test for Hunter "L" Means of Strawberry Varieties

Varieties:	Northwest	Marshall	Lassen	Puget Beauty	Siletz
Means:	18.73	18.96	21.25	21.38	24.13

The Hunter "L" value corresponds to visual lightness (18, p. 3). This means that varieties with higher Hunter "L" values were lighter in color, and those with lower Hunter "L" values were darker in color. The result of the new multiple range test, Table 3, shows that Siletz had a significantly higher Hunter "L" value or was significantly lighter in color than Puget Beauty and Lassen. Northwest and Marshall had significantly lower Hunter "L" values or possessed significantly darker color than Siletz, Puget Beauty, and Lassen. This indicates that Hunter "L" value could differentiate among Northwest-Marshall, Lassen-Puget Beauty, and Siletz, but was unable to differentiate between Northwest and Marshall, and between Lassen and Puget Beauty.

The values of Table 4 show that the Hunter "L" readings of all varieties except Puget Beauty were lower during the late harvest, indicating that on an average the berries from the late harvest were darker in color than those from the early harvest.

TABLE 4.
Hunter "L" Values of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	21.48	21.03	21.25
Marshall	19.28	18.65	18.96
Siletz	24.83	23.43	24.13
Northwest	20.35	17.10	18.73
Puget Beauty	21.00	21.75	21.38
Harvest Means	21.39	20.39	
Mean Variety x Harvest LSD at the 5% Level = 0.65			

The Hunter "L" value of Puget Beauty was higher during the late harvest, resulting in the interaction of variety x harvest. In order to determine whether the changes were significantly different, the differences between the early and the late harvests were compared with $LSD_{.05} = 0.65$. This comparison shows that these changes were significant in case of Siletz, Northwest, and Puget Beauty. The color changes in Lassen and Marshall due to the harvest dates were not significant.

The results of analysis of variance calculations, new multiple range test, and LSD show that the Hunter "L" measurements may successfully be used for determining the changes in color, or for describing the color, as such, of frozen strawberries.

Hunter "a"

The Hunter "a" values are given in Table 5, and the analysis of variance calculations are shown in Table 6.

TABLE 5.
Mean Hunter "a" Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	25.90	25.45	21.15	22.95	23.86
Marshall	24.50	20.50	24.95	25.30	23.81
Siletz	24.40	20.60	23.05	22.25	22.58
Northwest	24.85	23.45	23.50	23.40	23.80
Puget Beauty	23.05	19.70	23.50	25.85	23.03
Storage Means	24.54	21.94	23.23	23.95	

Table 6 shows that the differences due to variety, harvest, storage, and the interaction of variety x storage were not significant at the 5% level. The Hunter "a" value was unable to measure color differences due to these factors. It may be seen that within the limits of this experiment, the Hunter "a" value was unable to differentiate the three primary variables due to the significant interaction involving any two of the three variables. The significant interaction resulted in masking the differences amongst individual variables such that the Hunter "a" value was unable to measure color differences of strawberries.

TABLE 6.
Analysis of Variance for Hunter "a" Values
Of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	2.7284	1.8110	N.S.
Harvest	1	1.2250	.8131	N.S.
Storage	1	8.8360	5.8649	N.S.
Variety x Harvest	4	15.4106	10.2287	S.
Variety x Storage	4	2.7354	1.8156	N.S.
Harvest x Storage	1	27.5560	18.2902	S.
Variety x Harvest x Storage	4	1.5066		
Error	20	.4965		

It is clear from Table 7 that the changes in color of the various varieties as measured by Hunter "a" fluctuated considerably, resulting in an interaction of variety x harvest.

On comparing the differences of Hunter "a" values of the early and late harvests with the $LSD_{.05} = 0.66$, it can be seen that these differences were significant in all varieties except Siletz.

The differences due to the interaction of harvest x storage are shown by values given in Table 8.

TABLE 7.
Hunter "a" Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	25.68	22.05	23.86
Marshall	22.50	25.13	23.81
Siletz	22.50	22.65	22.58
Northwest	24.15	23.45	23.80
Puget Beauty	23.88	24.68	23.03
Harvest Means	23.24	23.59	

Mean Variety x Harvest LSD at the 5% Level = 0.66

TABLE 8.
Hunter "a" Values of Frozen (4:1) Strawberries As Affected by the Interaction Harvest x Storage

Storage	Harvest Early	Harvest Late	Storage Means
3 months	24.54	23.23	23.89
6 months	21.94	23.95	22.95
Harvest Means	23.24	23.59	

The Hunter "a" values of berries from the early harvest decreased when these berries were stored for six months, whereas these values increased in case of berries from the late harvest when stored for the same length of time.

The results presented here indicate that the Hunter "a" measurement was not able to show changes in color which were present in different varieties of strawberries, and which were affected by the date of harvest and length of storage. It may be postulated that, as long as the berries have a certain red hue or possess a certain basic amount of red pigment, changes in color due to other attributes of color, i.e., value and chroma, cannot be measured by Hunter "a" values. This means that the Hunter "a" values will measure color differences which are due only to shift in hue or dominant wavelength in the color of strawberries.

