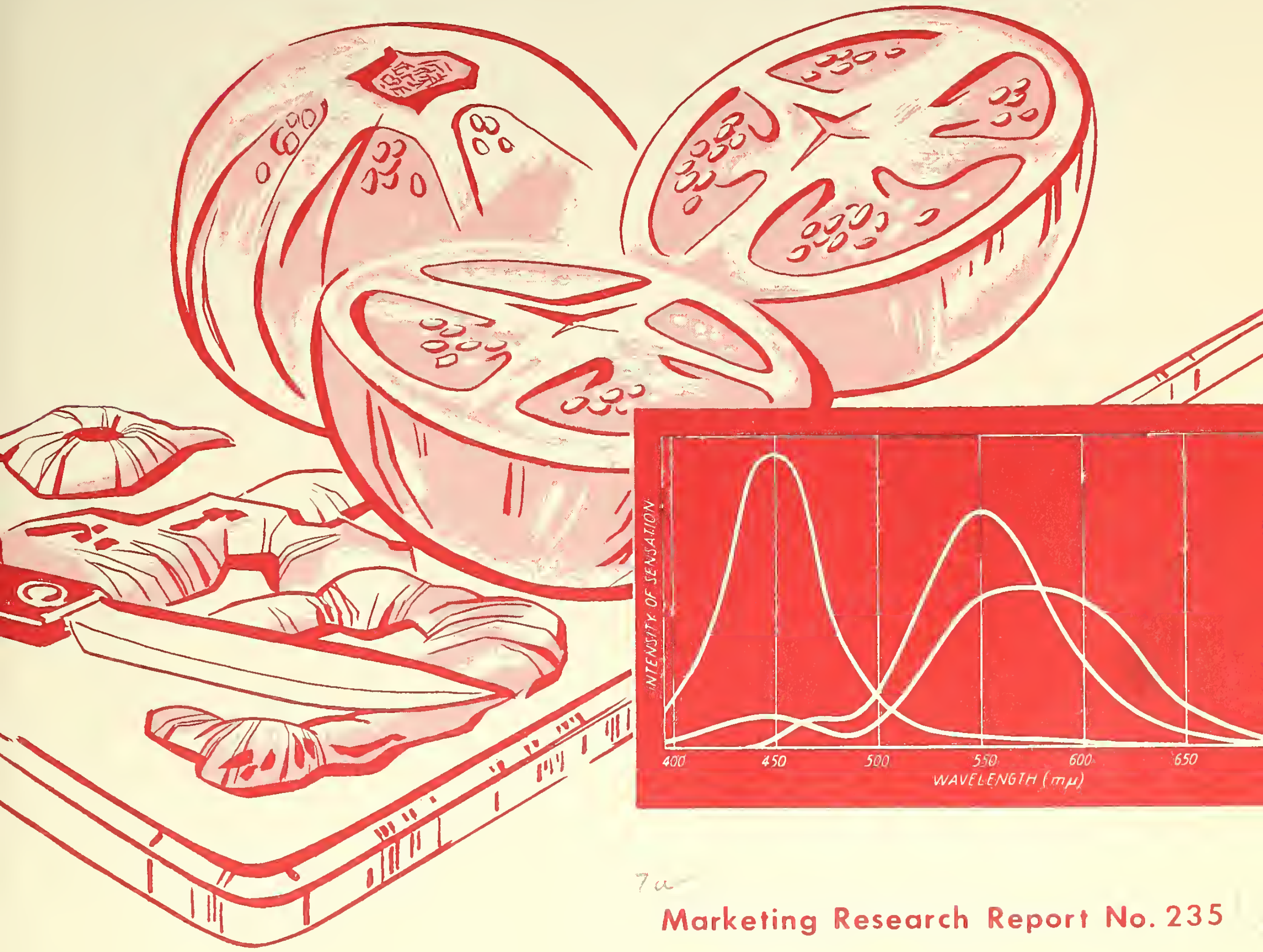
JUDGING QUALITY OF TOMATOES FOR PROCESSING BY OBJECTIVE COLOR EVALUATION

WITH SUBJECTIVE ESTIMATION OF DEFECTS



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The study on which this report is based is part of a larger research project on quality evaluation and development of objective measurement of quality factors in agricultural products. This study was conducted under the supervision of Calvin Golumbic, Head, Quality Evaluation Section, Biological Sciences Branch.

Earl E. Houseman, Director, Statistical Standards Division, and Dorothy Nickerson, color technologist, Cotton Division, gave invaluable assistance in developing the statistical phases of the research, preparing many of the analyses of data, and contributing many suggestions on the presentation of the color charts and other guidance.

George B. Dever, Jr., marketing specialist, Fruit and Vegetable Division, helped to set up inspection procedures.

Many individuals in standardization and inspection services for fresh and processed products and manufacturers of processed foods also helped in this research. The authors wish especially to thank the following for making their facilities available: Libby, McNeill and Libby, Wyoming, Del.; Campbell Soup Company, Napoleon, Ohio; C. H. Musselman Company, Biglerville, Pa.; Magnuson Engineers, Inc., San Jose, Calif.; Macbeth Daylighting Corporation, Newburgh, N. Y.; Gardner Laboratories, Inc., Bethesda, Md.; Hunter Associates, Falls Church, Va.; Purdue University, Lafayette, Ind.

Carlos Martin and Ray E. Lewis, Federal-State inspectors, and Ernest J. Sellers, terminal market inspector, Fruit and Vegetable Division, assisted in grading the raw products used in the study.

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SUMMARY AND CONCLUSIONS

A new inspection procedure for measuring the quality of tomatoes for processing can be successfully based on these two factors: (1) Objective color measurement by use of photoelectric instruments, and (2) subjective estimation of defects in the fruit.

This new procedure was developed in a study made by the Agricultural Marketing Service, which has for a number of years recognized the need for a more accurate method of measuring the color of tomatoes when applying the standards set forth in "U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products."

In addition, as a possible adjunct to a modified inspection procedure, information was obtained in the study which should facilitate grading for defects.

Incorporation of defective portions of tomatoes for processing into composite juice causes erroneous color readings on various electronic instruments; therefore, defective portions were trimmed from all tomatoes for composite juices throughout the study.

Improvement in color readings by deaeration of juice samples was found throughout a season's study to be constant and predictable. The additional time required and the equipment needed to accomplish the deaeration process did not warrant its incorporation as a part of the inspection procedure. (Deaeration in this case refers to the removal of air bubbles from the juice by alternately pulling and breaking a 25- to 30-inch vacuum to which the sample is subjected.) Color evaluation of nondeaerated juices was therefore made a part of the established procedure of this study.

A good deal of information was obtained about the Macbeth-Munsell Disk Colorimeter, the Hunter Color and Color Difference Meter, and the Agtron Model F, which has led to several significant conclusions. The IDL-Color Eye was used for the first time in 1956 and shows promise as a research tool in making not only innumerable ratio measurements, but also rough spectrophotometric curves and X, Y, Z trichromatic coefficient readings with appropriate filters. The Hunter CDM was found to be the most reliable of the instruments for evaluating the color of raw tomato juice. Of the 5 instruments tested in the 3-year study, 1, the Purdue Color Ratio Meter, has been discarded for use in evaluating the color of tomato juices as well as the external color of whole tomatoes. The expression of color attributes in terms of L, a_L and b_L relationships agreed with findings of other research workers.

There is some doubt whether the visual evaluation of tomato juice, raw or processed, i.e., by the Macbeth-Munsell Disk Colorimeter, is made entirely by estimating hue and chroma differences or whether various observers discern only value differences. This observation is significant, in that knowledge of the way in which tomato juices are evaluated by inspectors and quality control technicians will determine the type of electronic instrument that should be used to differentiate samples accurately.

Evidence indicates that the color of a blend of two raw tomato juice samples of different hues is biased in favor of the redder sample. Hunter CDM readings expressed in Munsell terms graphically showed the extent of this bias with varying proportions of samples.

Evidence of bias in color readings of composite samples of juice also occurred in a sampling study when the average readings of blends, as indicated by instrument readings, increased as successively intensive levels of sampling were made. The extent of this bias was seen to be as great as one point in the visual score. This may be significant to tomato juice manufacturers and producers of other blended products.

A mechanical sampling device was used in 1954 to select a subsample of approximately 10 percent of a hamper of tomatoes. This device proved unsatisfactory and was abandoned. No automatic or mechanical sampling device has been used since that time. The perishability of the product makes it very difficult to make a sampling device which will handle the fruit without completely mutilating it.

Expected sampling errors with variations in numbers of hampers selected from loads of tomatoes and in numbers of tomatoes selected from each hamper have been computed for both estimation of defects (trim loss) and the percentage of U. S. No. 1 tomatoes for color.

In blend studies designed to gain information about additivity of raw tomato juice color readings, it was found that estimates of variance for instruments on blended samples decreased with increased intensity of sampling in accordance with statistical laws.

Attention was given to the subjective estimation of defects calculated as a trim loss factor which could possibly be applied as a single factor in combination with an evaluation for color of a load of tomatoes. This method would be used instead of the conventional method of estimating percentages of U. S. No. 1, U. S. No. 2, and Culls. Expected errors were computed for variations in number of hampers selected and in number of tomatoes selected from a hamper.

JUDGING QUALITY OF TOMATOES FOR PROCESSING BY OBJECTIVE COLOR EVALUATION

With Subjective Estimation of Defects

By John N. Yeatman and Arthur P. Sidwell, food technologists
Biological Sciences Branch, Marketing Research Division
Agricultural Marketing Service

INTRODUCTION

A more accurate and efficient method of measuring the quality of tomatoes for processing is needed so that inspection and grading can be expedited and payments for the tomatoes can be made on a more equitable basis for both processors and growers.

Evaluation of the color of raw tomato juice and condition of tomatoes for processing, with an accompanying investigation of sampling methods, is the subject of continuing studies by the Marketing Research Division of the Agricultural Marketing Service.

In 1954, continuing the earlier work of the Department, AMS emphasized the following two objectives: (1) Development of a method for determining the quality of tomatoes for processing based on an objective evaluation of the color of raw juice by various electronic instruments and a subjective determination of the percentage of defects; and (2) determination of the relationship between the results obtained from this method and those obtained from the method in use at the time. In addition, emphasis was placed on the determination of the variation between samples associated with various sampling methods both for color and for inspection of defects.

Color and defects parameters have been correlated with the requirements set forth in the U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products (50).[1]

The grade specifications set forth in these standards define tomatoes having at least 90 percent of the flesh with good red color as "well colored" and classify them as U. S. No. 1, subject to accounting for defects. Those tomatoes having at least 66-2/3 percent of the flesh with good red color are defined as "fairly well colored" and classified as U. S. No. 2, subject to accounting for defects. Cull tomatoes are those which fail to meet the requirements of either U. S. No. 1 or U. S. No. 2.

Certain limitations have arisen as a result of these specifications. The most profound limitation is the interpretation of "good red" color by the inspector. Many factors contribute to this difficulty:

1. The color "lines" representing the separation of U. S. Grades No. 1, No. 2, and Culls are "fixed" for the inspector at preseason training schools. The colors representing the various grades are subject to the memory of the inspector. This leads to some inconsistencies between inspectors. Steps have been taken in the course of time to attempt to maintain uniform color standards for the inspectors. This was done by the use of hand-painted replicas of tomato cross-sections which represented the minimum color for U. S. No. 1 and U. S. No. 2 tomatoes (fig. 1). Duplicates were distributed to Federal-State supervisors who make periodical checks on the inspectors' color interpretations. The main shortcomings of such visual aids are: (A) They are not applicable to

[1] Underscored figures in parentheses refer to Literature Cited, p. 38.

all tomato varieties, (B) they are not available for individual inspectors, and (C) the high gloss surfaces of both cross-sectioned tomatoes and replicas and the differences in materials observed make visual comparisons difficult.

2. Various lighting conditions, which occurred throughout the season and at different inspection platforms, contributed to the difficulty in maintaining uniform color lines.

3. The element of fatigue greatly influenced the ability of an inspector to distinguish colors efficiently.

4. It is generally conceded that the inspector automatically lowers his standards when the overall quality is poor. When the overall quality is high, he automatically raises his standards. This obviously has its effect on the interpretation of the color lines during the season. Another source of error is the physical differences between human eyes.

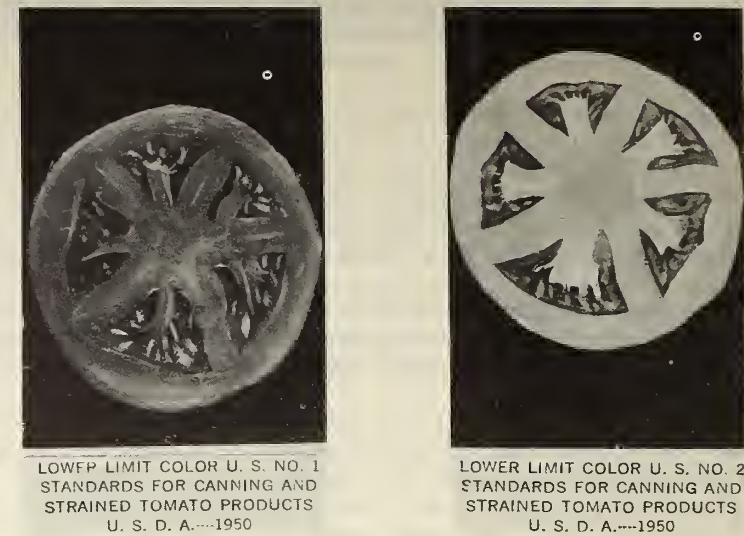

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Figure 1.--Hand-painted replicas, made of plastic, showing cross-sections of tomatoes for lower limit U. S. No. 1 color and lower limit U. S. No. 2 color.

Tomatoes are graded primarily on the basis of external color. In doubtful cases, the inspector is permitted to peel back the skin and cut and examine the color of the flesh. Under the U. S. Standards for strained tomato products, the fruit may be cross-sectioned and the cell wall examined. It has been demonstrated, however, that external or cross-section colors are not accurate indications of the raw juice color (4, 53). It is also known that the color of the skin greatly alters the appearance of the color of the flesh beneath. Growing conditions as well as variety influence the relationship between the external and internal color of tomatoes.

Another shortcoming in the grading system is the abrupt change in prices made necessary by only three separations for color. This often results in an inequitable return to the grower. It has been deemed impractical, if not impossible, for the inspector to make additional subdivisions on the basis of color.

Sampling is another major problem in the application of the grading system for fresh tomatoes for processing. Procedure calls for a minimum sample of 3 hampers (5/8 bushel) from an average load of 50 to 450 hampers. The conclusion that such a sample is representative is hardly valid. Selections at random are also unlikely, for in practice, hampers are usually selected from the uppermost portions of a load.

Research was initiated as a result of a cooperative study in 1948 by the U. S. Department of Agriculture and the Agricultural Experiment Stations in New York, Indiana, and Ohio (13, 18, 19). Growers, processors, and cooperating agencies felt that accurate data should be obtained through research to show the relationship between the grades of fresh and processed tomatoes and tomato products.

In 1950, representatives of the several groups interested in tomato quality met to discuss a proposed investigation of the need for and development of an objective color measurement system that might ultimately replace or supplement the current visual color evaluation.[2] Among those present were representatives of the New Jersey Canners' Association, the National Canners' Association, the New Jersey Farm Bureau, New Jersey-Pennsylvania Cooperative Tomato Growers' Association, the Division of Markets of the New Jersey Department of Agriculture, the U. S. Department of Agriculture, the agricultural experiment stations, and manufacturers of tomato products (48).

As a result of this conference, research was undertaken with color measurement of raw tomato juice as the prime objective. Sampling methods were also considered. Loss from defects was estimated and defective portions of tomatoes were trimmed out before color was measured but in no case was trimming in excess of 10 percent of the tomato[3]. More intensive and individual research was undertaken by the U. S. Department of Agriculture in 1952 and has continued to the present time.

BACKGROUND OF RESEARCH

In 1933, when standards for tomatoes for the manufacture of strained tomato products were recommended, the flat-rate method of purchase became obsolete (47). Although the acceptance of these standards has never been put on a mandatory basis, they have been used more and more through the years.

MacGillivray (32, 33) recognized that color is one of the most important factors indicating the quality of tomatoes. He offered one of the first methods for color determination, based on the Munsell color system, in which an objective color evaluation was specified for tomato pulp. The Maxwell spinning disks were used to match the color of samples. Color components of hue, value, and chroma were expressed in terms of Munsell color notations for different internal areas of the tomato.[4]

In his report (33), he stated that "the method that gives data which may be expressed directly in psychological terms; that is, in terms of what the eye sees is the one which shall be used as most pertinent to the measurement of tomato color." He referred to a color index based on the Munsell color system. Hue and chroma numbers were determined by finding the percentage of the area on the Munsell spinning disks of Munsell notation 5 R 2.6/13 and 2.5 YR 5/12 which, when combined with small percentages of N1 (black) and N4 (gray), gave the closest match of sample and disk. Value was considered to be unimportant. Derivation of this color rating was based on formulas developed and published for use with early Munsell standard papers (40).

Various researchers (16, 20, 29, 32, 37, 38, 39) have reported on the method of disk colorimetry developed in the laboratories of the U. S. Department of Agriculture. This simple and fundamentally sound method of additive color mixture has been refined somewhat in recent years (16) but the basic features of the spinning disks of color viewed under standardized illumination remain the same. Disk colorimetry is still widely used in the evaluation of the color of processed tomato products. In fact, the U. S. Standards for grades of tomato catsup, juice, puree, paste, and sauce, and the U. S. Food and Drug Administration's Standards for quality for canned tomatoes clearly specify that the color of these products must be equal to or better than that produced by spinning a combination of Munsell color disks.

