SOME EFFECTS OF CHROMATIC ILLUMINATION, REFLECTANCE, AND PRODUCT ROTATION ON SORTING EFFICIENCY OF CHERRIES AND TOMATOES

By

Blaine Frank Parker

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

Year 1954

ABSTRACT

This work concerns the sorting efficiency of cherries and tomatoes as affected by the spectral distribution of the illuminant, the reflectance of the fruit and its defects, and the rotation of the fruit as it moves along on the sorting belt. The investigation of illumination was begun by running reflectance curves for the outside surface of cherries, tomatoes, and cherry defects. These curves were used as basic data for calculating a number of possible spectral distributions of illumination which should enhance the perceptibility of defects on red ripe cherries. It was found theoretically possible to enhance the perceptibility of dark defects on cherries by selection of illuminant spectral distribution; by the same analysis perceptibility of under-color defects could be increased only slightly.

An effort was made to produce a spectral distribution from commercially available illuminants and gelatine filters which would enhance the perceptibility of dark defects on cherries. Four illuminant-filter combinations (rose pink, magenta, purple, and red) which considerably enhanced dark defects on cherries were tested in cherry processing plants. Red and rose pink were eliminated because some workers complained that these colors of illumination caused eye strain and headaches; magenta was eliminated mainly on the basis of workers' comments which favored the purple illumination.

The purple illumination, produced by incandescent filament lamps and the purple filter, was tested for six five-hour periods during which samples of cherries were taken from the sorting belt with the purple illuminant and from a comparsion belt with the regular illuminant.

The results of tests using purple illumination showed that the sorting efficiency was increased about 10 percent (statistically significant at the 95 percent confidence interval). This represented an improvement of approximately 50 percent over the regular illuminant used in the plant.

The perceptibility of dark defects on red tomatoes may be enhanced by the same method as used for cherries. No tests were conducted in tomato processing plants. The problem of color grading tomatoes was discussed briefly.

Reflectance curves were run for three common belt colors (white, tan, and black) used in cherry processing plants, and recommendations were made for belt reflectance based on the reflectance curves and the theory of adaptation of the eye.

Rotation of cherries as they move along sorting belts was investigated and two devices for rotation of cherries, a stationary rod and a friction-coated rotating rod, were developed and tested. The rotating rod was more efficient than the stationary rod when the belt was completely loaded with cherries.

Rate of inspection, spreading cherries on the sorting belt, fluorescence of cherry defects, sorting cherries by transmitted light, and other factors which affect efficiency were discussed briefly.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the guidance, suggestions and interest of Professor D. E. Wiant under whose direction the research was conducted. He expresses appreciation to Dr. C. D. Hause of the Physics department for his suggestions and contributions and to Professor A. W. Farrall for making available the necessary funds for conducting the research.

Also, he expresses sincere appreciation to the following: Dr. D. B. Judd, Head, Colorimetry Unit, National Bureau of Standards and Mr. I. Nimeroff of the National Bureau of Standards for their suggestions; Michigan State Highway Department for use of its spectrophotometer and Mr. Bruce W. Preston of the highway department for his suggestions on its operation; Mr. W. C. Pracejus, Lamp Department General Electric Co. for providing data on spectral distribution of commercial lamps; Mr. M. F. Morse, DuPont Co. and Mr. J. C. Thompson of the Pittsburgh Plate Co. for information on spectral reflectance of paint; Mr. Abe Vander Weele of the Dunkley Co. Kalamazoo, Michigan for suggestions and samples of cherry sorting belts; Paw Paw Canning Company, Paw Paw, Michigan, Lawrence Packing Company, Lawrence, Michigan, and Northport Cherry Factory, Northport, Michigan for their cooperation in the field tests; and to many others who contributed suggestions or materials for the project.

The writer expresses his deep gratitude and special thanks to his wife, Peggy, for her untiring work in sorting the cherry samples and for typing the manuscript several times as well as the final draft. Her continued aid and encouragement has been of priceless value.