Hunter "b"

Table 9 shows the data for Hunter "b" values. These data were subjected to analysis of variance calculations, the results of which are given in Table 10.

TABLE 9.
Mean Hunter "b" values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	14.20	11.15	9.40	9.90	11.16
Marshall	10.30	9.35	9.25	10.25	9.79
Siletz	11.20	10.05	10.20	9.90	10.34
Northwest	10.65	10.55	10.45	9.95	10.40
Puget Beauty	12.95	9.30	9.85	10.20	10.58
Storage Means	11.86	10.08	9.83	10.04	

TABLE 10.
Analysis of Variance for Hunter "b" Values
Of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	1.9546	1.1594	N.S.
Harvest	1	10.7122	6.3540	N.S.
Storage	1	6.1622	3.6551	N.S.
Variety x Harvest	4	2.7504	1.6314	N.S.
Variety x Storage	4	.9416	.5552	N.S.
Harvest x Storage	1	9.9003	5.8724	N.S.
Variety x Harvest x Storage	4	1.6859		
Error	20	.1148		

The values of Table 10 show that the Hunter "b" measurements were not affected significantly by any of the factors studied. These results are in agreement with those of Hoover and Dennison (19, p. 196-197), who pointed out that the Hunter "b" values were not affected proportionately by a change in the red pigment and, therefore, could be disregarded in the measurement of color in strawberries.

On the basis of the results presented here and also those of Hoover and Dennison, it may be argued that as long as a certain amount of red pigment of certain intensity is present the Hunter "b" measurement will not show differences in color of strawberries due to value notation.

Hunter a/b Ratio

The values for Hunter a/b ratio are given in Table 11, and the analysis of variance calculations are shown in Table 12.

TABLE 11.
Mean Hunter a/b Ratios of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

Variety	Harvest				Variety Means
	Early		Late		
	3 months storage	6 months storage	3 months storage	6 months storage	
Lassen	1.83	2.28	2.26	2.32	2.17
Marshall	2.39	2.19	2.72	2.47	2.44
Siletz	2.18	2.05	2.26	2.25	2.19
Northwest	2.33	2.23	2.25	2.35	2.29
Puget Beauty	1.78	2.12	2.39	2.53	2.21
Storage Means	2.10	2.17	2.37	2.38	

It may be seen from Table 12 that differences due to all factors except harvest were not significant at the 5% level.

The data of Table 13 show that the Hunter a/b ratio was higher during the late harvest for all the five strawberry varieties.

It has been shown that the Hunter "a" values could measure differences due only to hue or dominant wavelength and that the Hunter "b" values were not affected by increments of red pigment as

TABLE 12.
Analysis of Variance for Hunter a/b Ratios
Of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% level
Total	39			
Variety	4	.1003	3.4232	N.S.
Harvest	1	.5856	19.9863	S.
Storage	1	.1068	3.6451	N.S.
Variety x Harvest	4	.0673	2.2969	N.S.
Variety x Storage	4	.0844	2.8805	N.S.
Harvest x Storage	1	.0102	.3481	N.S.
Variety x Harvest x Storage	4	.0293		
Error	20	.0095		

TABLE 13.
Hunter a/b Ratios of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest

Variety	Harvest		Variety Means
	Early	Late	
Lassen	2.05	2.29	2.17
Marshall	2.29	2.59	2.44
Siletz	2.12	2.26	2.19
Northwest	2.28	2.30	2.29
Puget Beauty	1.95	2.46	2.21
Harvest Means	2.14	2.38	

long as a certain amount was present in the strawberries. The Hunter a/b value, which correlates with dominant wavelength (35, p. 270), may be affected due to an increase or decrease in Hunter "a" or Hunter "b" value. The examination of the data of harvest means of Hunter "a" and Hunter "b" values shows that the Hunter "b" values were lower for all the varieties during the late harvest, whereas the Hunter "a" values did not show such a trend. These lower Hunter "b" values affected the Hunter a/b ratios in that they were larger for all the varieties during the late harvest. This indicates that there was a slight shift in wavelength or hue of the color of berries due to harvest date. This explains why the Hunter a/b ratio was able to measure the differences in color of strawberries as affected by date of harvest.

Hunter $(a^2 + b^2)^{\frac{1}{2}}$

Table 14 shows the data for Hunter $(a^2 + b^2)^{\frac{1}{2}}$ values. These data were subjected to analysis of variance calculations, the results of which are given in Table 15.