[2] Classifying defective tomatoes is considered entirely within the realm of subjective evaluations. However, classifying defective tomatoes objectively, possibly by rapid electronic sorting devices, may be feasible (2).

[3] Younkin, S. G. A Comparison of Colorimetric Grading With Visual Color Grading of Tomatoes. New Jersey Agr. Expt. Sta., Rutgers Univ. 1950. (Unpublished.)

[4] Hue is that attribute of color associated with the sensation of redness, yellowness, blueness, etc. Value (or lightness) is associated with the brightness aspect of color and usually depends on the relative luminous flux transmitted or reflected by the colorant. Chroma (or saturation) is the attribute associated with the strength of hue or freedom from admixture with white (3).

In 1931 when the C.I.E. (Commission Internationale de l'Eclairage) color system was adopted, specification of the Munsell notations could be expressed in accurate formulas deriving trilinear coordinates.[5] Judd (26) clearly described the C.I.E. system and explained its uses.

Hardy (21) published a handbook of colorimetry which provided tables and charts for arriving at trilinear coordinates and calculating dominant wavelength and purity.[6] Newhall, Nickerson, and Judd, (38) in a final report, specified the Munsell papers in C.I.E. tristimulus specifications and trilinear coordinates.

With the notation of Munsell standard papers in C.I.E. specifications, conversion from one system to the other was possible. Although the color of such products as tomato juice may be expressed in either Munsell hue-value-chroma notation or dominant wavelength-purity notation, it is usually the practice in color measurement to refer both to the C.I.E. (x, y) diagram (21, 40).

The usual method in the U. S. Department of Agriculture, however, involves the use of the Munsell system of color notation, since color measurements are thus kept in terms of scales whose steps approximate equal-sense intervals closely corresponding to the visual judgments of inspectors (40).

With the advent of electronic instruments that could be used in evaluating the color of agricultural products, conversions to trilinear coordinates of the C.I.E. system were often found to be more appropriate and more widely interpreted than Munsell terms. Physical methods of color measurement have a distinct advantage over the psychophysical from the standpoint of not being affected by quality of light or color vision of an observer.

Whenever subjective visual color judgments are to be made, the color normality of the observer's eyes should be known and all possible external conditions of judging a sample should be standardized, so that reproducible judgments may be made.

Many workers (3, 5, 7, 15, 30, 31, 34, 36, 43, 44, 46) have described color in tomato products by resorting to spectrophotometric analysis of juice extracts. Such information is most valuable, and by proper mathematical computations, trichromatic coefficients may be derived. Either reflectance or transmittance curves afford specification of the color components of many agricultural products. Such measurements, however, are entirely physical in nature and when conversion to psychophysical dimensions is made with some agricultural products, an erroneous color match often results (22). This has not been the case with tomato juice whether raw or processed. The nature of the juice itself enables expression with only slight error in both physical and psychophysical terms.

Although data obtained from spectrophotometers may be considered objective, the time and skill required to interpret such data prevent their use in routine work.

In 1948, Hunter (24, 25) reported a photoelectric color difference meter that measured color by the use of three filters approximating the X, Y, and Z functions of the C.I.E. system. This new instrument was designed after basic studies completed in 1942 (23). His "Color and Color-Difference Meter," hereafter abbreviated CDM, represented a departure from usual colorimeters as it afforded data in a form closely related to the spacing of the Munsell system. This instrument immediately aroused interest for

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[5] Sometimes abbreviated I.C.I. in American publications.

[6] Dominant wavelength of a color is the wavelength of the part of the spectrum required to be mixed with some fixed light (like daylight) to produce the color. Purity is the ratio of the amount of the spectrum component in this mixture to the sum of the spectrum and daylight components. Dominant wavelength indicates rather well what hue the color will be perceived to have; and purity the saturation (chroma) perceived (27).

the color measurement of agricultural commodities. This improved photoelectric reflectometer in which calculations are largely done by electric circuits yields quantities Rd, a_{Rd}, and b_{Rd} defined by Judd (27) as:

$$Rd = 100\ Y \qquad a_{Rd} = 175\ fy\ (1.02\ X - Y) \qquad b_{Rd} = 70\ fy\ (Y - 0.847Z)$$

where $fy = 0.50\ (21 + 20Y) / (1 + 20Y)$ and X, Y and Z are the trichromatic coefficients of the color on the standard CIE system. Another circuit yields the quantities L, a_L and b_L defined as:

$$L = 100\ Y^{\frac{1}{2}} \qquad a_L = 175\ (1.02\ X - Y)/Y^{\frac{1}{2}} \qquad b_L = 70\ (Y - 0.847Z)/Y^{\frac{1}{2}}.$$

Newer models of the Hunter CDM include circuitry enabling data expression directly in trichromatic coefficients and trilinear coordinates by automatic servo motor drive (1).

Robinson and others (44) reported that the Hunter CDM, when used for grading purposes, offered a ratio of the a_L to b_L readings which "is a convenient and accurate method of expressing the color of tomato juice within the brightness and chromaticity ranges normally encountered."

The Hunter CDM was the standard instrument used to measure the color of raw and processed tomato juice in the tomato grade relationship studies in New York, Indiana, and Ohio, and in the 1950 studies in New Jersey.

In the studies a new development, the tomato hue colorimeter, was also tested as a simple direct reading instrument applicable to accurate color measurement in a packinghouse or on an inspection platform. Younkin (54, 55) reported the results of this study.

The tomato hue colorimeter showed considerable promise and was judged to be a well-designed apparatus. It measured the hue of tomato purees as the ratio of $\frac{X_c - Y_c}{Y_c - kZ_c}$ or a/2.5bk, where k is a constant, slightly higher than 1.00, which may be adjusted to make the instrument readings correlate better with Munsell hue, and X_c, Y_c and Z_c are the trichromatic coefficients of the sample expressed in terms of illuminant C.[7]

The New Jersey studies indicated differences in grade concepts of color between different inspectors and with individual inspectors from one period to another, using the Hunter CDM measurements as a criterion of color. These studies also demonstrated that the present grades for color were perhaps too broad to permit estimation of colors of unconcentrated tomato juice obtained from fruits of a given grade, based on color only. Fruit that graded 50 percent No. 1 and 50 percent No. 2 in some cases, yielded an unconcentrated juice that was superior in color to that obtained from fruit grading 80 percent No. 1, and 20 percent No. 2 for color only.[8] Such problems also occurred in the Ohio, New York, and Indiana studies (13, 18, 19).

These investigations suggested that grades for tomatoes for processing could, however, be based on (1) an objective evaluation of color of unconcentrated juice and (2) a subjective estimation of defects (other than color) which could possibly provide a more accurate specification of the value of loads of tomatoes for processing than the present grading procedures.

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[7] Hunter, R. S. Personal correspondence, Hunter Assoc. Lab., 5421 Brier Ridge Road, Falls Church, Va.

[8] Maclinn, W. A., Younkin, S. G., and Healy, N. C. Report of the 1951 Investigations on the Development of an Objective Method of Grading Raw Tomatoes. New Jersey Agr. Expt. Sta., Rutgers Univ., 1951. (Unpublished.) (See also footnote 3.)

RECENT DEVELOPMENTS

With information afforded by earlier workers to serve as a guide, the U. S. Department of Agriculture, through its marketing research groups, undertook a program to study whether a practical method of grading tomatoes for color using objective techniques might be established.

In 1952, studies were authorized under the Agricultural Marketing Act of 1946 (1) to test the applicability, under field conditions, of several objective methods for determining the color lines separating U. S. No. 1, U. S. No. 2, and Cull tomatoes, (2) to collect data in different locations in order to study the influence of variety and environmental conditions on the color lines, and (3) to determine the relationship between external and internal tomato color (53).

This research was conducted in six important tomato-producing States. The studies were designed to determine the ability of three different instruments to measure small differences in tomato color, the color of external surface, the cross-section surface, and the extracted juice. External color was measured with the Purdue Color Ratio Meter, hereafter abbreviated Purdue CRM, (8, 9, 10) cross-section surface color with the Agtron Model E, and extracted raw juice color with the Hunter CDM and the Purdue CRM, shown in figure 2.[9]

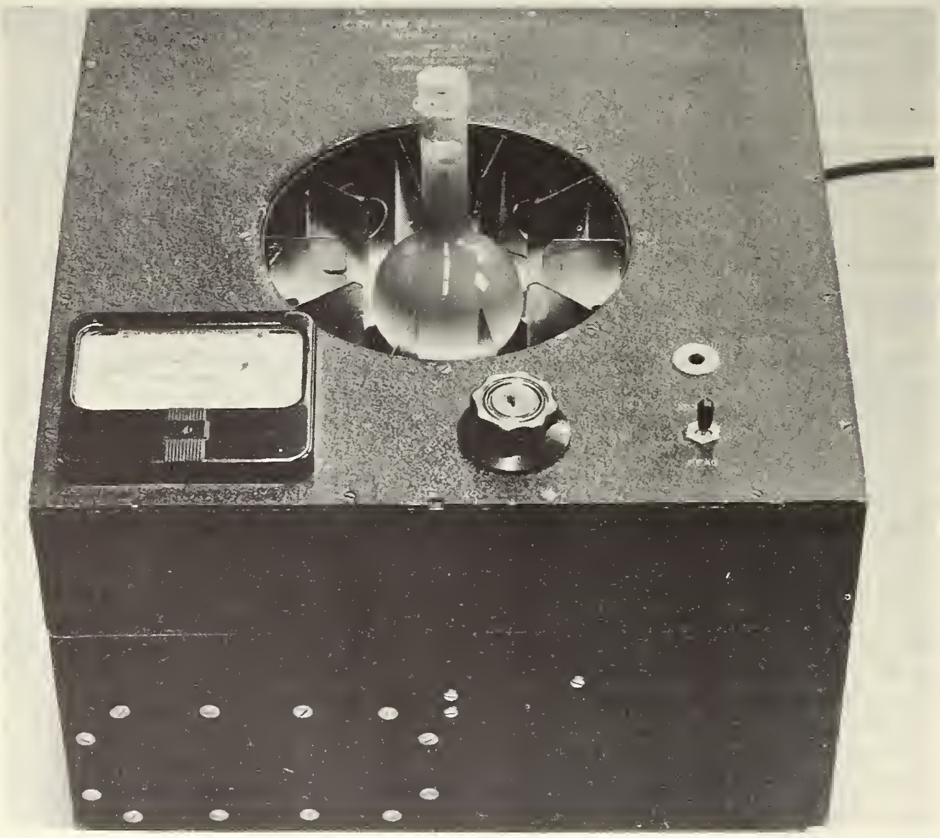

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Figure 2. --Purdue Color Ratio Meter.

[9] The mention of specific instruments or trade names is made for the purpose of identification and does not imply any endorsement by the U. S. Government.

The Agtron Model E (46, 45) was developed for use as a referee in the evaluation of borderline tomatoes encountered in the establishing of a grade. This instrument, which evaluates the cross-section color of a whole tomato, expresses this color as a ratio reading between 546 millimicron and 640 millimicron filter arrangements with appropriate light source and phototube combinations. It has been widely used in California and has been reported as a valuable adjunct to inspection procedure in that State (52).

It was concluded from the 1952 studies that a homogeneous medium such as the juice offered the most promising method of objectively evaluating tomato color.

Large differences were found to exist between the external and internal color of tomatoes. In only one-third of the cases were inspectors able to predict cross-section color by observing only the external color. The formulation of tentative color specifications defining at least 90 and 66 2/3 percent "good red color" were offered. These definitions were based on objective evaluations of external color, cross-section color, and raw juice color.

In 1953, Wilson and Dever (53) investigated "the possibility of determining the quality of tomatoes for processing on the basis of an objective evaluation of color (using a raw juice medium) combined with a subjective determination of the percentage of grade defects." Two photoelectric instruments, the Hunter CDM and the Agtron Model F were tested. In addition, an inspector's score of raw tomato juice color using the Macbeth-Munsell Disk Colorimeter, hereafter abbreviated MMDC, shown in figure 3, was evaluated and a sampling device was tested. This device was designed to remove a representative subsample for color evaluation from the sample of tomatoes customarily used by the inspector to determine grade. Incidentally, the effect on juice color of small amounts of air introduced during extraction was determined, and the practicability of using a standard source of illumination for grading purposes was tested.

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Figure 3.--Macbeth-Munsell Disk Colorimeter.

Wilson and Dever suggested that a series of equations be formulated, based on the evaluation of the quality of raw tomatoes by objective means and subjective determination of the percentage of grade defects. The abnormalities of the 1953 season indicated the necessity for obtaining additional information in subsequent seasons on samples which represented wider ranges of color and defects.

Color indices computed from evaluation of raw juice with the photoelectric instruments showed relatively high correlations with visual color scores made with the MMDC: Hunter a_L/b_L = 0.81; Hunter L, a_L and b_L = 0.88; and Agtron Model F = -0.82. The higher correlation with L, a_L and b_L confirms Younkin's finding, that the full expression of the color of tomato juice should include the lightness or "L" factor when using the Hunter CDM and not just a ratio measurement of a_L/b_L (55, 56). The Agtron Model F, as shown in figure 4, was developed expressly for the evaluation of raw tomato juice (45, 46). In cooperation with industry, Wilson and Dever (53) found in preliminary tests that the Agtron Model F apparently offered an answer to the tomato color problem. Gould (17) describes its design and some of its uses. High correlations with Hunter L, a_L and b_L, and visual scores on raw tomato juice have been obtained. Some researchers feel that such instruments as the Agtron Model F are not the answer (4).

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Figure 4.--Agtron Model F.

Smith (45) suggests that a single wavelength instrument, such as the Agtron, will differentiate samples of tomato juice as to color.

Younkin (56) states that "tomato puree colors cannot be properly classified on a one-dimensional scale;" and also "adoption of any one of the ratio instruments presently available will inevitably lead to situations where color similarities are indicated when in reality, obvious color differences exist." These facts and others led to continued studies in 1954 by the U. S. Department of Agriculture.

RESEARCH METHODS AND TECHNIQUES

The 1954 investigations were conducted at a processing plant in Wyoming, Del., from August 6 through August 19 and at a plant in Napoleon, Ohio, from August 31 through October 2. Procedures of objective evaluation of color and subjective determination of defects were designed to adjust to the peculiarities of each location. Procedures were similar, but not identical at the two locations.

Figure 18 shown in Appendix A is a schematic diagram of the detailed procedure employed at the Ohio location. A description of the procedure also appears in this Appendix.

It was readily apparent that the procedures studied in 1953-54 for judging color and defects were impractical. The results of the 1954 studies emphasized the necessity for research on sampling, which has long been neglected, in problems of this kind. Although modified and somewhat improved for use in the 1954 research program, a mechanical sampling device designed to remove a subsample for color evaluation from a sample of tomatoes was nevertheless highly impractical and was discarded (fig. 5). Theoretically, this device was supposed to take a subsample not in excess of 10 percent of a hamper of tomatoes with the tomatoes passing through the device only once.

It was recognized, in planning the 1955 studies, that estimation of defects as part of an inspection procedure should remain subjective. Additional research on sampling was needed to determine the size of sample required for reliable estimates of error. This research was planned and accomplished in the 1955 program as shown in Appendix B. Research was conducted at a processing plant in Wyoming, Del., from August 2 through September 16, 1955.

In the 1955 research program the first real attempt was made to provide artificial illumination over the grading table to standardize grading conditions. A 500-watt Macbeth Daylight lamp, filtered, pendant-type, was mounted approximately 28 inches over the grading table. In addition, a light gray (Munsell N 7.5/) cloth screen 36 inches in height was installed on 3 sides of the table. Inspection under these conditions proved most satisfactory and approximated recommended lighting conditions for color grading (41, 42). Color and energy distribution of the light source was close to that of a moderately overcast sky at 7500^{o} Kelvin. A light intensity of 85 foot-candles was maintained at the surface of the table.

The emphasis in 1956 was placed on size of sample for evaluating defects. This program involved two major objectives: (1) To determine the size of sample from a load and the size of subsample which represented the greatest reliability for use in developing a method for determining the quality of tomatoes for processing based on subjective evaluation of defects; (2) to determine the quality of tomatoes for processing by objective measurements of color involving various alternative samples and composition of raw tomato juices.

As in all phases of this research, a licensed Federal-State inspector experienced in grading tomatoes was assigned to inspect all hampers of tomatoes used in the tests according to requirements regarding defects described in the U. S. Standards for strained tomato products. He was also required to classify the tomatoes by percentage of defects. The research was conducted at a processing plant in Biglerville, Pa., from August 31 through October 3, 1956, and the procedure was as follows:

1. The facilities at this particular plant were unique, in that all incoming trucks of tomatoes could be unloaded onto individual cradles, part of an endless belt arrangement. Each cradle was painted 1 of 4 primary colors to facilitate efficient unloading of 4 vehicles at 1 time. A different color was assigned to each vehicle, and the hampers of tomatoes were unloaded only on cradles of the same color. Such an arrangement greatly facilitated more thorough sampling of loads by the regular inspectors and in the research procedure (fig. 6).

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Figure 5. --Mechanical sampling device (courtesy of Purdue University, Lafayette, Ind.).

Large and small loads were sampled alike; no restrictions were put on the type of loads sampled, except where pooled loads were encountered. No load purchased on the open market or representing a pooling of several local growers was sampled.