It may be seen from Table 15 that the differences due to variety, harvest, storage, and the interaction of variety x storage were not significant at the 5% level. The Hunter $(a^2 + b^2)^{\frac{1}{2}}$ value was unable to measure color differences due to these factors. Within the limits of this experiment, the Hunter $(a^2 + b^2)^{\frac{1}{2}}$ value was unable to differentiate the three primary variables due to the significant interaction involving any two of the three variables. The significant

TABLE 14.
Mean Hunter $(a^2 + b^2)^{\frac{1}{2}}$ Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

Variety	Harvest: Early, 3 months storage	Early, 6 months storage	Late, 3 months storage	Late, 6 months storage	Variety Means
Lassen	29.54	27.79	23.15	25.00	26.37
Marshall	26.58	22.54	26.62	27.30	25.76
Siletz	26.85	22.92	25.21	24.36	24.83
Northwest	27.04	25.71	25.73	25.43	25.98
Puget Beauty	26.44	21.79	25.48	27.79	25.37
Storage Means	27.29	24.15	25.24	25.97	

TABLE 15.
Analysis of Variance for Hunter $(a^2 + b^2)^{\frac{1}{2}}$ Values Of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	2.7468	1.1540	N.S.
Harvest	1	.1266	.0532	N.S.
Storage	1	14.4120	6.0550	N.S.
Variety x Harvest	4	16.8977	7.0993	S.
Variety x Storage	4	1.6822	.7067	N.S.
Harvest x Storage	1	37.6166	15.8040	S.
Variety x Harvest x Storage	4	2.3802		
Error	20	.4888		

interaction resulted in masking the differences of individual variables such that the Hunter $(a^2 + b^2)^{\frac{1}{2}}$ value was unable to measure color differences of strawberries.

It is clear from Table 16 that the differences in the Hunter $(a^2 + b^2)^{\frac{1}{2}}$ did not follow any certain pattern from one harvest to the other. There was an increase in these values of Marshall and Puget Beauty during the late harvest. These values, however, decreased in the case of Lassen, Siletz, and Northwest from the same harvest. The differences between the early and the late harvests when compared with the $LSD_{.05} = 3.30$ show that color differences were significant only in case of Lassen and were not significant in other varieties.

TABLE 16.
Hunter $(a^2 + b^2)^{\frac{1}{2}}$ Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	28.66	24.07	26.37
Marshall	24.56	26.96	25.76
Siletz	24.89	24.78	24.83
Northwest	26.37	25.58	25.98
Puget Beauty	24.11	26.64	25.37
Harvest Means	25.72	25.60	

Mean Variety x Harvest LSD at the 5% Level = 3.30

The differences due to the interaction of harvest x storage are shown by the data given in Table 17.

TABLE 17.
Hunter $(a^2 + b^2)^{\frac{1}{2}}$ Values of Frozen (4:1) Strawberries
As Affected by Date of Harvest and Length of Storage

Storage	Harvest Early	Harvest Late	Storage Means
3 months	27.29	25.24	26.26
6 months	24.15	25.97	25.06
Harvest Means	25.72	25.60	

The Hunter $(a^2 + b^2)^{\frac{1}{2}}$ values of berries from the early harvest decreased when these berries were stored for six months, whereas these values increased in the case of berries from the late harvest and stored for the same length of time.

The results presented here indicate that the Hunter $(a^2 + b^2)^{\frac{1}{2}}$ values were unable to show differences in color due to variety, harvest, storage, and the interaction of variety x storage.

It has been shown earlier that the Hunter "a" and the Hunter "b" values were poor indices for describing the color of strawberries. In calculating the Hunter function $(a^2 + b^2)^{\frac{1}{2}}$, which represents saturation (21, p. 270), equal weight is given to the Hunter "a" and the Hunter "b" values. Since these two individual values could not measure differences in color of strawberries as long as a certain amount of red pigment of certain intensity was present, it might be concluded that the Hunter function $(a^2 + b^2)^{\frac{1}{2}}$ would not consequently be able to measure differences in color of strawberries.

Hunter a + b

The data of the Hunter a + b values were subjected to the analysis of variance calculations. It was found that the results obtained followed those of the individual Hunter "a" and Hunter "b" values in that the Hunter a + b values were not able to measure the color differences due to the three primary variables, i.e., variety, harvest, and storage.

Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$

The Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ values are given in Table 18, and the analysis of variance calculations are shown in Table 19.

TABLE 18.
Mean Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ Values of Five Frozen (4:1) Strawberry Varieties as Affected By Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	36.13	35.54	31.60	32.36	33.90
Marshall	32.62	29.90	32.86	32.73	32.02
Siletz	35.98	34.44	34.43	33.78	34.66
Northwest	34.24	32.40	31.23	30.31	32.04
Puget Beauty	33.62	30.44	33.65	35.17	33.22
Storage Means	34.51	32.54	32.75	32.87	

TABLE 19.
Analysis of Variance for Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ Values
of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	10.6620	8.1845	S.
Harvest	1	5.1553	3.9574	N.S.
Storage	1	8.6305	6.6251	N.S.
Variety x Harvest	4	13.9876	10.7374	S.
Variety x Storage	4	.7551	.5796	N.S.
Harvest x Storage	1	10.8993	8.3667	S.
Variety x Harvest x Storage	4	1.3027		
Error	20	.3332		

The values given in Table 19 show that differences in Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ values due to variety, interaction of variety x harvest, and that of harvest x storage were significant at the 5% level. The differences due to harvest, storage, and the interaction of variety x harvest were not significant.

In order to determine which of the variety means were significantly different from others, the new multiple range test (27, p. 238-241) was applied. The results of this test are shown in Table 20.

TABLE 20.
New Multiple Range Test
For Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ Means of Strawberry Varieties

Varieties:	Marshall	Northwest	Puget Beauty	Lassen	Siletz
Means:	32.02	32.04	33.22	33.90	34.66

The Hunter function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ shows perceptibility differences (28, p. 403-409). This means that this function will differentiate the color of strawberry varieties as a trained AMS inspector will do on the basis of visual observation. It is clear from Table 20 that Siletz had significantly higher Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ values than Lassen and Puget Beauty. Marshall and Northwest had significantly lower Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ values than Siletz, Lassen, and Puget Beauty. This shows that the Hunter function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ can successfully differentiate among the various varieties on the basis of visual color differences.

The values given in Table 21 show that the Hunter function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ was able to measure the color differences as affected by date of harvest. These values changed considerably during the harvests but did not follow any certain pattern. The values for Lassen, Siletz, and Northwest were lower during the late harvest, whereas they were higher for Marshall and Puget Beauty.

TABLE 21.
Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ Values of Five Frozen (4:1) Strawberry Varieties as Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	35.83	31.98	33.90
Marshall	31.26	32.79	32.02
Siletz	35.21	34.10	34.66
Northwest	33.32	30.77	32.04
Puget Beauty	32.03	34.41	33.22
Harvest Means	33.53	32.81	

Mean Variety x Harvest LSD at the 5% Level = 1.81

On comparing the color differences of the varieties due to affect of harvest date as measured by the variety x harvest interaction LSD, it can be seen that these differences were significant in case of Lassen, Northwest, and Puget Beauty, but were not significant in case of Marshall and Siletz.

The differences due to the interaction of harvest with storage are shown by values given in Table 22.

TABLE 22.
Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ Values of Frozen (4:1) Strawberries As Affected by Date of Harvest and Length of Storage

Storage	Harvest Early	Harvest Late	Storage Means
3 months	34.51	32.75	33.63
6 months	32.54	32.87	32.70
Harvest Means	33.53	32.81	

The Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ values of berries from the early harvest decreased when these berries were stored for six months, whereas these values increased in case of berries from the late harvest and stored for the same length of time. On examining the means of the early and late harvests, it can be seen that the Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ values decreased during the late harvest. These means also show that the differences in color did not follow any consistent pattern.

Hunter L + a, L + b, and L + a + b

The data of Hunter L + a, Hunter L + b, and Hunter L + a + b values were subjected to the analysis of variance calculations. It was noticed that all these values were able to differentiate among varieties the same as Hunter "L" alone did. It has previously been shown that the individual Hunter "a" and Hunter "b" values were not able to measure color differences when a certain amount of red pigment of a certain intensity was present in the berries. On the basis of the results of the Hunter L + a, Hunter L + b, and Hunter L + a + b, it may be argued that it is the Hunter "L" value alone or, where it may form a component of a particular function, like Hunter $(L^2 + a^2 + b^2)^{\frac{1}{2}}$, that is able to measure color differences of strawberries.

The Hunter "L" value corresponds to visual lightness (18, p. 3), and the Hunter function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ shows perceptibility differences (28, p. 403-409). On examining the results of this experiment in the light of these interpretations it may be noticed that when certain values of Hunter "a" and Hunter "b" were present, the differences in color of strawberries were due to Munsell value (21, p. 285). Shah (38, p. 93-95) showed that the Hunter "a" values of frozen (4:1) strawberries ranged from 21.7 to 25.5, and that the Hunter "b" values for these berries ranged from 7.7 to 10.9. The data of this experiment show that the respective values ranged from 19.7 to 25.9, and from 9.3 to 14.2. It is, however, not known what minimum values of Hunter "a" and Hunter "b" were necessary below which these scales would start measuring color differences due to hue and chroma in strawberries.

When the results of all the Hunter values, alone or combined, are examined with a view to determine the over-all usefulness of the Hunter Color and Color-Difference Meter for measuring the color of frozen strawberries, it may be seen that only the Hunter "L" value and the Hunter function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ yield significant results. Since the Hunter function $(L^2 + a^2 + b^2)^{\frac{1}{2}}$ involves considerably lengthy calculations, the Hunter "L" value alone may be used in measuring the color of frozen strawberries.

It has been reported (38, p. 52) that the Hunter "L" values of commercially frozen (4:1) strawberries ranged from 14.8 to 20.6. These studies revealed that such values for the five varieties included in this experiment ranged from 16.5 to 25.7. It can be seen that there is a great variation in the two sets of these figures. It is, therefore, necessary that extensive measurements be obtained on a large number of varieties, gathered from different locations, and over a number of years in order to fix the limits of Hunter "L" values for the color description of the various AMS grades of frozen strawberries.