2. A sample consisted of 8 hampers regardless of the size of the vehicle or number of hampers. They were selected at random as the hampers were being unloaded. Selection was made in such a manner that the sample represented 8 distinct areas within a load from back to front and from bottom layer to topmost layer. The facilities for unloading at this particular processing plant enabled the researchers to eliminate the usual procedure of obtaining samples from only the periphery of the load, which in most cases is only the top layer.

Neg. BN-5547

Figure 6.--Endless belt, cradle arrangement at Biglerville, Pa., for unloading hampers of tomatoes to be processed. Each cradle is painted 1 of 4 primary colors, in sequence, to facilitate efficient unloading of 4 vehicles at 1 time. A different color was assigned each vehicle and hampers of tomatoes were unloaded only on cradles of the same color.

All samples to be used during the day were selected in the forenoon and placed in the shade until needed.

If the color requirements set forth in the U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products, which presumably can be evaluated objectively by electronic measurements, are disregarded, only the requirements for other defects are left. If no more than 10 percent of the tomato was estimated to require trimming for defects, the tomato normally fell in the classification of No. 1 for defects. Similarly, if no more than 20 percent nor less than 10 percent of the tomato was estimated to require trimming for defects the tomato was normally classified as No. 2 for defects. Those tomatoes requiring over 20-percent trim were classified as Culls.

Tomatoes can be graded for defects, therefore, by determining the percentage-trim factor for a graded sample, that is, the nonusable portion of the sample, for which no payment should be made. The defective portions of a sample of cannery tomatoes can be estimated or trimmed out, removing only the defects required by the definition of defects so as to expedite the grading. The tomatoes can then be paid for on the basis of (1) the percentage of the load that was nonusable, or conversely, the percentage of the load that was usable, and (2) a color-grade score on a composite juice sample determined objectively by photoelectric measurement.

3. To determine the variables associated with such a procedure, each hamper in an 8-hamper sample was divided by random selection into 2 one-half hampers. The non-usable portion of each tomato in each one-half hamper was estimated and the defective portions immediately trimmed with a paring knife. The estimations of condition or trim categories set forth in the research procedure were as follows: (a) Those tomatoes requiring 0- to 5-percent trimming of defects and those requiring 6- to 10- percent trimming of defects. This would normally be the upper limit of the U. S. No. 1 grade for defects. (b) Those tomatoes requiring 11- to 15-percent trimming and those requiring 16- to 20-percent trimming. This would normally be the upper limit of the U. S. No. 2 grade for defects. (c) Those tomatoes of which more than 20-percent trimming would be required were graded as Culls and were included with Culls as part of the total trim loss for the sample. Figure 7 shows a schematic diagram of the research procedure of grading for defects.

This more precise classification into 0- to 5-percent, 6- to 10-percent, 11- to 15-percent, and 16- to 20-percent was made to pinpoint the variation to be expected within limits of the grade for defects presently used.

The weight of trim and weight and number of the tomatoes remaining in each classification were recorded. Tomatoes classed as Culls for defects (requiring more than 20-percent trim) remained untrimmed, only weight and count being recorded. Culls and trimmings were discarded.

4. The trimmed tomatoes in each half-hamper graded U. S. No. 1 and U. S. No. 2 for defects were recombined and mixed thoroughly to make 8 hampers of tomatoes. One 4-tomato subsample and one 16-tomato subsample were selected at random from each of the 8 hampers of trimmed tomatoes for subsequent pulping.

5. The 4- and 16-tomato subsamples from each hamper were then extracted with an Enterprise Meat and Food Chopper (Model 2112) fitted with an 0.034-inch mesh screen. The nondeaerated juices were then measured in sequence on the MMDC, Agtron Model F, Gardner CDM (fig. 8), and the IDL-Color Eye shown in figure 9.

6. A blend study designed to determine the error of estimate associated with various numbers of tomatoes for hampers expressed in a composite juice was undertaken. The 4- and 16-tomato composite juices were handled similarly. For example, the 4-tomato juice from hamper number 1 was mixed with an equal volume, 125 milliliter, from the 4-tomato juice from hamper number 2 and color measurements made. Then a 125 milliliter portion of the resultant mixture was mixed with another 125 milliliters of a similarly prepared juice from hampers 3 and 4, and similarly for hampers 5 and 6 with hampers 7 and 8. Mixtures of 4-tomato blends from hampers 1, 2, 3, and 4 were made with hampers 5, 6, 7, and 8. Similarly, mixtures of blends of the 16-tomato composites were made and color measurements read at each step. Figure 10 shows a schematic diagram of this study.

The color of all nondeaerated portions of the raw juice was evaluated on the MMDC by comparison of the juice with 5 Munsell disks which were assigned values of 10, 15, 20, 25, and 30 points. Wilson and Dever (53) explain the development of these disks. Munsell renotations were assigned to the disks based on percentages of components of standard Munsell papers. The disk with a color score of 20 points was designed to match the color of raw juice extracted from 10 pounds of tomatoes graded by their cross-section color, as minimum U. S. No. 1. Similarly, a disk with a color score of 10 points was designed to match the color of extracted juice representing minimum U. S. No. 2 tomatoes for cross-section color. The disk with a color score of 30 points consisted of 100 percent of the red component Munsell standard paper and was considered to represent maximum U. S. No. 1 tomatoes for cross-section color. Equal portions of juices which matched the 20- and 30-point color score spinners were blended and a spinner was designed to match the resultant mixture. This spinner was assigned a value of 25-point color score. Similarly, a juice was prepared from equal portions of 10- and 20-point juices, and a 15-point spinner designed to match it.

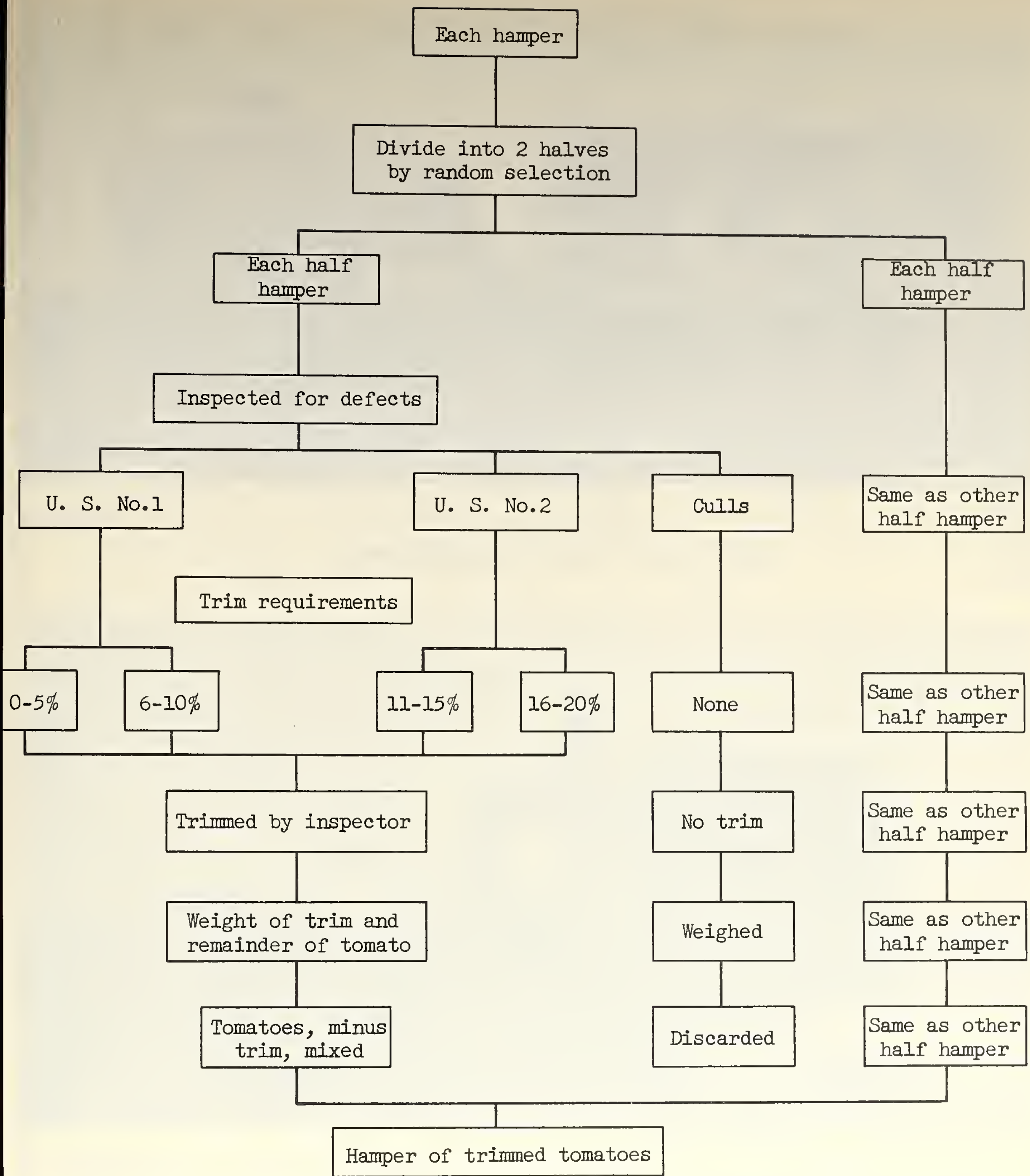

Figure 7.--Schematic flow diagram of the defects grading procedure for each hamper selected from a load (1956).

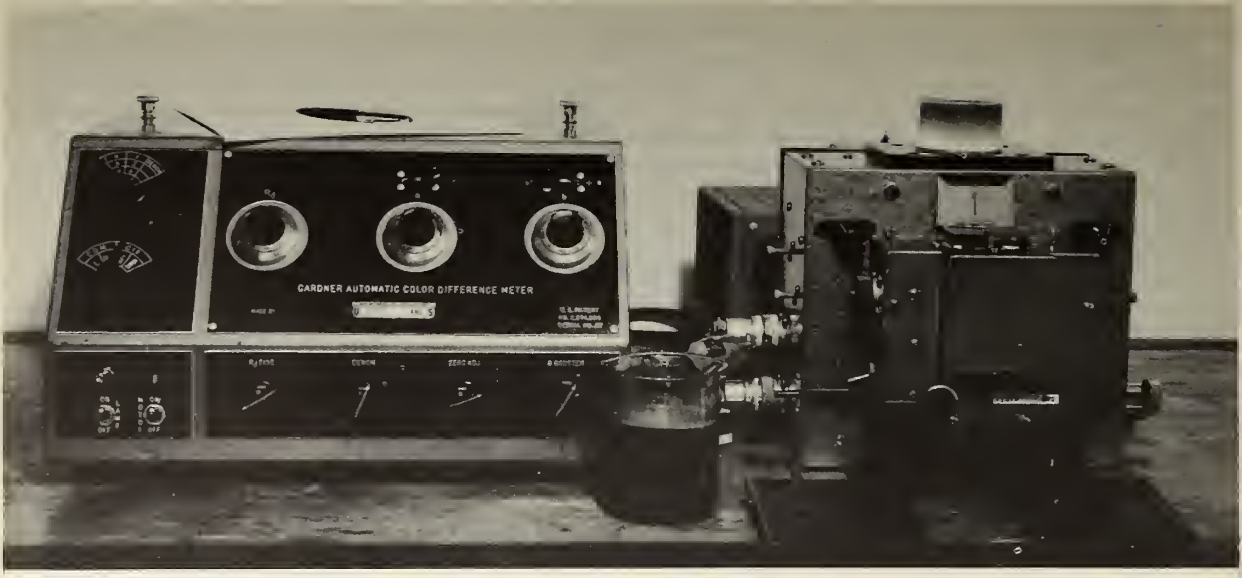

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Figure 8.--Gardner Automatic Color Difference Meter.

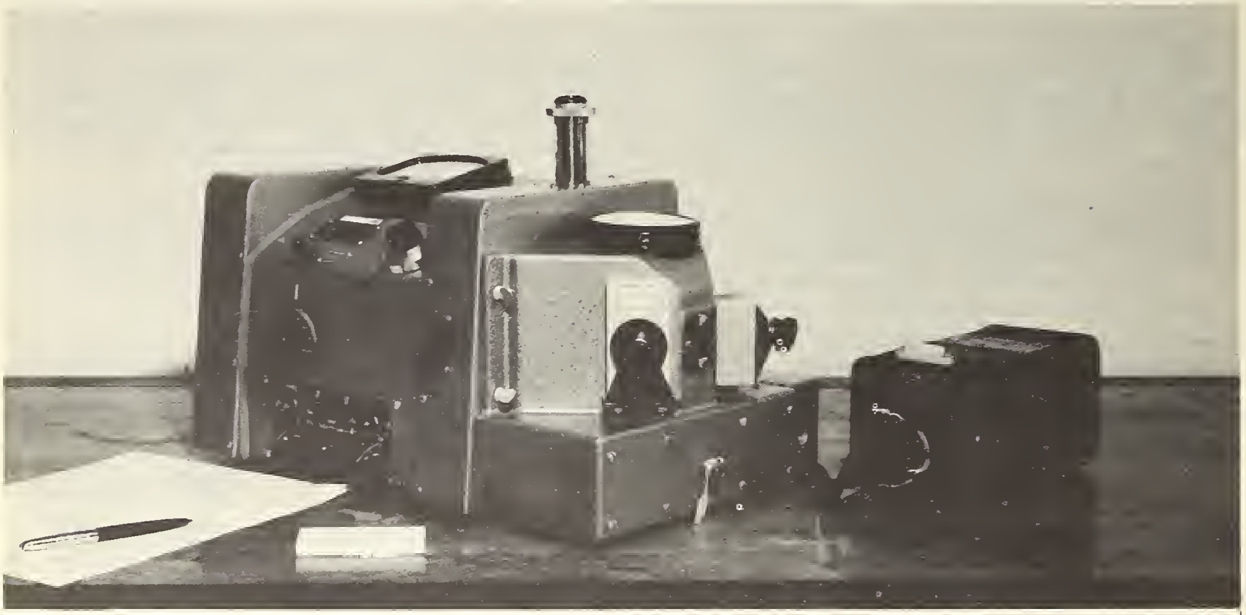

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Figure 9.--IDL-Color Eye.

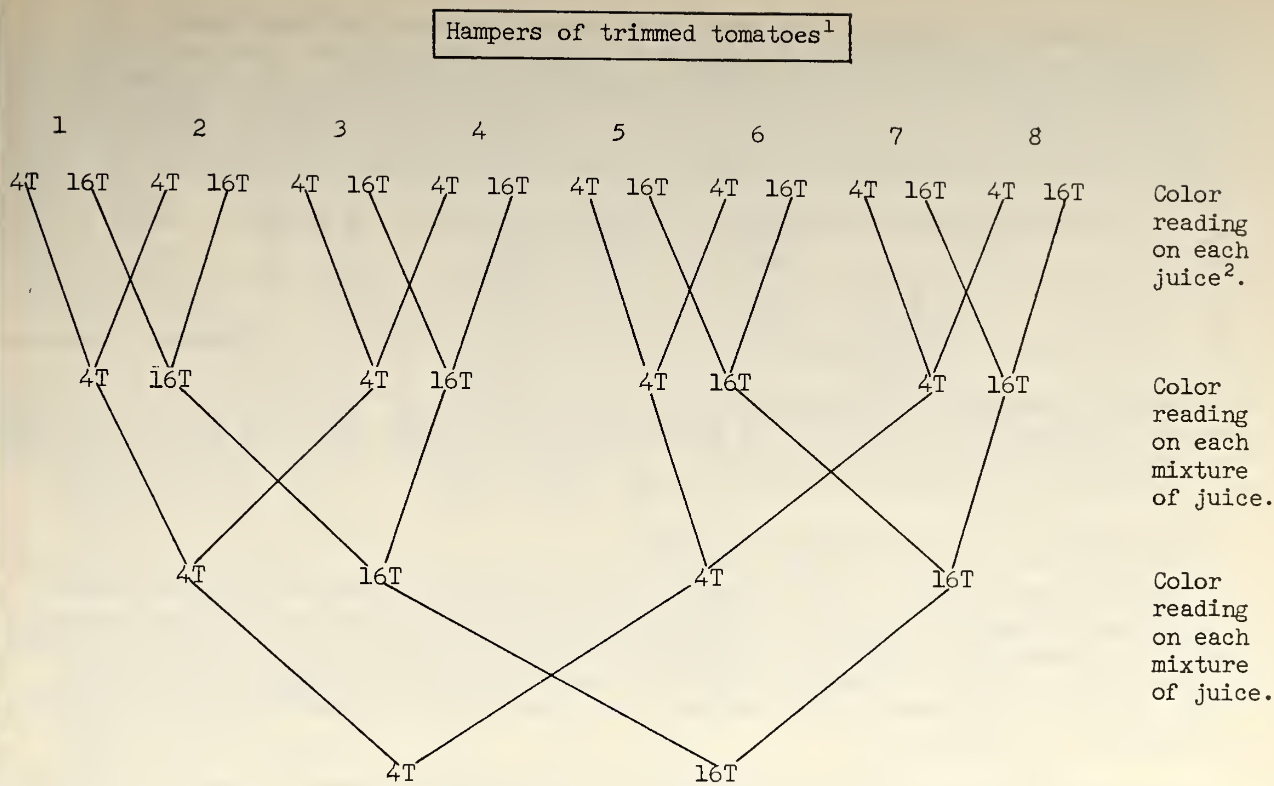

Figure 10.--Schematic flow diagram of the blend study for composite subsamples from each hamper selected from a load (1956).