Results of Volatile Reducing Substances (VRS)

A food may be nourishing and have many vitamins, but if flavor is missing or is of unpleasant nature all the pleasure and enjoyment obtained from it are eliminated. Odor is a major attribute of flavor. The volatile reducing substances determinations have been obtained to study odor differences in frozen strawberries.

The values for the volatile reducing substances are presented in Table 23. The data were subjected to the analysis of variance calculations, the results of which are given in Table 24.

TABLE 23.
Mean VRS Values of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	38.75	33.50	38.00	29.50	34.94
Marshall	52.50	47.00	45.50	42.00	46.75
Siletz	45.50	37.00	42.00	36.00	40.13
Northwest	57.25	53.50	41.50	37.00	47.31
Puget Beauty	44.35	40.00	50.00	43.00	44.34
Storage Means	47.67	42.20	43.40	37.50	

TABLE 24.
Analysis of Variance for VRS Values of Five Frozen (4:1) Strawberry Varieties as Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	214.4916	62.4593	S.
Harvest	1	201.1523	58.5750	S.
Storage	1	323.1923	94.1127	S.
Variety x Harvest	4	112.4241	32.7376	S.
Variety x Storage	4	3.8516	1.1216	N.S.
Harvest x Storage	1	.4622	.1346	N.S.
Variety x Harvest x Storage	4	3.4341		
Error	20	2.5648		

Table 24 shows that differences in VRS values due to variety, harvest, storage, and the interaction of variety x harvest were significant at the 5% level. The differences due to the interaction of variety x storage and that of harvest x storage were not significant.

To know which of the variety means were significantly different from others, the new multiple range test (27, p. 238-241) was applied. The results of this test are shown in Table 25.

TABLE 25.
New Multiple Range Test for VRS Means of Strawberry Varieties

Varieties:	Lassen	Siletz	Puget Beauty	Marshall	Northwest
Means:	34.94	40.13	44.34	46.75	47.31

The result of the new multiple range test shows that Northwest and Marshall possessed significantly more odor than Siletz and Lassen. Lassen had significantly less odor than all the other varieties. The position of Puget Beauty was not clearly determined. It might belong to the same group as Siletz, or the same group as Marshall and Northwest. Indeed, it might be a group by itself. Only further experimental evidence, that is, an increased number of observations, will clarify the situation.

The data of differences in VRS due to harvest are given in Table 26. These values show that all the varieties except Puget Beauty had less odor during the late harvest. Puget Beauty had more odor during the late harvest resulting in the interaction of variety x harvest.

TABLE 26.
VRS Values of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	36.13	33.75	34.94
Marshall	49.75	43.75	46.75
Siletz	41.25	39.00	40.13
Northwest	55.38	39.25	47.31
Puget Beauty	42.18	46.50	44.34
Harvest Means	44.94	40.45	

Mean Variety x Harvest LSD at the 5% Level = 4.77

In order to determine whether the changes in odor due to interaction of variety x harvest were significant, the differences between the VRS of the early and the late harvests were compared with $LSD_{.05} = 4.77$. This comparison shows that these differences were significant in case of Marshall and Northwest. These differences were, however, not significant in case of Lassen, Siletz, and Puget Beauty.

The changes in VRS of frozen strawberries as affected by length of storage are shown in Table 27.

TABLE 27.
VRS Values of Five Frozen (4:1) Strawberry Varieties
As Affected by Length of Storage

Variety	Storage 3 months	Storage 6 months	Variety Means
Lassen	38.38	31.50	34.94
Marshall	49.00	44.50	46.75
Siletz	43.75	36.50	40.13
Northwest	49.38	45.25	47.31
Puget Beauty	47.18	41.50	44.34
Storage Means	45.54	39.85	

It may be seen from the values of Table 27 that the VRS content of all the varieties was lower after storage for six months at 0° F. It means that the longer the frozen berries are stored, the poorer they become in odor. This information can be of great importance to the berry packers and the retailers in that they may arrange their marketing schedules so that they do not hold the frozen berries for longer periods than necessary. The VRS determinations can also be helpful in inspection and quality control work. It may, however, be necessary for this purpose to establish limits of VRS content which berries must possess to be classed in a particular grade.

Results of Other Physical and Chemical Determinations

Soluble Solids

The data for the soluble solids are given in Table 28, and the analysis of variance calculations are shown in Table 29.

TABLE 28.
Mean Soluble Solids Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	22.50	23.40	28.55	28.10	25.64
Marshall	24.25	24.30	27.20	27.50	25.81
Siletz	22.35	22.50	26.65	26.40	24.48
Northwest	22.25	23.10	30.00	30.00	26.34
Puget Beauty	24.55	24.30	27.80	27.90	26.14
Storage Means	23.18	23.52	28.04	27.98	

TABLE 29.
Analysis of Variance for Soluble Solids Values
Of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	4.2260	16.1730	S.
Harvest	1	217.1560	831.0601	S.
Storage	1	.1960	.7501	N.S.
Variety x Harvest	4	5.9823	22.8944	S.
Variety x Storage	4	.0860	.3291	N.S.
Harvest x Storage	1	.4000	1.5308	N.S.
Variety x Harvest x Storage	4	.2613		
Error	20	.0845		

The values of Table 29 show that the differences due to variety, harvest, and the interaction of variety x harvest were significant at the 5% level. The differences due to storage, the interaction of variety x storage, and the interaction of harvest x storage were not significant.

The data of variety means were subjected to the new multiple range test (27, p. 238-241), the result of which is given in Table 30. The result of the new multiple range test shows that Northwest had significantly higher soluble solids than Marshall and Lassen. Siletz and Lassen had significantly lower soluble solids than Northwest, Puget Beauty and Marshall. The positions of Puget Beauty and Marshall were not clearly determined. Puget Beauty might belong to the same group as Northwest, or the same group as Marshall, whereas Marshall might belong to the same group as Puget Beauty and Northwest, or the same group as Lassen. Indeed, Puget Beauty and Marshall might be separate groups in their individual capacity. This indicates that the soluble solids determinations may be of some value in measuring differences in frozen strawberry varieties.

TABLE 30.
New Multiple Range Test for Soluble Solids Means
Of Strawberry Varieties

Varieties:	Siletz	Lassen	Marshall	Puget Beauty	Northwest
Means:	24.48	25.64	25.81	26.14	26.34

Table 31 shows that the soluble solids of all the varieties were higher during the late harvest. The differences in soluble solids due to interaction of variety x harvest when compared with $LSD_{.05}$ = 0.36 were found to be significant in case of all varieties. This shows that the soluble solids determinations are useful for evaluating frozen strawberries.

TABLE 31.
Soluble Solids Values of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest

Variety	Harvest		Variety
	Early	Late	Means
Lassen	22.95	28.33	25.64
Marshall	24.28	27.35	25.81
Siletz	22.43	26.53	24.48
Northwest	22.68	30.00	26.34
Puget Beauty	24.43	27.85	26.14
Harvest Means	23.35	28.01	

Mean Variety x Harvest LSD at the 5% Level = 0.36

Reducing and Total Sugars and Total Solids

The data of reducing and total sugars and total solids of the frozen (4:1) strawberries showed that these values ranged from 21.62% to 31.14%, from 7.50% to 11.72%, and from 23.48% to 32.42%, respectively. The data of these determinations were subjected to the analysis of variance calculations, and it was noticed that these results were similar to the results of the soluble solids determinations. The significant factors differentiated were variety, harvest, and the interaction of variety x harvest, the same as shown for the soluble solids determinations. These determinations, therefore, can serve a useful purpose in measuring the differences in frozen strawberries. Since these determinations are complicated, lengthy and time consuming, soluble solids determinations alone may be used in measuring differences in frozen strawberries.

pH

Table 32 shows the data for pH values. These data were subjected to analysis of variance calculations, the results of which are given in Table 33.

TABLE 32.
Mean pH Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	3.56	3.55	3.54	3.49	3.54
Marshall	3.50	3.58	3.40	3.49	3.49
Siletz	3.63	3.60	3.52	3.61	3.59
Northwest	3.57	3.48	3.40	3.48	3.48
Puget Beauty	3.65	3.55	3.51	3.50	3.55
Storage Means	3.58	3.55	3.47	3.51	

It may be seen from Table 33 that the pH measurements were not affected significantly due to variety, storage, or any interaction of variety x harvest, variety x storage, and harvest x storage. There were, however, significant differences in pH values due to harvest.

TABLE 33.
Analysis of Variance for pH Values of Five Frozen (4:1) Strawberry Varieties as Affected By Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	79			
Variety	4	.0332	4.2564	N.S.
Harvest	1	.1081	13.8590	S.
Storage	1	.0005	.0641	N.S.
Variety x Harvest	4	.0028	.3590	N.S.
Variety x Storage	4	.0117	1.5000	N.S.
Harvest x Storage	1	.0238	3.0513	N.S.
Variety x Harvest x Storage	4	.0078		
Error	60	.0009		

The data given in Table 34 show that the differences in pH between harvests were very small.

Since the factor responsible for these differences is of minor importance and also that it is difficult to measure such small differences in routine inspection or quality control work, it may be concluded that pH measurements are a poor index for judging the quality of frozen strawberries.

TABLE 34.
pH Values of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	3.56	3.52	3.54
Marshall	3.54	3.44	3.49
Siletz	3.62	3.57	3.59
Northwest	3.52	3.44	3.48
Puget Beauty	3.60	3.50	3.55
Harvest Means	3.57	3.49	

Titratable Acidity

The data for titratable acidity values are given in Table 35 and the analysis of variance calculations are shown in Table 36.

TABLE 35.
Mean Titratable Acidity Values of Five Frozen (4:1) Strawberry
Varieties as Affected
By Date of Harvest and Length of Storage at 0° F.