[1] 4T = 4-tomato composite juice; 16T = 16-tomato composite juice.
[2] Mixture of juice made with equal volumes of each component.

The Wilson and Dever disk specifications for color of raw tomato juice are shown in table 1.

The Agtron measures color in values relating to reflectance in percentage. By selected source-filter-phototube combinations, the color of raw tomato juice is indicated in arbitrary values from 100 to 0 which can be converted to approximate percentage diffuse reflectance at the 546-millimicron mercury line.[10]

This formula is based on use of a 1.5-percent reflectance reference material to standardize on 100 and a 5.0-percent reflectance reference material to standardize on 0. The formula should be accurate within one- or two-tenths of 1 percent. Note that this is diffuse reflectance and not total reflectance, since the glossy component has been eliminated.

With the use of plastic standards, one representing approximately 1.5-percent reflectance and the other 5.0-percent reflectance, a 3.5-percent reflectance range is expanded over 100 units of Agtron. Slight differences in brightness of tomato juice are therefore indicated. One unit Agtron reading represents approximately a 0.05-percent difference in reflectance.

---

[10] $R = 1.5 + (0.05)(100-M)$

where R = approximate percentage diffuse reflectance at 546 mu.
" M = meter reading on inverse scale 100-0.

TABLE 1.--Standard disk specifications for color of raw tomato juice

Score	Munsell components in percent[1]				Munsell renotation for mixture
	R	YR	N1	N4	
30........................	100.0	--------	--------	--------	7.5R 2.92/9.9
25........................	93.9	2.1	1.3	2.7	7.75R 3.0/9.5
20........................	89.0	7.1	2.6	1.3	8.8R 3.13/9.6
15........................	69.3	12.0	10.7	8.0	9.25R 3.25/8.4
10........................	51.7	21.0	14.0	13.3	0.25YR 3.52/7.91

[1] Munsell renotation for components: R = 7.5R 2.92/9.9; YR = 3YR 5.09/12.5; N1 = N 2.5 PB 0.26/0.3; N4 = N 3.95. The C.I.E. specifications for these notations are: (R): X = .1102 Y = .0620, Z = .0192; (YR): X = .2856, Y = .2055, Z = .0262; (N1): X = .0030; Y = .0031; Z = .0042; (N4): X = .1132; Y = .1154; Z = .1360, respectively.

From Wilson, D. E., and Dever, G. B. (53).

Gardner CDM values were read as direct trichromatic coefficients X, Y, and Z with Hunter L, a_L, and b_L values computed therefrom. The Gardner CDM was standardized between each reading with a tomato red tile, supplied by S. G. Younkin, courtesy of Campbell Soup Company, with X, Y, and Z trichromatic coefficients of 10.9, 7.02, and 2.5, respectively. All readings were made with wide aperture (2 1/4 inches) and large area illumination.

The IDL-Color Eye values were read as a percentage of relative intensity reflectance at 10 equally spaced intervals through the visible spectrum. The abridged spectrophotometer feature of this instrument enables construction of numerous ratios for readings at different wavelengths as well as simple reflectance curves. Percentage reflectance is read at every 33 1/3 millimicrons from 400 to 700 millimicrons. Measurements are made at diffuse reflectance with glossy component excluded. This instrument is also a 3-filter photometer but was not used as such in these studies.

7. Standardized illumination was used over the grading table. Although color was not a factor to be evaluated subjectively in the inspection procedure, it was found that grading for defects was facilitated by having a uniform distribution of light over the entire grading table. Illumination was provided by a Macbeth Model T Examolite, 10 x 12 x 49 inches, containing 2 standard Examolite fluorescent tubes and 4 standard Examolite long-life, incandescent bulbs and Crista-Lite diffusing glass (42, 51).[11]

RESULTS AND DISCUSSION

Color Evaluation Studies

Samples of juice evaluated throughout the 1954 season were taken from lots of tomatoes with defective portions included. This method of preparing juice for color measurement was found to be contrary to the true and accurate expression of color components. The incorporation into a sample of all the defects encountered in fresh tomatoes for processing--such as black mold, extensive sunburn, and sunscald--caused erroneous evaluation of juice to the extent that highly colored samples containing contaminating materials gave color readings equal to highly colored samples containing no contaminating materials.

[11] Ide, L. E., and Burrows, Glenn L. Preliminary Report on Tests of Artificial Light Sources for Cannery Tomato Inspection. U. S. Agr. Mktg. Serv. 1957. (Unpublished.)

With the use of the Hunter instrument, it was possible to separate the contaminated samples from those without contamination. But with such instruments as the Agtron, and even with visual estimation of color, contamination produced errors in readings. Table 2 shows the effect of contaminants on color readings. Because contaminants produced errors in readings, the practice of trimming out defects from the sample to be made into juice was introduced and has been continued since that time.

TABLE 2.--Effect of contaminating materials on the color evaluation of raw tomato juice, 1954

Sample composition	Hunter				Agtron	Visual color score	Remarks
	L	a_L	b_L	a_L/b_L			
(1) U.S. No. 1's for color, U.S. No. 2's for black mold, no sunburn, minus trim.	26.2	22.2	9.4	2.36	74	24	High color, acceptable.
(2) Sample No. 1 with all trim included.	26.1	20.7	9.6	2.16	72	24	Nonacceptable due to contaminants.
(3) U.S. No. 1's for color, U.S. No. 2's and Culls for decay and discolored growth cracks, minus trim.	25.7	23.8	9.4	2.53	78	24	High color, acceptable.
(4) Trim portion of sample No. 3.	21.3	10.5	7.2	1.46	85	Too dark	Very dark, heavy with black particles.
(5) Two parts sample No. 3 mixed with one part sample No. 4.	23.2	15.6	8.2	1.90	82	Too dark	Very thick with black particles, nonacceptable.
(6) U.S. No. 1's for color, U.S. No. 2's and Culls for decay and discolored growth cracks, trim included.	23.9	16.7	8.7	1.92	80	Too dark	Heavy with black particles, nonacceptable.
(7) U.S. No. 1's for color, U.S. No. 2's for sunburn, no decay, minus trim.	25.3	22.3	9.0	2.48	78	25+	High color, acceptable.
(8) Trim portion of sample No. 7.	28.1	20.2	10.2	1.98	59	21	Low color, nonacceptable.
(9) Two parts sample No. 7 mixed with one part sample No. 8.	25.7	22.3	8.9	2.51	74	24	High color, acceptable.

Comparisons between deaerated and nondeaerated juices indicated that deaeration caused constant improvement throughout the season in color readings, but the time required and the equipment needed for deaeration did not warrant its incorporation as a part of procedure. Figure 11 illustrates the improvement in color which was due to deaeration as shown by MMDC, Agtron, and Hunter instruments. As illustrated in this figure, the improvement was so constant and predictable that it was found logical to discontinue deaeration, thus simplifying the procedure.

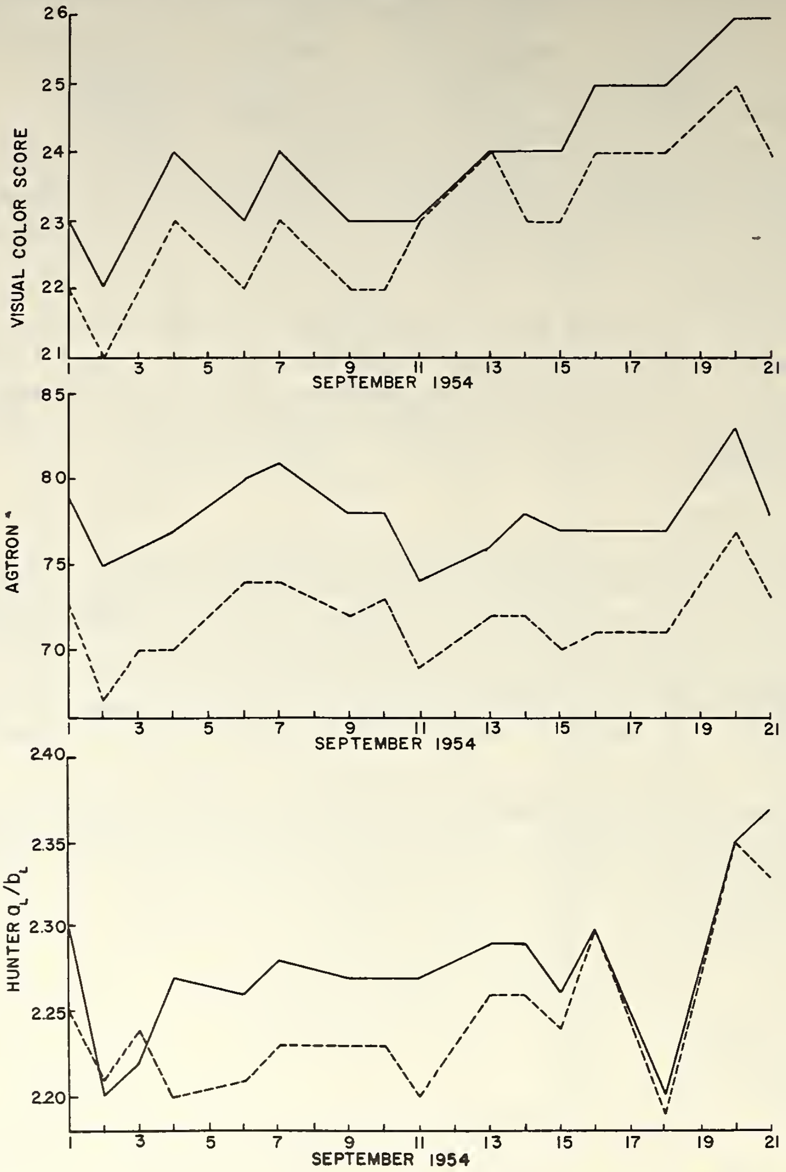

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Figure 11.--Improvement in color because of deaeration of raw tomato juice samples as shown by visual color score (MMDC), Agtron Model F values, and Hunter a_L/b_L ratio. Solid lines are deaerated samples. Dotted lines are nondeaerated samples.

As indicated earlier, the instruments tested in 1954 were the Hunter CDM, Agtron Model F, Purdue CRM, and MMDC. The Purdue CRM, a 2-wavelength, ratio-measuring color device, was used to evaluate not only the color of raw tomato juice, but also the external color of the tomato. The findings in table 3 indicated that the range in color readings, as determined by the Purdue CRM, between samples of juice rated by other instruments to be widely different in color, was too small to be usable. Borderline U. S. No. 1 and No. 2 tomatoes were also evaluated for external color with the Purdue CRM, but the effect of variation in the surface and size of the tomatoes was so great, that widely divergent readings were obtained from measurements on the same tomatoes (table 15, Appendix A). Evaluation of the data was impossible. The attempt to use the instrument which has never been put into commercial production was therefore abandoned.

TABLE 3.--Comparison of Purdue Color Ratio Meter readings on raw tomato juice with readings made with other instruments, 1954

Location	Color measuring instrument			
	Purdue CRM	Hunter a_L/b_L	Agtron Model F	Visual MMDC
Wyoming, Del.:[1]				
Average	50	2.26	67	21
Range	45 - 54	1.70 - 2.64	48 - 85	13 - 27
Napoleon, Ohio:[2]				
Average	46	2.24	72	23
Range	41 - 50	1.84 - 2.61	52 - 83	17 - 27

[1] 65 observations.
[2] 103 observations.

The Hunter CDM and Agtron Model F instruments have been used for 3 years in this study, their readings have been compared with each other, and visual scores have been obtained with the aid of the MMDC. The purpose of these comparisons has been to determine which, if either, of these instruments was better adapted for objective grading of raw tomato juice. The Hunter CDM was developed for measuring indirectly the true color components of hue, value, and chroma; the Agtron Model F was developed for measuring reflectance indirectly at a single wavelength (46). Should the reflectance pattern of raw tomato juices made from tomatoes of different maturities be similar in all other spectral regions, the measurement of reflectance at a single wavelength would be justified. Some workers have reported that this assumption is justified (17).[12] Others take exception (4, 35, 56). For the purpose of a possible modified grading procedure, a reasonably low-cost instrument is obviously much to be preferred.

It has been found in this study that the Hunter L (luminous reflectance) value correlates quite highly and linearly with the Agtron as does the IDL-Color Eye at 533 millimicron with Agtron. Hunter a_L/b_L ratios do not correlate well with Agtron nor in a linear fashion. Hunter a_L and b_L values measure indirectly the hue and chroma components of color and the Hunter L value is a measure of reflectance (brightness of a color). Hunter a_L/b_L ratio is a measure of hue (44). Table 4 shows the correlation of Hunter L values with Agtron, indicating that a measure of reflectance with the Hunter instrument is essentially an Agtron measurement and measurement of this component of color need not be duplicated with the Agtron when the Hunter will suffice for all color components.

During 2 of the last 3 years' studies, correlations between these two instruments and between these instruments and visual color scoring have been calculated. The scoring has been done with the aid of the MMDC and has been done by research personnel rather than official Government inspectors. The range of color readings for all loads

[12] Mavis, J. O., Color Measurement of Tomato Juice and the Adaptation of a Reflectance Instrument, Agtron Model F, for Continuous Measurement. Ph.D. Dissertation, Ohio State Univ. 1955. (Unpublished.)

sampled in the 1956 season for visual color score, Agtron Model F, and Hunter values are shown in figure 12. With the exception of one observer in 1956, whose observations will be explained later, neither the Hunter a_L/b_L relationship, nor the Agtron, nor the L readings of the Hunter has correlated as highly with visual readings as desired. Multiple regression of L, a_L and b_L has indicated that these three Hunter factors combined would correlate to a more highly desirable degree. This is in agreement with Younkin (56). Table 5 shows the comparison of correlation coefficients for the various instruments.

TABLE 4.--Comparison of Hunter L versus Agtron Model F coefficients of correlation with appropriate regression equations[1]

Year	Regression equation	Correlation coefficient	Range	
			L	Agtron
1954..........	Y = 38.79 - 0.172 X	-0.87	24.4 - 30.4	52 - 82
1955..........	Y = 41.55 - .183 X	-.86	24.1 - 35.4	48 - 86
1956..........	Y = 38.79 - .169 X	-.96	21.9 - 32.7	32 - 94

[1] Hunter L = Y (dependent variable).

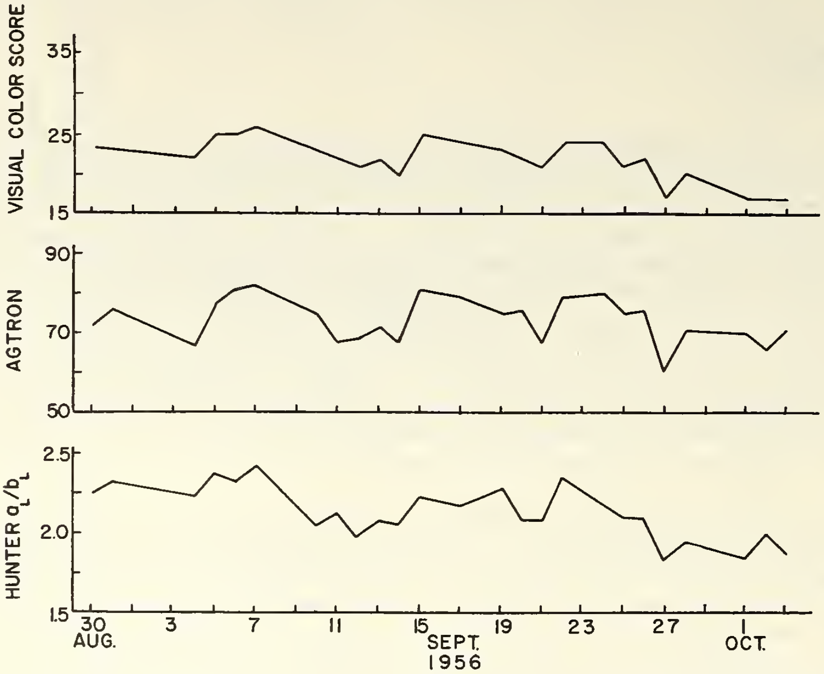

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Figure 12.--Average color readings for all loads sampled for juice in 1956 for visual color score (MMDC), Agtron Model F, and Hunter Color Difference Meter. Visual color score readings show fair agreement with percentage of U. S. No. 1 tomatoes determined by official inspection methods in 1956. (See figure 17.)

TABLE 5.--Comparison of the coefficients of correlation for various instruments

Year	Instrument comparison	Correlation coefficient
1954:	Visual versus Agtron	0.68*
	Visual versus Hunter a_L/b_L	.77
	Visual versus Hunter L	-.56*
	Visual versus Hunter L, a_L/b_L	-.69*
	Hunter a_L/b_L versus Agtron	.77*
	Hunter L, a_L/b_L versus Agtron	-.83
1955:	Hunter a_L/b_L versus Agtron	.75*
	Hunter L, a_L/b_L versus Agtron	.85
1956:	Visual versus Agtron:	
	Operator No. 1	.95
	Operator No. 2	.85*
	Visual versus Hunter a_L/b_L:	
	Operator No. 1	.75*
	Operator No. 2	.84
	Visual versus Hunter L, a_L and b_L	.87
	Hunter a_L/b_L versus Agtron	.64*
	Visual versus IDL Color Eye 533 mu	-.81*
	Agtron versus IDL Color Eye 533 mu	-.94
	Visual versus IDL Color Eye $\frac{533}{633}$ mu	-.74
	Visual versus IDL Color Eye $\frac{533}{667}$ mu	-.76
	Hunter a_L/b_L versus IDL Color Eye $\frac{533}{633}$ mu	-.73

*Evidence of nonlinearity.