	Harvest				
	Early		Late		
Variety	3 months storage	6 months storage	3 months storage	6 months storage	Variety Means
Lassen	.5888	.5800	.6528	.6800	.6254
Marshall	.6096	.5616	.6832	.6904	.6362
Siletz	.7072	.6944	.7632	.7896	.7386
Northwest	.5456	.5464	.5792	.6304	.5754
Puget Beauty	.6192	.5824	.6496	.6832	.6336
Storage Means	.6141	.5930	.6656	.6947	

TABLE 36.
Analysis of Variance for Titratable Acidity Values
Of Five Frozen (4:1) Strawberry Varieties
As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	79			
Variety	4	.0566	283.0000	S.
Harvest	1	.1175	587.5000	S.
Storage	1	.0003	1.5000	N.S.
Variety x Harvest	4	.0011	5.5000	N.S.
Variety x Storage	4	.0012	6.0000	N.S.
Harvest x Storage	1	.0126	63.0000	S.
Variety x Harvest x Storage	4	.0002		
Error	60	.00003		

Table 36 shows that the differences in titratable acidity due to variety, harvest, and the interaction of harvest x storage were significant at the 5% level. The differences due to storage, interaction of variety x harvest, and that of variety x storage were not significant.

In order to determine which of the variety means were significantly different from others, the new multiple range test (27, p. 238-241) was applied. The result of this test is given in Table 37.

The result of the new multiple range test shows that all varieties possessed significantly different amounts of titratable acidity.

Siletz had the highest total acid and Northwest the lowest. The other varieties were in between Siletz and Northwest.

TABLE 37.
New Multiple Range Test for Titratable Acidity Means Of Strawberry Varieties

Varieties:	Northwest	Lassen	Puget Beauty	Marshall	Siletz
Means:	0.5754	0.6254	0.6336	0.6362	0.7386

The values given in Table 38 show that the titratable acidity values of all the varieties were higher during the late harvest.

TABLE 38.
Titratable Acidity Values of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	.5844	.6664	.6254
Marshall	.5856	.6868	.6362
Siletz	.7008	.7764	.7386
Northwest	.5460	.6048	.5754
Puget Beauty	.6008	.6664	.6336
Harvest Means	.6035	.6802	

The data of titratable acidity values as affected by the interaction of harvest x storage are shown in Table 39. The titratable acidity values of berries from the early harvest decreased when the berries were stored for six months, whereas these values in case of berries from the late harvest increased when stored for the same length of time.

TABLE 39.
Titratable Acidity Values of Frozen (4:1) Strawberries As Affected by the Interaction Harvest x Storage

Storage	Harvest Early	Harvest Late	Storage Means
3 months	.6141	.6656	.6398
6 months	.5930	.6947	.6438
Harvest Means	.6035	.6802	

The results presented here show that the total acid determinations were able to measure differences due to variety, harvest, and the interaction of harvest x storage. Since these determinations can be performed rapidly at a nominal cost, they can be used successfully in evaluating the frozen strawberries.

Soluble Solids/Acid Ratio

Table 40 shows the data for soluble solids/acid ratios. These data were subjected to analysis of variance calculations, the results of which are given in Table 41.

It may be seen from the values of Table 41 that the differences in the ratios of soluble solids/acid due to variety, harvest, the interaction of variety x harvest, and that of harvest x storage were significant at the 5% level. The differences due to storage and the interaction of variety x storage were not significant.

TABLE 40.
Mean Soluble Solids/Acid Ratios of Five Frozen (4:1) Strawberry Varieties as Affected By Date of Harvest and Length of Storage at 0° F.

Variety	Harvest: Early, 3 months storage	Harvest: Early, 6 months storage	Harvest: Late, 3 months storage	Harvest: Late, 6 months storage	Variety Means
Lassen	38.21	40.40	43.95	41.42	41.00
Marshall	39.68	44.17	39.91	39.79	40.89
Siletz	31.61	32.56	35.00	33.40	33.14
Northwest	40.90	42.09	51.51	47.59	45.52
Puget Beauty	41.96	41.50	42.80	40.94	41.80
Storage Means	38.47	40.14	42.63	40.63	

TABLE 41.
Analysis of Variance for Soluble Solids/Acid Ratios Of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest and Length of Storage at 0° F.

Source of Variation	Degrees of Freedom	Mean Square	F	Significance at the 5% Level
Total	39			
Variety	4	162.9082	124.1205	S.
Harvest	1	53.9401	41.0972	S.
Storage	1	.2806	.0214	N.S.
Variety x Harvest	4	29.0577	22.1392	S.
Variety x Storage	4	3.9921	3.0416	N.S.
Harvest x Storage	1	33.8743	25.8090	S.
Variety x Harvest x Storage	4	1.3125		
Error	20	1.4568		

In order to determine which of the variety means were significantly different from others, the new multiple range test (27, p. 238-241) was applied. The result of this test is shown in Table 42.