The Munsell spinning disks developed for evaluation of raw tomato juice in 1953 by Wilson and Dever (53), and used in the past 2 out of 3 years' research, were found to be incorrect for regularity in hue and chroma relationship but regular for value steps. Color evaluation of juice by other than hue and chroma differences using these Munsell spinners would highly agree with Agtron or Hunter L readings. Conversely, in an evaluation of juice by its color components of hue and chroma with these Munsell spinners correlation with Agtron would be relatively poor and nonlinear.

In 1956, two researchers, working separately, evaluated raw tomato juice with the MMDC, using newly prepared Munsell spinners based on the 1953 specifications of Wilson and Dever, and differed in regard to agreement with Agtron readings. Although the two individuals did not grade the same samples of juice, the fact that one's scoring correlated to the extent of 0.95 and linearly with the Agtron and the other's scoring correlated to the extent of 0.84 with the evidence of nonlinearity indicates that the one with the high correlation was seeing the regular value steps of the Munsell spinners and would be expected to have high correlations. Conversely, the scorings of the individual who evaluated juice by its color components of hue and chroma correlated better with the Hunter a_L/b_L ratio, and the researcher appeared to be following the irregular hue and chroma steps inherent in these Munsell spinners. Figures 13 and 14 show this relationship of visual color score (Munsell spinners) to Agtron and Hunter readings. Both of the observers had successfully passed the Inter-Society Color Council Color Aptitude Test (12); thus, some other feature of their previous experience may have caused them to see the color of raw tomato juice differently. Whether such divergence can be expected among others called upon to grade such a product is an important question.

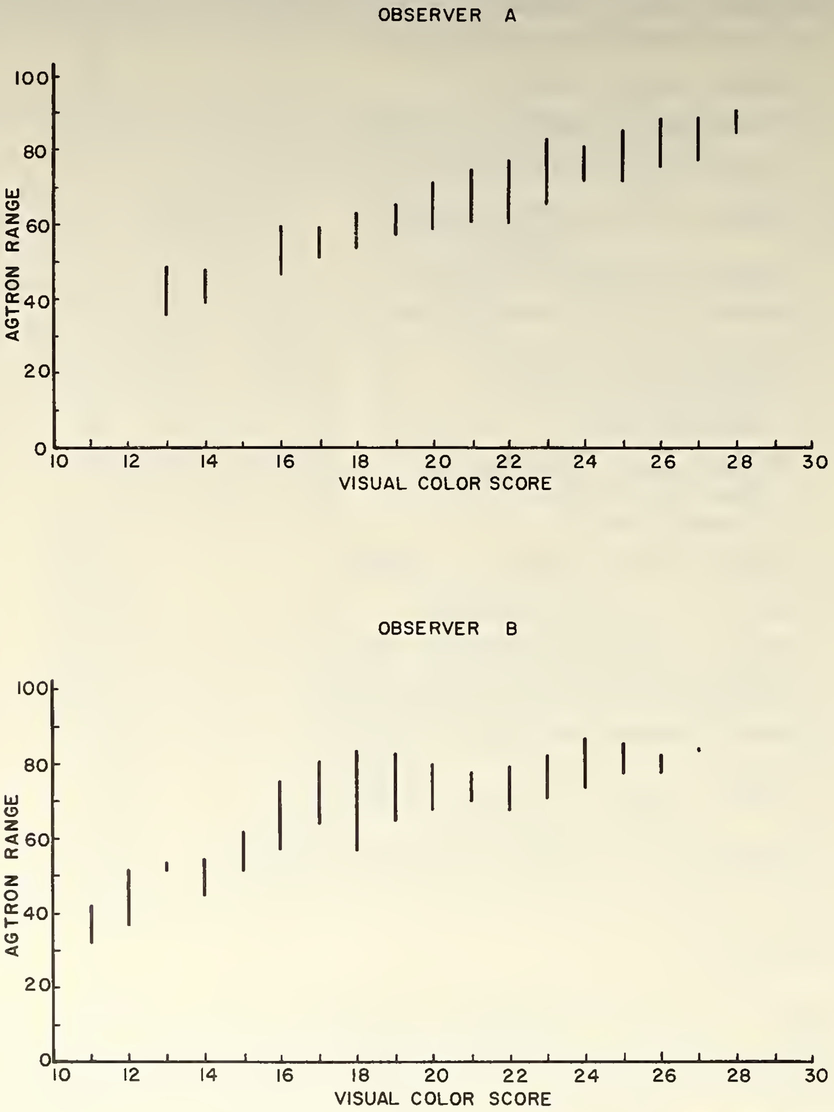

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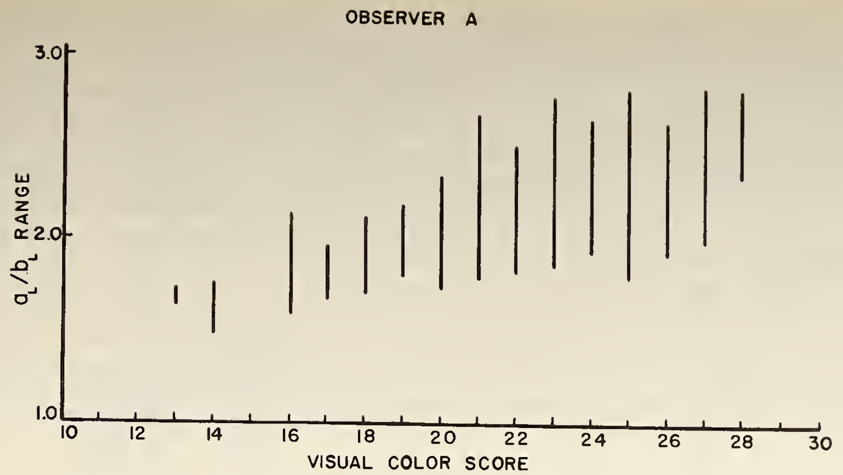
Figure 13.--Relationship of visual color score (MMDC) to Agtron Model F values for two observers. Observer A sees the color of raw tomato juice as regular value changes, an inherent characteristic in the Munsell disks used and changes which the Agtron will record. Observer B sees the color as irregular hue and chroma changes, also inherent characteristics of the disks and color changes which the Agtron will not record.



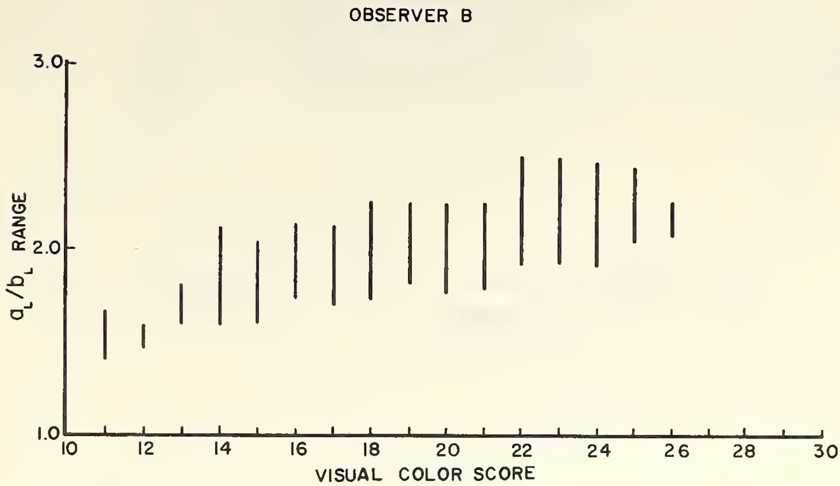


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Figure 14.--Relationship of visual color score (MMDC) to Hunter a_L/b_L ratio values for two observers. Observer A is unable to see irregular hue and chroma changes inherent in the Munsell disks, changes which the Hunter instrument will record. Observer B is able to see the irregularities of hue and chroma in the disks and therefore correlates better with Hunter a_L/b_L values.

The irregularity in hue and chroma of the Munsell spinners alluded to earlier evidently came about as a result of matching spinners to the color of a juice made by blending two samples of different hues. The laboratory of the Quality Evaluation Section, of the Agricultural Marketing Service, has accumulated evidence that when two samples of juice of different degrees of redness are blended, the color of the resultant blend is biased toward the redder sample.[13] The spinners referred to were designed by matching four component standard Munsell papers in varying percentages to a sample of juice made from tomatoes selected for minimum U. S. No. 2 color (color score 10), minimum U. S. No. 1 color (color score 20), and "maximum" full red color (color score 30).

[13] Yeatman, J. N., and Sidwell, A. P. Changes in Color Attributes Associated With Processing of Tomato Juice. Presented at Amer. Inst. of Biol. Sci. meeting, Stanford Univ., August 1957. (Unpublished.)

These 3 color scores appear to be regular in all color components of hue, value, and chroma; however, the other 2 points (color score 15 and 25) were arrived at by designing Munsell spinners that matched 50-50 blends of juice with color scores of 10 and 20 and blends of juice with color scores of 20 and 30, respectively. The extent to which this technique of designing spinners causes departure from regularity of color attributes is illustrated in figure 15. The points connected by a solid line are indicated to be irregular as to hue and chroma but regular as to value. The dotted line in figure 15 is theoretical for positions in color space on which values assigned to spinners and the juices matching those spinners should fall if the color of the blend were not biased by the redder sample.

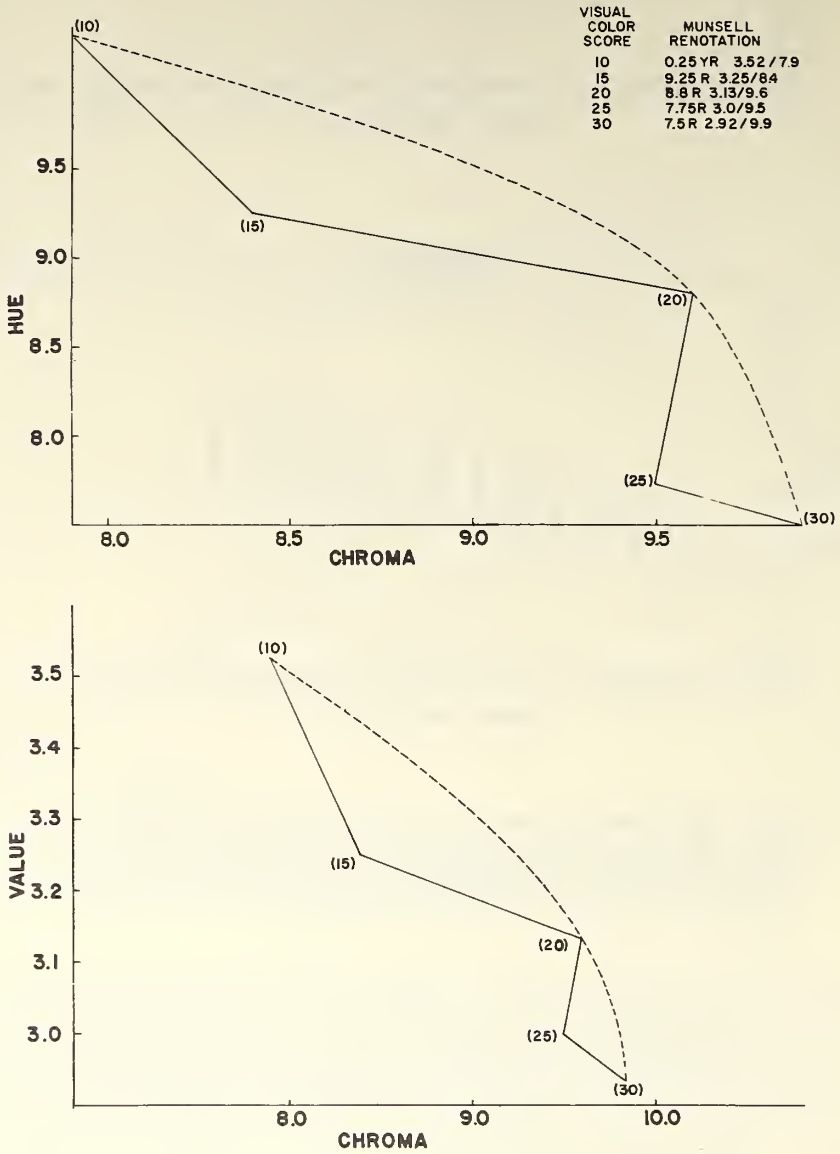

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Figure 15.--Relationship of hue and chroma, and value and chroma of the Munsell disks assigned visual color scores of 10, 15, 20, 25, and 30 points. Points connected by solid lines indicate irregularities as to hue and chroma which exist in these disks. (Note the regularity of value steps). Dotted lines indicate theoretical paths upon which visual color-score points 15 and 25 should fall in juxtaposition to their present relationship.

Work on measuring the extent of bias was initiated formally in 1956, after lack of additivity in color readings was suspected because estimates of variance were not reduced as expected in sampling studies in 1955. Blends of varying proportions of processed tomato juice, as well as raw tomato juice, on which instrument readings and visual scorings had been taken were made, and the resultant color components of these blends were compared with those arrived at by arithmetic calculations. These measurements and scorings indicated bias toward the redder sample as illustrated in table 6.

Similarly, when Hunter data were plotted on Munsell-Hunter chromaticity diagrams (6, 55), the location of the blend was closer to the hue line of the redder sample (fig. 16). Note in this chart that the juice components cross hue lines and represent different levels of chroma. The arrows point from the measured values to the theoretical or calculated value. In every case, the measured value of resultant blends of the samples shows a bias toward a redder hue and a higher chroma value. These blends are composed of measured amounts, in milliliters, of each of the samples in the proportions indicated.

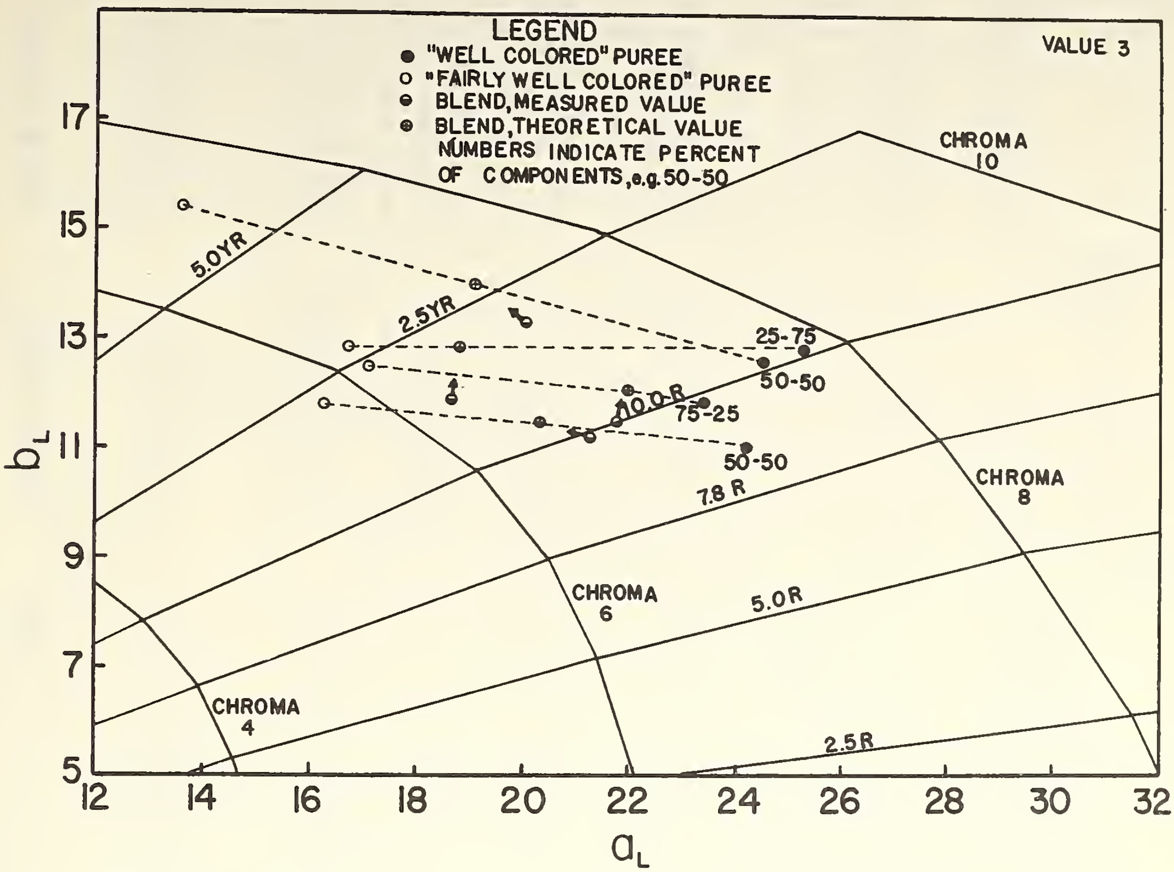

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Figure 16. --Munsell-Hunter chromaticity diagram calculated for Hunter a_L and b_L values indicating the relationship of juice samples of different hues and blends made therefrom, showing a bias in the resultant blends toward the color of the sample of redder hue and higher chroma value.

Further evidence of the bias indicated above was found in the data on sampling collected in the late summer of 1956. In this study, increasing average readings of blends representing successively intensive levels of sampling showed progressively higher color scores of Hunter a_L/b_L ratios, visual color score, and Agtron readings as shown in table 7. In these data, the bias was seen to be as great as one point in the visual score,

TABLE 6.--Effect of the color of samples of raw tomato juice of different hues on the color of resultant blends, 1956

[Arithmetic calculations appear in parentheses under each found value]

Sample	Instrument readings						
	Visual color score	Gardner CDM					Agtron Model F
		L	a_L	b_L	a_L/b_L	Tan^{-1} a_L/b_L [1]	
	Raw tomato juice						
Components:							
"Well colored:"							
1..................	17	28.0	25.0	12.2	2.05	64.0	69
2..................	16	28.5	25.3	12.9	1.96	63.0	67
3..................	18	26.4	25.3	11.4	2.21	65.7	78
4..................	17	27.1	23.4	11.9	1.96	63.0	72
5..................	20	26.2	26.0	11.8	2.20	65.6	80
6..................	20	27.0	26.1	11.2	2.34	66.8	78
7..................	19	26.3	24.3	11.1	2.19	65.5	78
8..................	18	27.0	25.8	12.4	2.08	64.3	76
"Fairly well colored:"							
9..................	10	30.9	15.1	11.9	1.26	51.5	38
10.................	11	32.0	16.7	12.9	1.29	52.3	32
11.................	10	31.0	14.0	12.3	1.14	48.8	34
12.................	12	31.4	17.1	12.6	1.36	53.7	38
13.................	14	29.6	19.9	12.3	1.62	58.3	52
14.................	12	30.7	19.4	13.3	1.46	55.7	45
15.................	12	30.8	16.3	11.8	1.39	54.3	38
16.................	13	30.5	19.2	12.3	1.56	57.5	42
Blends: [2]							
1 + 9..............	14	28.8	20.9	11.5	1.81	61.2	60
(50-50)	(13)				(1.66)	(57.8)	(53)
2 + 10.............	14	29.2	21.3	12.2	1.75	60.3	59
(50-50)	(13)				(1.63)	(57.7)	(50)
2 + 10.............	13	30.2	18.7	11.9	1.58	57.7	45
(25-75)	(12)				(1.46)	(55.0)	(41)
2 + 10.............	16	28.2	23.0	12.4	1.85	61.7	65
(75-25)	(15)				(1.79)	(60.3)	(58)
3 + 11.............	16	28.0	20.3	11.4	1.78	60.7	65
(50-50)	(14)				(1.68)	(57.3)	(56)
4 + 12.............	16	28.7	20.7	11.8	1.75	60.3	60
(50-50)	(15)				(1.66)	(58.4)	(55)
4 + 12.............	14	29.8	19.0	11.7	1.62	58.3	52
(25-75)	(13)				(1.51)	(56.0)	(47)
4 + 12.............	16	27.9	21.7	11.5	1.89	62.2	67
(75-25)	(16)				(1.81)	(60.7)	(64)
5 + 13.............	17	27.1	22.8	11.7	1.95	62.9	72
(50-50)	(17)				(1.91)	(61.9)	(66)
6 + 14.............	16	28.3	22.5	12.2	1.85	61.7	64
(50-50)	(16)				(1.90)	(61.2)	(62)

TABLE 6.--Effect of the color of samples of raw tomato juice of different hues on the color of resultant blends, 1956--Continued

[Arithmetic calculations appear in parentheses under each found value]

Sample	Visual color score	Gardner CDM L	Gardner CDM a_L	Gardner CDM b_L	Gardner CDM a_L/b_L	Gardner CDM Tan^{-1} a_L/b_L [1]	Agtron Model F
				Raw tomato juice			
Blends--Continued							
6 + 14............	14	29.4	20.5	12.1	1.69	59.5	55
(25-75)	(14)				(1.68)	(58.4)	(53)
6 + 14............	19	27.2	23.6	11.7	2.02	63.7	72
(75-25)	(18)				(2.12)	(64.0)	(70)
7 + 15............	17	28.0	21.2	11.2	1.90	62.3	65
(50-50)	(16)				(1.79)	(59.9)	(58)
8 + 16............	17	28.6	22.8	11.9	1.92	62.5	64
(50-50)	(16)				(1.82)	(60.9)	(59)
8 + 16............	15	29.3	21.0	11.8	1.79	60.8	56
(25-75)	(14)				(1.69)	(59.2)	(51)
8 + 16............	17	27.3	24.2	11.7	2.07	64.2	72
(75-25)	(17)				(1.95)	(62.6)	(67)
				Processed tomato juice			
Components:							
"Fancy:"							
1.................	A-29	29.3	19.9	12.6	1.58	57.7	
2.................	A-29	29.0	20.5	12.7	1.61	58.2	
3.................	A-28	28.6	20.4	12.8	1.60	58.0	
"Standard:"							
4.................	C-24	32.0	17.6	13.7	1.28	52.0	
5.................	C-25	31.3	18.3	14.0	1.31	52.9	
6.................	C-25	31.3	18.3	14.0	1.31	52.9	
7.................	C-25	31.3	17.8	13.8	1.29	52.2	
Blends:[2]							
1 + 4.............	A-26	30.6	18.7	12.2	1.53	56.8	
(50-50)					(1.43)	(55.0)	
2 + 5.............	A-27	30.7	18.6	13.3	1.41	54.7	
(25-75)					(1.38)	(54.0)	
2 + 5.............	A-27	29.2	19.7	12.6	1.57	57.5	
(75-25)					(1.53)	(58.6)	
3 + 6.............	A-27	30.5	18.8	12.9	1.46	55.6	
(25-75)					(1.38)	(54.0)	
3 + 6.............	A-28	29.1	19.8	12.3	1.61	58.2	
(75-25)					(1.53)	(56.8)	
3 + 7.............	A-27	30.7	18.1	12.7	1.42	54.9	
(25-75)					(1.37)	(53.9)	
3 + 7.............	A-28	29.3	19.7	12.5	1.58	57.7	
(75-25)					(1.52)	(56.7)	

[1] According to F. J. Francis, Amer. Soc. Hort. Sci. 60: pp. 213-220, 1952. (14)
[2] Blends = sample components with proportions in percent.

thus, it may be of some significance to manufacturers of tomato juice and other blended products.

It should not be assumed that such a bias is due to color changes associated with time lost from initial blending to final blending as more intensive levels of sampling were made. Laboratory tests showed that the changes in color occurring from zero time and thereafter, at 45-minute intervals up to a total of 5 hours, were never more than 0.04 a_L/b_L ratio. This difference was consistent with instrument readings for the holding temperatures of 37°, 50°, and 75° F. of the juices. Therefore, it is reasonable to assume that the bias associated with more intensive sampling was valid and predictable of improved color readings as larger numbers of tomatoes are expressed in the sample juice.

TABLE 7.--Average readings of blends representing successively intensive levels of sampling, 1956

Intensity of sampling[1]	Average of instrument readings			
	Visual color score--Operator #1		Visual color score--Operator #2	
	4T[2]	16T[3]	4T[2]	16T[3]
Number of readings:				
8..................	23.01	23.06	19.22	19.40
4..................	23.38	23.31	20.21	20.28
2..................	23.81	23.71	20.11	20.57
1..................	24.00	23.90	20.69	21.07
	Hunter a_L/b_L		Agtron Model F	
8..................	2.127	2.196	73.27	73.61
4..................	2.151	2.225	74.93	74.70
2..................	2.150	2.262	75.78	75.59
1..................	2.191	2.263	76.28	75.88

[1] See figure 10.
[2] 4T = 4-tomato subsample initial blend per hamper.
[3] 16T = 16-tomato subsample initial blend per hamper.

Sampling and Evaluation of Defects

The subjective evaluation of samples for defects in 1954 continued along the same lines as those outlined by Wilson and Dever in 1953. Samples were separated into U. S. No. 1, U. S. No. 2, and Cull tomatoes by visual estimation of defective tomatoes in each category and by objective evaluation of a composite juice of all grades. In addition to the breakdown of defects within the grade, samples of tomatoes were graded by the official inspection procedure into U. S. No. 1, U. S. No. 2, and Culls. Grade comparisons between the official and research inspection procedures were quite comparable. Table 8 indicates this grade comparison as well as the average percentage breakdown for color and estimation of defects within the research grades. The comparison of the subsample grades, percentage of U. S. No. 1, U. S. No. 2 for color, U. S. No. 2 for defects, Culls for color, and Culls for defects, obtained in the research inspection procedure indicated fairly good agreement in all categories.

In this study, a mechanical sampling device was used which was designed to subsample approximately 10 percent of a hamper of tomatoes (fig. 5). The so-called Purdue sampling table was utilized throughout the 1954 season even though it was recognized early in the study that this device would not consistently cut out a 10-percent subsample. Table 9 indicates the range in size of subsample derived from this device with various numbers of 6-inch openings. The use of this mechanical sampling device was abandoned at the end of the season. No mechanical or automatic sampling device has been tried since that time.

The need for more information regarding actual sample size from growers' loads of cannery tomatoes was of paramount importance. During the 1955 season, the emphasis was placed squarely upon the problem of sampling and subsampling. Comparisons were made between an official inspector's grades, employing the regular method of visual estimation of color of individual whole tomatoes, and an objective evaluation of the color of raw juice with the Hunter CDM and Agtron Model F.

TABLE 8.--Comparisons of tomato grades by official inspection procedure and research procedure, 1954

Inspection method and sample graded	Average percentage of tomatoes grading--			Average weight
	U. S. No. 1	U. S. No. 2	Culls	
Regulation:	*Percent*	*Percent*	*Percent*	*Pounds*
Official inspection[1]....	62	36	2	-----------
Regulation inspection[2]..	56	40	4	-----------
Combined residue[3].......	57	39	4	80
Combined 2S-residue.....	56	38	6	16
Combined 3S-residue.....	55	39	6	6

Inspection method and sample graded	Average percentage of tomatoes grading--					Average weight
	No. 1	No. 2 for color	No. 2 for defects	Culls for color	Culls for defects	
Research:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*
Residue grade...........	57.4	18.1	20.7	0.3	3.4	79.7
2S-residue grade........	55.8	17.0	21.5	.3	5.4	15.6
3S-residue grade........	54.7	14.4	25.1	.3	5.5	5.6

[1] Average data taken from official memoranda issued by Federal-State inspectors engaged in normal grading procedures at the plant.
[2] Average data from grades given by the Federal-State inspector assigned to the project for replicated samples taken from the same loads graded by the regular Federal-State inspectors.
[3] Another way of presenting the data shown in the lower part of the table combining the No. 2 categories for color and defects and Cull categories for color and defects.

The range in percentage of tomatoes grading U. S. No. 1, as determined by official inspection, is shown in figure 17 for the 1954, 1955, and 1956 seasons. These percentages are based on loads of tomatoes received during the research period at the plant where the research was being done. The samples acquired for research procedures were representative of the ranges indicated.

Statistical analysis of the data enabled prediction of the expected sampling error with variation in number of hampers taken from a load and the number of tomatoes taken from each hamper for inspection.

TABLE 9.--Variations in size of subsample of tomatoes from Purdue sampling table, 1954

Test	Size of subsample[1]		
	Weight	Percentage of total weight	Number of tomatoes [2]
Five 6-inch openings[3]:	*Pounds*	*Percent*	
Average..................	7.7	22.4	31.0
Range....................	3.3 - 11.8	8.5 - 35.1	15.0 - 61.0
Four 6-inch openings[4] (one opening blocked off):			
Average..................	5.0	14.0	14.0
Range....................	2.5 - 8.0	7.0 - 24.0	6.0 - 23.0
Three 6-inch openings[4] (two openings blocked off):			
Average..................	4.3	12.6	15.0
Range....................	2.0 - 5.5	6.0 - 16.0	7.0 - 22.0
Two 6-inch openings[4] (three openings blocked off):			
Average..................	2.9	8.2	11.0
Range....................	0 - 5.0	0 - 14.0	0 - 22.0

[1] Average weight of hamper of tomatoes = 34 pounds.
[2] Average number of tomatoes per hamper = 129.
[3] 50 hampers.
[4] 30 hampers.

The standard error in percentage of the ratio of weight of tomatoes with U. S. No. 1 color to the weight of all tomatoes for selected rates of sampling agreed well with Kramer's work (28). Table 10 indicates this expected error in sampling. For example, if a load of tomatoes is sampled by taking 5 hampers from the load and subsampling 5 tomatoes from each hamper, a grade breakdown of say 56 percent of U. S. No. 1, 35 percent of U. S. No. 2, and 9 percent of Culls might be expected. If a second unbiased grading were made, the second grade for U. S. No. 1 tomatoes would be within the range of 56 ± 9.2 percent for 66 2/3 percent confidence level and an expression of 56 ± 18.4 percent for 95 percent confidence level. This assumes the normal distribution.

It can be seen from the above example that inspectors of raw tomatoes for processing have a difficult job, with this type of variation in expected grades under present sampling and grading procedures.

All random subsamples of tomatoes from hampers were taken manually, and no attempt to devise a sampling device was made.

Attempts were made to apply statistical laws of sampling to color measurements on blended samples of juice. Estimates of variance for instruments on blended samples were computed by multiplying the observed mean square by the number of tomatoes in a blend. This formula was applied by analogy to the statistical laws appropriate to discrete units. However, it was found that the computed estimates of variance did not decline as expected with increase in numbers of tomatoes expressed in a blend but followed an irregular and unpredictable pattern. This led to a study in 1956 to gain information about the additivity of tomato juice color readings. As already discussed in the section on color measurements, the observed color readings on blends of tomato juice were compared with expected values arrived at by calculations. This work led to the conclusion that when two samples of significant hue differences were blended, the resultant color as indicated by Hunter instrument readings L, a_L and b_L are biased in the direction of the redder sample.

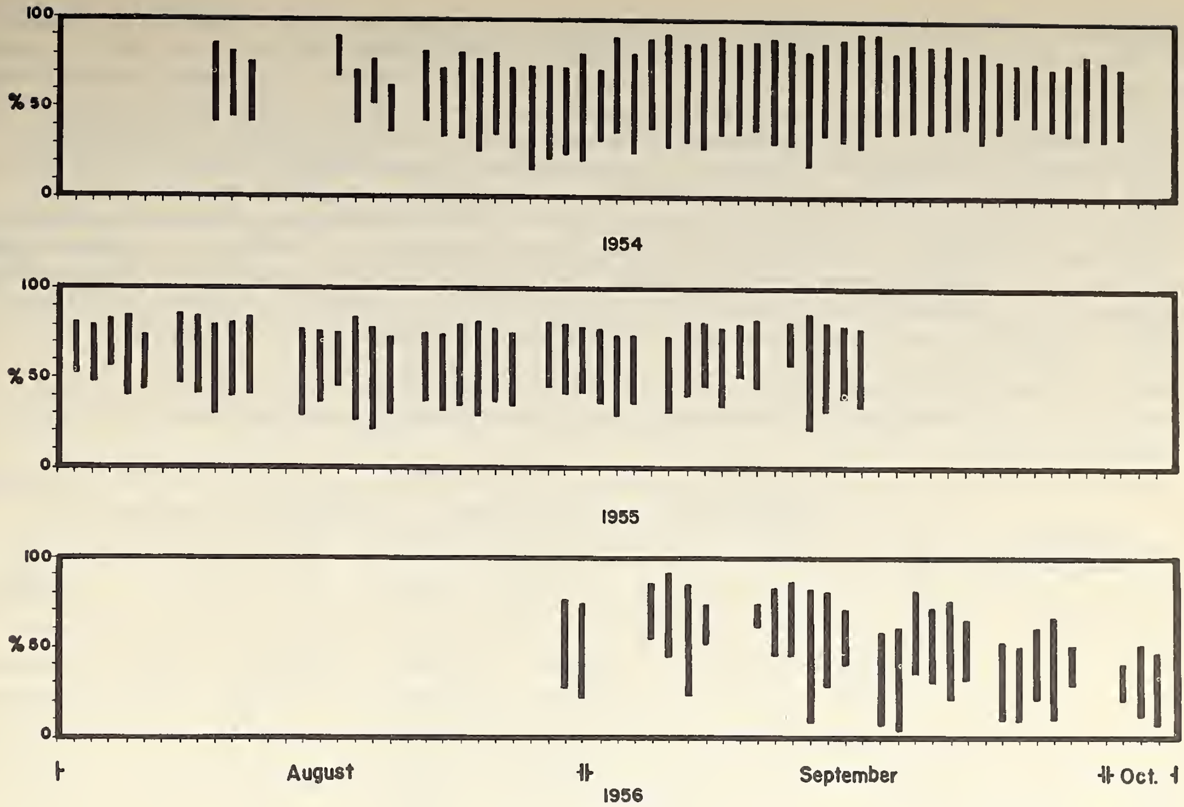

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Figure 17.--Range in percentage of tomatoes grading U. S. No. 1, as determined by Federal-State inspectors by official grading procedures. Based on loads representative of those received daily during the research periods in 1954, 1955, and 1956, at the plant where research was being done.

The sampling study was continued with greater formality and detail in 1956. Using all the data, standard errors of the three instrument readings were computed for several rates of sampling, and these values are shown in table 11. These values may be useful in predicting the variation expected in color readings of samples selected according to the systems reported in the table. For example, if a sample of 8 hampers was selected from a load and 8 tomatoes from each hamper were made into raw juice (trim excluded from the sample), the table could be used as follows: If the true Hunter a_L/b_L ratio is 2.00, the sample estimate is expected to fall between the limits of 2.00 $\pm$ .059 with a 66 2/3 percent confidence level and 2.00 $\pm$ .118 with a 95 percent confidence level. The standard error .059 in this case is equivalent to one grade point in the visual color score.