TABLE 42.
New Multiple Range Test for Soluble Solids/Acid Means Of Strawberry Varieties

Varieties:	Siletz	Marshall	Lassen	Puget Beauty	Northwest
Means:	33.14	40.89	41.00	41.80	45.52

The result of the new multiple range test shows that Northwest had significantly higher soluble solids/acid ratio than Puget Beauty, Lassen, and Marshall. Siletz had significantly lower ratio than Puget Beauty, Lassen, and Marshall. There were no significant differences amongst the soluble solids/ acid ratios of Puget Beauty, Lassen, and Marshall.

The data given in Table 43 show that on over-all basis the soluble solids/acid ratio was higher during the late harvest. However, all the varieties did not show the same trend. This ratio for Marshall was lower during the late harvest, whereas in case of all other varieties it followed the general mean. These differences when compared with $LSD_{.05}$ = 1.82 showed that changes in ratios during the harvests were significant in all varieties except in case of Puget Beauty.

TABLE 43.
Soluble Solids/Acid Ratios of Five Frozen (4:1) Strawberry Varieties As Affected by Date of Harvest

Variety	Harvest Early	Harvest Late	Variety Means
Lassen	39.31	42.69	41.00
Marshall	41.92	39.85	40.89
Siletz	32.08	34.20	33.14
Northwest	41.50	49.55	45.52
Puget Beauty	41.73	41.87	41.80
Harvest Means	39.31	41.63	

Mean Variety x Harvest LSD at the 5% Level = 1.82

The mean harvest and mean storage data are given in Table 44. These data show that the soluble solids/acid ratio decreased in berries from the early harvest on storage for six months, whereas this ratio was higher for berries from the late harvest and also stored for six months.

TABLE 44.
Soluble Solids/Acid Ratios of Frozen (4:1) Strawberries As Affected by Date of Harvest and Length of Storage

Storage	Harvest Early	Harvest Late	Storage Means
3 months	38.47	42.63	40.55
6 months	40.14	40.63	40.38
Harvest Means	39.31	41.63	

The results presented here show that the soluble solids/acid ratios could measure the differences due to variety, harvest, interaction of variety x harvest, and that of harvest x storage. On this basis this ratio was better than the soluble solids values or titratable acidity values alone for measuring differences in frozen strawberries.

Reducing Sugars/Acid and Total Sugars/Acid Ratios

The results of the analyses of variance of the data for total sugars/acid and reducing sugars/acid ratios showed that the total sugars/acid ratios followed exactly the same trend as shown by the soluble solids/acid ratios in that they were able to differentiate the differences due to variety, harvest, the interaction of variety x harvest, and the interaction of harvest x storage. The reducing sugars/acid ratios behaved similarly except that they could not differentiate the differences due to harvest. It was noticed that the mean reducing sugars values for the early and the late harvests were 9.01 and 10.32, respectively. The mean acid values for the early and the late harvests were 0.6035 and 0.6802, respectively. The calculated values for the reducing sugars/acid ratios are 14.93 and 15.17, which are not significantly different. It may, then, be seen that the significant interaction involving variety x harvest resulted in masking the differences due to date of harvest such that the reducing sugars/acid ratios were unable to measure them.

SUMMARY AND CONCLUSIONS

Five varieties of commercially grown strawberries were obtained at two different harvest periods. They were frozen in the ratio of 4:1 (fruit:sugar) and stored at 0° F. for three and six months. After each period of storage the thawed berries were examined by the Hunter color attributes, volatile reducing substances, reducing and total sugars, soluble solids, total solids, pH, and titratable acidity. The individual values of volatile reducing substances, reducing and total sugars, soluble solids, total solids, pH, titratable acidity, Hunter color attributes and various ratios of these attributes, as well as ratios of reducing sugars/acid, total sugars/acid, and soluble solids/acid were subjected to the analysis of variance calculations. The least significant difference and the new multiple range test were also applied where necessary.

On the basis of this experiment it is concluded that:

1. The Hunter "L" values are capable of differentiating differences between varieties and date of harvest but not between the periods of storage.

2. The other Hunter attributes, "a" and "b", are unable to measure differences due to any of the variables studied, however, when combined with the Hunter "L" value they are capable of good differentiation between varieties.

3. Any combinations of Hunter attributes which include the "L" value should be considered when selecting methods for measuring the color of frozen strawberries.

4. The volatile reducing substances determination is capable of differentiating differences in frozen strawberries due to all the three primary variables, i.e., variety, harvest, and storage.

5. The soluble solids measurement and associated sugar analyses are also capable of good differentiation between varieties and date of harvest.

6. The titratable acidity determination is capable of differentiation between varieties and harvests.

7. The pH measurement is capable only of differentiation between harvests.

8. The ratios such as soluble solids/acid, reducing sugars/acid, and total sugars/acid are capable of measuring differences between varieties.

From a practical standpoint the use of the Hunter "L" value, VRS, soluble solids, and titratable acidity measurements should be used in establishing procedures for evaluating the quality of frozen strawberries. It will, however, be necessary that a large number of strawberry varieties, grown at different locations, and over many seasons be examined by using the four suggested objective methods in order to fix the limits of color and flavor attributes for the various AMS grades of frozen strawberries which will be useful in routine quality control and inspection work.

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