However, the values of table 11 are valid extensions of the 1956 results only if it can be assumed that the measurements are additive and that errors of subsampling (i. e. sampling the raw juice made from all tomatoes in a sample) are negligible. Also, the values are based on weighted estimates of the two variance components, σ^2_t and σ^2_h, involving all the sampling levels present in the study. The predicted values of table 11 can be compared with actual estimates of standard errors obtained in the study for the particular sampling situations present. These comparisons, shown in table 12, provide some information as to the validity of the values of table 11.

In table 12, it is noted that the actual estimates do decrease with increased intensity of sampling. Moreover, the estimates for Agtron Model F and MMDC decline as one would expect from a consideration of the changes in sampling scheme alone. For example, the standard errors for 4 hampers and 4 tomatoes per hamper are roughly 70 percent of the standard errors for 2 hampers and 4 tomatoes per hamper and similarly for the 2 schemes with 16 tomatoes per hamper. The actual estimates for the 2 instruments, Agtron Model F and MMDC, are generally less than the predicted values, but there is no obvious trend among the 4 comparisons possible for each instrument. However, for the Hunter CDM instrument, the actual estimates are larger than the predicted values in 3 of the 4 situations. The actual estimates for the Hunter CDM instrument do decline, but the rate of decline is not so great as would be expected on the basis of the changes in sampling scheme. In view of the discrepancy between predicted and actual estimates and the failure of the actual estimates to decline as expected, the effects of non-additivity on the variability of readings, as well as on the means, should apparently be studied more closely before a table such as table 11 can be considered reliable in predicting standard errors for Hunter CDM instrument readings.

TABLE 10.--Standard error of the ratio of weight of tomatoes with U. S. No. 1 color to weight of all tomatoes, for selected rates of sampling hampers and tomatoes within hampers, 1955

Number of hampers (n)	Standard error as percentage[1], by number of tomatoes (k)[2]						
	2	3	5	10	20	50	All tomatoes
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2.................	22.0	18.3	14.6	11.1	8.9	7.2	6.4
5.................	13.9	11.6	9.2	7.0	5.6	4.5	4.0
10................	9.8	8.2	6.5	5.0	4.0	3.2	2.8
20................	7.0	5.8	4.6	3.5	2.8	2.3	2.0
50................	4.4	3.7	2.9	2.2	1.8	1.4	1.3

[1] Formula for tabulated data = $\left[\frac{100}{(4.08)\sqrt{n}}\right]\left[\sqrt{\frac{3.00}{k} + 0.112}\right]$

where: n = number of hampers.

k = number of tomatoes.

4.08 = average weight of a tomato in ounces.

3.00 = mean square (m.s.) "within hampers" on a per tomato basis.

$0.112 = \frac{\text{m.s. between hampers—m.s. within hampers on a per tomato basis}}{\text{coefficient of m.s. between hampers on a per tomato basis}}$

[2] Average percentage of U. S. No. 1 tomatoes for color = 56.0.

TABLE 11.--Standard error of instrument readings for selected rates of sampling hampers and tomatoes within hampers, 1956

Identification	Number of tomatoes (k)	Standard error[1], by number of hampers (n)							Formula for tabulated data
		2	3	4	5	8	16	32	
Visual (MMDC) Operator #1:	Average visual color score = 23.28								
	2	2.16	1.76	1.52	1.36	1.08	0.76	0.54	
	4	1.69	1.38	1.19	1.07	.84	.60	.42	
	8	1.40	1.14	.99	.89	.70	.49	.35	$\sqrt{\frac{14.28}{kn} + \frac{2.15}{n}}$
	16	1.23	1.01	.87	.78	.62	.44	.31	
	32	1.14	.93	.81	.72	.57	.40	.28	
Operator #2:	Average visual color score = 19.78								
	2	1.94	1.59	1.37	1.23	.97	.69	.49	
	4	1.53	1.25	1.08	.97	.76	.54	.38	
	8	1.27	1.04	.90	.80	.64	.45	.32	$\sqrt{\frac{11.56}{kn} + \frac{1.78}{n}}$
	16	1.12	.91	.79	.71	.56	.39	.28	
	32	1.03	.84	.73	.65	.54	.37	.26	
Agtron Model F:	Average Agtron value = 74.28								
	2	7.08	5.78	5.00	4.48	3.54	2.50	1.77	
	4	5.41	4.42	3.82	3.42	2.71	1.91	1.35	
	8	4.34	3.54	3.07	2.74	2.17	1.53	1.08	$\sqrt{\frac{166.92}{kn} + \frac{16.77}{n}}$
	16	3.69	3.01	2.61	2.33	1.84	1.30	.92	
	32	3.32	2.71	2.34	2.10	1.66	1.17	.82	
Hunter CDM:	Average Hunter a_L/b_L ratio = 2.18								
	2	.161	.130	.113	.101	.079	.056	.040	
	4	.134	.109	.095	.085	.067	.047	.034	
	8	.118	.097	.084	.076	.059	.042	.029	$\sqrt{\frac{.060}{kn} + \frac{.021}{n}}$
	16	.109	.091	.078	.071	.056	.039	.027	
	32	.104	.087	.075	.067	.053	.037	.026	

[1] Statistical formula:

$$\sqrt{\frac{\sigma^2 t}{kn} + \frac{\sigma^2 h}{n}}$$

Where: $\sigma^2 t$ = estimate of component of variance within hampers on per tomato basis.
$\sigma^2 h$ = estimate of component of variance between hampers on per tomato basis.
k = number of tomatoes per sample.
n = number of hampers.

TABLE 12.--Comparison of predicted standard errors of instrument readings with actual estimates for particular sampling situations

Intensity of sampling		Estimates of standard error for instrument readings							
		Visual (MMDC)				Agtron Model F		Hunter CDM	
		Operator 1		Operator 2					
Hampers (n)	Tomatoes (k)	Predicted[1]	Actual[2]	Predicted	Actual	Predicted	Actual	Predicted	Actual
2	4	1.69	1.63	1.53	1.47	5.41	5.09	0.134	0.133
4	4	1.19	1.09	1.08	1.13	3.82	3.89	.095	.123
2	16	1.23	1.22	1.12	1.14	3.69	3.30	.111	.120
4	16	.87	.90	.79	.71	2.61	2.59	.078	.108

[1] Standard errors for particular intensities of sampling taken from table 11.
[2] Calculated as root mean square of hampers within loads.

In addition to the 1956 sampling and blending study for color, equal attention was given to subjective estimation of defects in cannery tomatoes. An estimation of waste (defects as specified in the U. S. grades) expressed as a trim loss factor was assigned for each load evaluated in the research study. As indicated in methods and research techniques, each hamper of tomatoes selected was divided into equal half-hampers by random selection, making possible a study of the variation within hampers and between hampers within a load. The standard error of the percentage of waste (trim loss including Cull tomatoes) as affected by the number of hampers sampled from a load was calculated and is presented in table 13. This standard error is rather high, particularly where less than 10 hampers are used in the sample. The use of a lesser amount for sampling resulted in an even greater range of variation. This error compares quite closely with the determinations of the expected error of the percentage of U. S. No. 1 tomatoes for color (table 10) found in the 1955 study.

For all loads sampled in 1956, only 19 percent of the total tomatoes sampled actually needed to be trimmed according to the inspector as shown in table 14. Tomatoes classified in categories 0 to 4.9 percent required only a fraction over 1 percent trim on a half-hamper basis.

By estimating the percentage of waste or by actually expressing the percentage of defects as a direct trimming loss, it is possible to evaluate the quality of cannery tomatoes with only an objective measurement of the color and a subjective estimation of the defects. Information on the number of tomatoes requiring trim could be computed by inspecting table 16 to establish the economic value of the load.

TABLE 13.--Standard error of the percentage of waste, including trim loss and cull tomatoes 1956

Number of hampers (n)	Standard error as percentage[1]	
	Half hamper[2]	Full hamper
	Percent	*Percent*
2	6.94	6.20
4	4.91	4.38
6	4.00	3.58
10	3.10	2.77
15	2.53	2.26
20	2.19	1.95

[1] Formula for tabulated data = $\sqrt{\frac{1}{n}(.00576) + \frac{.00387}{k}}$

where: n = number of hampers.

k = number of loads sampled (45).

.00387 = mean square (m. s.) within hampers.

$.00576 = \frac{\text{m. s. "hampers in loads"} - \text{m. s. within hampers}}{\text{coefficient of m. s. "hampers in loads"}}$

[2] Average percentage waste per half hamper = 22.5 percent.

TABLE 14.--Comparison of estimation of defects between loads of tomatoes sampled in 1956

Sample[1]	Percentage of waste category																	
	0 - 4.9				5.0 - 9.9				10.0 - 14.9				15.0 - 20.0				Culls (over 20%)	
	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. total wgt. (gms.)	Av. no.
Load number:																		
1............	39.5	4286.4	24.9	0.9	48.3	726.3	4.1	6.7	67.4	560.8	2.8	12.0	74.1	494.6	2.8	15.0	1176.4	8.2
2............	38.3	4442.9	30.0	.9	26.9	317.5	2.1	8.5	40.7	338.2	2.1	12.0	34.9	217.3	1.6	16.1	1687.0	14.4
3............	36.5	4469.5	30.8	.8	73.2	886.8	5.3	8.3	26.0	203.7	1.2	12.8	22.3	153.1	.9	14.6	1231.9	9.3
4............	26.9	3175.9	19.1	.9	77.1	841.9	5.8	9.2	174.3	1515.1	7.8	11.5	81.0	525.8	2.6	15.4	1065.3	7.2
5............	36.0	5690.8	44.9	.6	63.6	855.9	5.8	7.4	57.5	482.7	3.1	11.9	10.1	56.0	.4	18.0	593.5	5.4
6............	37.1	2510.8	15.9	1.5	15.6	196.3	1.4	7.9	92.1	896.6	10.5	10.3	135.0	859.6	5.3	15.7	2934.5	20.5
7............	12.5	5106.8	40.4	.2	26.6	334.8	2.1	7.9	33.6	297.4	1.9	11.3	9.2	48.1	.4	19.1	973.1	8.8
8............	34.2	4949.5	29.2	.7	72.5	990.4	5.0	7.3	51.6	438.2	2.4	11.8	16.5	105.0	.6	15.7	987.7	6.3
9............	44.3	4393.8	26.3	1.0	46.6	563.8	3.1	8.3	29.5	238.6	1.3	12.4	9.5	60.8	.2	15.6	1966.0	13.1
10............	35.0	5459.2	43.3	.6	36.8	488.6	3.6	7.5	15.7	134.3	1.0	11.7	3.2	16.0	.1	20.0	935.7	8.2
11............	42.1	4467.9	30.3	.9	55.9	727.3	4.3	7.7	50.4	380.2	2.3	13.3	0	0	0	0	1931.8	13.5
12............	34.1	4678.1	25.3	.7	42.2	561.3	2.8	7.5	65.4	581.0	2.8	11.3	50.7	328.6	1.5	15.4	1207.1	7.3
13............	38.3	5391.6	39.0	.7	70.0	1012.7	6.8	6.9	58.2	544.3	3.3	10.7	24.0	137.8	.8	17.4	549.5	4.8
14............	59.8	3942.9	20.6	1.5	67.6	888.4	3.3	7.6	88.0	850.6	3.9	10.4	85.6	567.7	2.9	15.4	1158.1	7.8
15............	66.6	4965.9	29.8	1.3	73.3	890.3	4.7	8.2	51.6	430.7	2.3	12.0	24.9	177.2	.6	14.1	1019.1	6.3
16............	42.1	5198.5	32.6	.8	58.1	766.1	4.1	7.6	10.9	78.2	.5	13.9	0	0	0	0	1364.9	10.6
17............	27.8	4508.8	23.3	.6	72.6	982.5	4.6	7.4	47.1	373.1	1.7	12.6	25.1	154.2	.7	16.3	692.7	3.8
18............	36.9	5227.1	38.7	.7	57.9	715.6	4.9	8.1	23.4	207.6	1.3	11.3	4.2	22.1	.1	19.0	983.7	7.8
19............	38.6	5227.1	33.8	.7	56.6	744.2	4.2	7.6	12.4	92.9	.5	13.4	0	0	0	0	574.1	4.8
20............	60.0	5525.1	31.6	1.1	50.9	677.9	3.3	7.5	19.3	150.4	.7	12.8	2.4	15.0	.1	16.0	855.9	6.1
21............	73.2	6756.6	40.2	1.1	46.2	581.2	3.4	7.9	1.5	12.1	.1	12.4	0	0	0	0	644.8	4.1
22............	81.9	4408.6	24.3	1.9	51.8	670.4	3.5	7.7	44.8	367.2	1.7	12.2	6.0	34.1	1.9	17.6	1758.6	11.3
23............	63.9	4429.7	28.9	1.4	74.3	1012.0	6.4	7.3	49.5	377.2	2.1	13.1	0	0	0	0	946.8	7.2
24............	35.4	4083.6	22.6	.9	63.7	903.8	4.4	7.1	63.6	522.3	3.0	12.2	54.2	310.9	1.9	17.4	1327.4	8.3
25............	35.9	4385.4	28.8	.8	55.1	795.7	4.4	6.9	36.5	346.4	1.9	10.5	28.4	157.6	.9	18.0	1175.2	8.9

TABLE 14.-- Comparison of estimation of defects between loads of tomatoes sampled in 1956--Continued

Sample[1]	Percentage of waste category																	
	0 - 4.9				5.0 - 9.9				10.0 - 14.9				15.0 - 20.0				Culls (over 20%)	
	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. wgt. trim (gms.)	Av. total wgt. (gms.)	Av. no.	% Loss	Av. total wgt. (gms.)	Av. no.
Load number:																		
26	48.6	4939.1	31.8	1.0	56.6	836.2	10.0	6.8	32.3	283.6	1.6	11.4	16.4	101.3	.4	16.2	772.1	5.6
27	79.6	4439.8	27.3	1.8	76.1	1095.2	5.4	6.9	24.1	197.5	.9	12.2	0	0	0	0	1235.5	6.7
28	81.2	5336.4	22.6	1.5	78.6	1193.4	5.4	6.6	44.9	372.6	1.8	12.1	5.9	32.4	1.2	18.2	751.1	3.9
29	47.1	5016.2	33.1	.9	67.3	932.2	6.1	7.2	18.1	158.0	1.0	11.5	11.3	57.3	.4	19.7	857.6	6.9
30	43.6	3772.3	21.4	1.2	99.2	1329.0	7.8	7.5	85.1	726.7	4.1	11.7	121.1	741.1	3.9	16.3	847.4	6.3
31	45.1	3960.2	22.8	1.1	65.2	873.4	4.8	7.5	29.8	237.0	1.5	12.6	97.1	625.2	3.2	15.5	1020.9	6.8
32	80.4	4642.8	25.8	1.7	65.0	915.6	5.0	7.1	36.7	336.1	1.7	10.9	23.8	160.1	8.8	14.9	1472.9	9.0
33	42.1	3900.4	26.2	1.1	78.2	1039.0	7.2	7.5	28.6	225.1	1.4	12.7	0	0	0	0	2015.6	15.7
34	74.5	3512.6	19.5	2.1	86.4	1160.4	6.0	7.5	52.9	456.8	2.6	11.6	97.1	619.6	3.1	15.7	2092.1	12.6
35	59.8	3017.2	17.9	2.0	78.6	1001.9	5.6	7.8	40.9	366.9	1.9	11.2	11.1	76.6	.4	14.5	2274.5	14.1
36	44.4	4669.3	33.0	.9	65.4	788.4	5.2	8.3	10.2	82.9	.5	12.3	4.4	25.6	.1	17.2	1439.2	11.2
37	104.2	3426.8	19.1	3.0	65.4	799.0	4.8	8.2	37.9	347.9	1.4	10.9	37.9	227.2	1.1	16.7	2849.2	16.8
38	107.1	3789.6	20.8	2.8	59.7	695.8	3.4	8.6	45.7	387.6	1.9	11.8	16.5	101.4	.6	16.3	2432.6	13.2
39	37.0	1925.1	9.9	1.9	78.1	1100.8	6.0	7.1	47.2	456.7	2.4	10.3	241.8	1500.3	8.2	16.1	2209.3	13.7
40	59.2	3320.0	15.1	1.8	86.2	1329.1	5.7	6.5	25.4	236.1	1.1	10.8	53.4	336.7	1.5	15.9	1588.5	7.4
41	73.8	3974.8	20.3	1.9	68.9	978.1	4.8	7.0	16.9	148.9	.8	11.4	76.4	544.1	2.4	14.0	183.2	6.5
42	62.7	5821.2	32.8	1.1	57.8	1032.6	6.2	5.6	18.2	175.8	.9	10.4	3.1	20.7	.1	15.0	299.1	2.2
43	60.2	3929.3	29.3	1.5	89.6	1381.2	9.9	6.5	32.2	306.8	2.0	10.5	24.9	187.9	1.2	13.3	1347.1	10.4
44	71.2	2668.4	15.4	2.7	66.5	977.5	5.7	6.8	39.2	371.2	2.1	10.6	85.4	537.1	2.8	15.9	3053.2	17.9
45	28.5	1008.6	6.4	2.8	53.8	838.8	4.9	6.4	36.1	333.6	1.8	10.8	48.5	315.8	1.5	15.4	4541.2	27.8
Average	51.7	4327.8	26.8	1.3	62.8	854.0	5.0	7.5	42.5	369.5	2.1	11.7	44.1	280.6	1.5	15.8	1400.5	9.5
Range:																		
Low	12.5	1008.6	9.9	.2	15.6	196.3	1.4	5.6	1.5	12.1	.1	10.3	0	0	0	0	183.2	2.2
High	107.1	6756.6	44.9	3.0	99.2	1381.2	10.0	9.2	174.3	1515.1	10.5	13.9	241.8	1500.3	8.8	20.0	4541.2	27.8

[1] Average 16 half-hamper readings per each load.

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APPENDIX A

In the 1954 investigations, the detailed procedure was as follows:

1. The Federal-State inspector assigned to the project selected at random 6 hampers of tomatoes in a load as it was being unloaded.

2. Three of the six hampers were graded by the inspector into U. S. No. 1, U. S. No. 2, and Cull tomatoes by the official method (49). The grades thus established were subsequently compared with the grades determined for other samples of the same loads. The official grades determined by Federal-State inspectors assigned to the processing plant were used for this comparison.

3. Each of the remaining 3 hampers of tomatoes was weighed and recorded. Each basket was in turn emptied onto a mechanical sampling device (11), shown in figure 5. It was so designed to permit the discharge of a representative subsample from fruit arranged 1 layer deep over the surface of the table. Releasing a side trip lever opened 5 traps, each 6 inches in diameter, and allowed a subsample to pass through into a waiting container.

Although this sampling device was found impractical for research sampling purposes it was used with some difficulty. By repetition of the subsampling operation, it was possible to obtain a representative sample.

4. The so-called residues (tomatoes remaining after subsample was taken) of the 3 hampers were combined and graded into 5 categories: U. S. No. 1, U. S. No. 2 for color (2c), U. S. No. 2 for defects (2d), Culls for color (Cc), and Culls for defects (Cd).

5. The 3 subsamples from the hampers were combined, weighed, and also subsampled on the sampling table. This additional step was necessary because of the inadequacies of the sampling device.

6. The residue (2S) of the second subsample was graded into the 5 categories mentioned in item 4. The grade was recorded and the tomatoes (2S) recombined and retained for subsequent pulping. Later these tomatoes were extracted.

The second subsample (3S) was weighed and graded into the same 5 categories, recombined, and the entire subsample (3S), consisting of an average of 6 pounds of tomatoes, was pulped with a laboratory-type meat and food chopper equipped with an 0.034-inch mesh screen.

Samples of raw tomato juice were deaerated by subjecting a relatively small amount of juice in a large container to a 25- to 30-inch vacuum. Alternately pulling and breaking this vacuum for a period of about 10 minutes removed the air from the sample.

7. A 600 milliliter portion of the (3S) juice was divided into 4 parts and the color measured on deaerated and nondeaerated portions using the manual Hunter CDM (not shown), Agtron Model F (fig. 4), MMDC (fig. 3), and for a limited time, the Purdue CRM (fig. 2). The Gardner CDM (fig. 8) was used in all subsequent tests.

8. The remainder of the juice from the second subsample (3S) was mixed thoroughly with the juice from the residue (2S) of this subsample and the same set of readings made on deaerated and nondeaerated portions.

9. This completed the research procedure for each load sampled, except that intact tomatoes considered borderline by the inspector at the time of the grading of the residue of the whole sample were measured directly on the Purdue CRM for reflected external surface color. The results of these determinations are summarized in table 15 for the 2 locations.

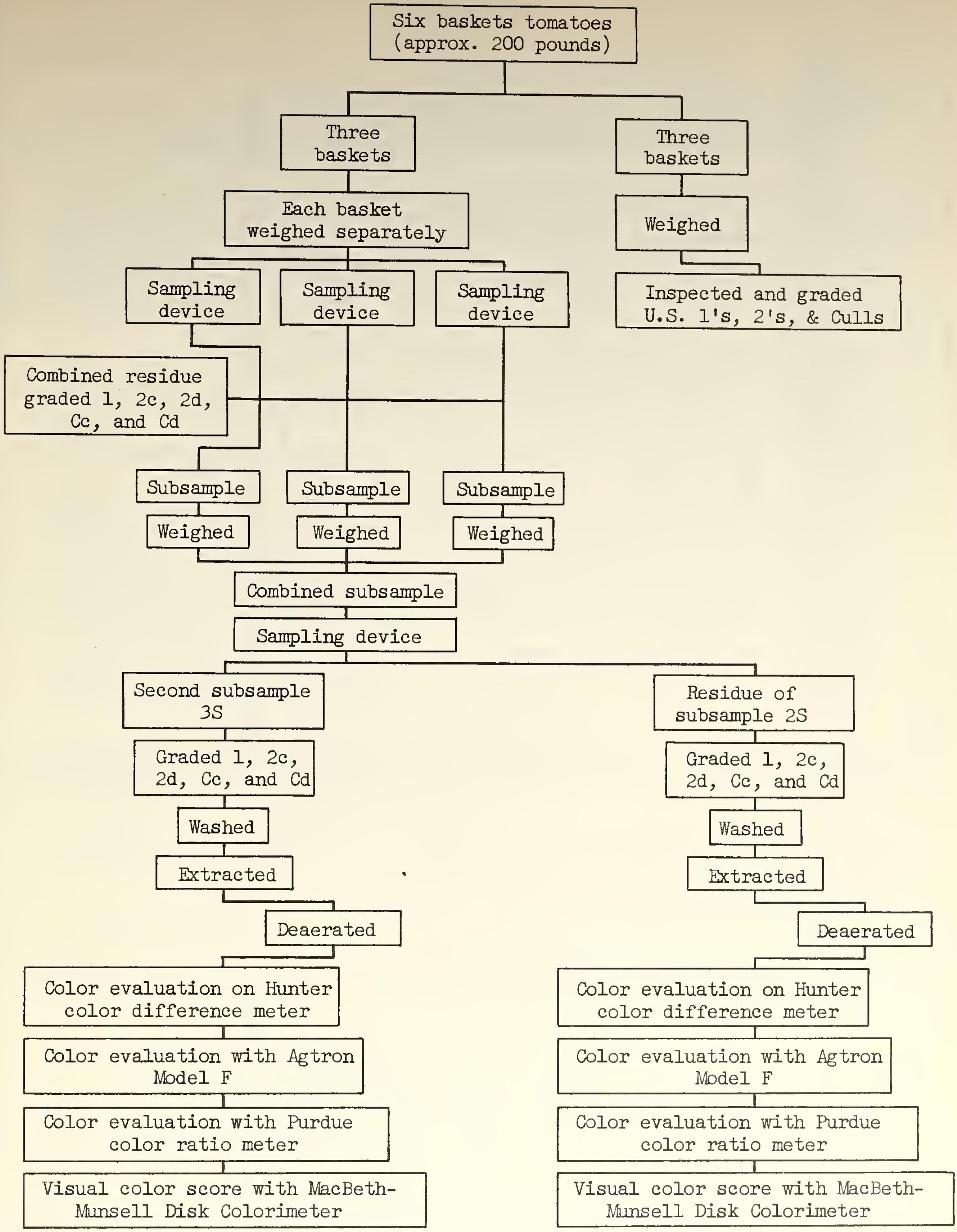

Figure 18.--Schematic diagram of the research procedure for 1954

TABLE 15.--Evaluation of external color of selected tomatoes of size and grade indicated using the Purdue Color Ratio Meter, 1954[1]

Instrument reading and location	Grade and size of tomatoes							
	U.S. No. 1 3 inch	U.S. No. 2 3 inch	U.S. No. 1 2-3/4 inch	U.S. No. 2 2-3/4 inch	U.S. No. 1 2-1/2 inch	U.S. No. 2 2-1/2 inch	U.S. No. 1 2-1/4 inch	U.S. No.2 2-1/4 inch
Wyoming, Del.:								
Average (all readings)....	59.0	48.5	54.9	44.8	46.3	40.4	40.9	36.4
Range (40 readings).......	66-54	54-44	60-51	49-42	54-40	46-36	48-35	42-32
Spread (4 readings per fruit)..................	7-2	6-2	7-2	5-1	6-1	5-1	6-1	5-2
Average weight per fruit...............oz..	6.5	--	5.8	--	4.4	--	3.1	--
Napoleon, Ohio:								
Average (all readings)....	54.6	47.8	53.5	46.6	52.3	46.2	43.6	39.3
Range (40 readings).......	58-49	51-42	56-49	50-43	56-48	50-43	51-40	44-33
Spread (4 readings per fruit)..................	5-1	7-1	6-1	4-1	5-1	8-1	9-2	6-1
Average weight per fruit...............oz..	6.8	7.0	5.5	5.7	4.6	4.6	3.3	3.2

[1] Color grade assigned by Federal-State inspector according to U. S. Standards for Manufacture of Strained Tomato Products.

APPENDIX B

In the 1955 investigations, the detailed procedure was as follows:

1. An experienced Federal-State inspector was assigned to make an inspection of all tomatoes used in the tests according to the color requirements set forth in the U. S. Standards for processed tomatoes (50).

2. Sampling was limited to pyramid-type hamper loads consisting mainly of 5 layers totaling approximately 210 hampers. A sample consisted of 10 hampers selected at random as the hampers were being unloaded. In general, they were taken in the following order: 3 from layer No. 1 (bottom layer); 3 from layer No. 2; 2 from layer No. 3; 1 from layer No. 4, and 1 from layer No. 5, the topmost layer. Deviations from this sampling method, depending on the size of load encountered, are shown in table 16.

TABLE 16.--Hampers selected through loads[1]

Type of load	Hampers selected from layer--[2]						Total hampers
	1	2	3	4	5	6	
3 layer....	4	3	3				10
4 layer....	3	3	2	2			10
5 layer....	3	3	2	1	1		10
6 layer....	3	2	2	1	1	1	10

[1] Loads selected for sampling limited to those with not less than 3 layers nor more than 6 layers.
[2] Layers numbered from bottom to top of load.

3. The contents of each of the 10 hampers comprising a load sample were graded on the basis of the following color requirements set forth in the U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products:

(a) U. S. No. 1 for color ("well colored," at least 90 percent of flesh has good red color).

(b) U. S. No. 2 for color ("fairly well colored," at least 66 2/3 percent of flesh has good red color).

(c) Cull (tomatoes failing to meet the color requirements of either U. S. No. 1 or U. S. No. 2).

The weight of tomatoes in each classification for each hamper was recorded.

While making the inspection, the inspector determined the color grade of any fruit which in his opinion was borderline by halving each fruit and comparing the halves visually with hand-painted, cross-section surfaces of minimum U. S. No. 1 and minimum U. S. No. 2 colored tomatoes (fig. 1).

4. After each hamper was graded, the fruit was mixed together for subsampling. From the jumbled fruit, 6 repeated samplings (replicates) of 3 tomatoes each were selected at random for a total of 18 fruit from each hamper. Three empty hampers labeled A, B, and C were set aside to receive the subsample from the 10 hampers. A special compartmented container with 10 sections each in 3 "banks" labeled D, E, and F was used to receive each replicate for which individual hamper identities were required.

Therefore, as a result of random subsampling, 3 composite sample hampers of 30 tomatoes each, marked A, B, and C were obtained, as well as 3 lots marked D, E, and F of 30 tomatoes each segregated into 10 lots of 3 tomatoes retaining the identity of the hamper from which each 3 tomatoes was drawn. See figure 19 for the diagram of research procedure.

5. Each 30-tomato composite subsample A, B, and C was graded for color only into U. S. No. 1, U. S. No. 2, and Cull tomatoes, and the weight and number in each classification was recorded. Each lot of 3 tomatoes in the subsample categories D, E, and F was similarly graded.

6. All tomatoes in the categories A, B, and C were trimmed when necessary according to the following procedure: (a) All mold, decay, badly discolored growth cracks, and dry sunscald were removed with a paring knife; (b) all other portions of the tomatoes less likely to materially contaminate a juice sample were removed when passed through an Enterprise Meat and Food Chopper (Model 2112).

All tomatoes in categories D, E, and F were trimmed as above by a Federal-State inspector, who was careful to keep segregated lots of 3 each apart.

7. Artificial illumination was used over the grading table to standardize grading conditions.

One 500-watt Macbeth Daylight lamp, filtered, pendant-type, was mounted at eye-level or approximately 28 inches above the center compartment of the grading table for the inspector. In addition, a cloth screen, 36 inches in height, was installed on 3 sides of the table. For the first 2 weeks of inspection, no screen was used. During the second 2 weeks, a white background, approximately Munsell N 9.5/, was used. During the last 2 weeks of operation, a light gray background, approximately Munsell N 7.5/, was employed.

The last of the 3 conditions of inspection proved most satisfactory and approximated recommended lighting conditions for color grading (41, 42). Color and energy distribution of the light source was close to that of a moderately overcast sky at 7500° Kelvin. A reading of 85 foot-candles was recorded on the table surface with the gray background.

8. All subsamples (A, B, and C and D 1-10, E 1-10, and F 1-10) were extracted with the meat and food chopper fitted with an 0.034-inch mesh screen. Each nondeaerated juice sample was mixed thoroughly, and a 100-milliliter portion was placed in a plastic viewing cell, 1 3/4 inches deep with an inside diameter of 2 1/4 inches and with an optically clear base, for measuring by the photoelectric instruments.

Color measurements of the juice sample were made on the Gardner Automatic CDM (readings expressed in Hunter L, a_L and b_L) and Agtron Model F. All readings on the Gardner CDM were made with wide aperture (2 1/4 inch) and large area illumination.

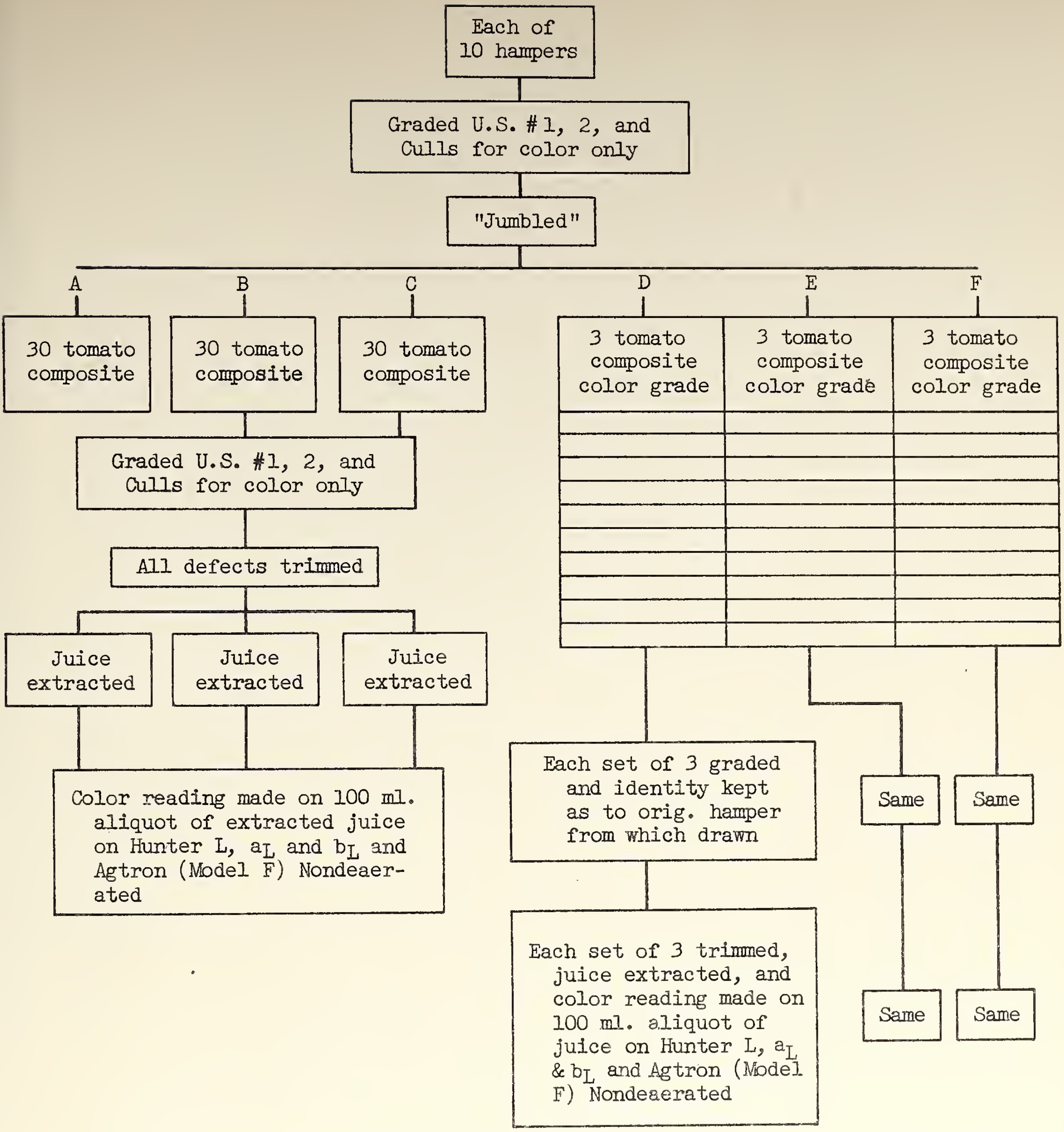

Figure 19.--Schematic representation of research procedure for 1955.

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