VITA

Blaine Frank Parker was born on June 12, 1924 in Gaston County, North Carolina and lived on a farm until he was eighteen years old. In high school he was active in debating, 4-H Club, F.F.A. and was president of his senior class. He attended Brevard Junior College at Brevard, North Carolina two semesters and entered the Army Air Force in March, 1943. The following three years were spent as an Aerial Gunnery Instructor with overseas duty in England.

In April of 1946 he entered Virginia Polytechnic Institute and enrolled in Agricultural Engineering. He was active in the student branch of the American Society of Agricultural Engineers, serving as reporter and vice president; Alpha Zeta, serving as Chancellor; Omicron Delta Kappa; and Phi Kappa Phi.

During the summer of 1947 he worked as an Agricultural Engineering Aide on a hay curing project for the U.S.D.A. He worked one full year before graduation on a co-op training program with the Tennessee Valley Authority.

In March 1950, after completing requirements for the B. S. degree, he studied Education and other courses of his choice at George Peabody College in Nashville, Tennessee. Beginning in September, 1950 he worked two years as instructor in the Agricultural Engineering Department at Virginia Polytechnic Institute. Requirements for the Masters degree in Agricultural Engineering were completed in September, 1952 and the thesis was published in Agricultural Engineering in October, 1953 under the title "Nomographs and Data for Determining Winter Ventilating Rates for Poultry Laying Houses".

In Septmeber, 1952 he entered Michigan State College to work for the Ph. D. degree in Agricultural Engineering; minor, Physics. He is a member of the National Physics Honorary Society, Sigma Pi Sigma. On June 20, 1953 he married Mary Margaret Isenberg of Morristown, Tennessee.

He registered as a Professional Engineer in 1952 and is a member of the following professional organizations: American Society of Agricultural Engineers, National Society of Professional Engineers, and Virginia Society of Professional Engineers.

TABLE OF CONTENTS

TABLE OF CONTENTS Continued

TABLE OF CONTENTS Continued

LIST OF TABLES

LIST OF TABLES Continued

Table | Page

LIST OF FIGURES

LIST OF FIGURES Continued

LIST OF FIGURES Continued

Figures Page

LIST OF PLATES

INTRODUCTION

As the art and science of agriculture advances and food production for our growing population increases, men of the agricultural industry are continually searching for ways of improving the quality of food products. There is a continual consumer demand for higher grades of fruits and vegetables. This consumer demand is frequently reflected in premium prices for high quality products. Higher grades may be achieved by production of better fruits and vegetables on the farm and by improved processing and preserving techniques. The task of sorting or grading fruits and vegetables is one of the main processing operations. Often 50 percent or more of the total labor (depending on the quality of the incoming product) employed in processing plants is used on the sorting belts.

Since labor is expensive and in some areas scarce, it appears that a mechanical means of sorting and/or grading fruits and vegetables might be justified. Electronic sorters for removing off-color or defective products from beans, peanuts, etc. are manufactured. However an electronic sorter has not been developed for fruits and vegetables which must be processed immediately after being harvested. The main obstactle appears to be the economic difficulty of manufacturing a machine for seasonal use. For example, cherries should be processed within 24 hours after harvest and the harvest season lasts for only four or five weeks. If a machine could be developed which would handle several seasonal fruits and vegetables, the economic difficulty might be overcome. However, until mechanical sorters are developed the problem of inspecting and sorting fruits and vegetables remains.

The method of sorting fruits and vegetables in processing plants today is that of visual inspection and manual separation. Much labor could be saved by improving the efficiency of this visual-manual operation.

Scope

There are two factors which appear fundamental to high efficiency in sorting operations; namely, the entire surface of the fruit should be brought into the worker's view, and the illumination must be such that the defective products or the color grades are easily perceived. In order to limit the problem to a working basis, the analysis and tests are concerned mainly with these two factors and with two products, cherries and tomatoes. It is hoped that the information obtained on research with these two products will be useful in other fruit and vegetable sorting operations. If this information cannot be applied directly, the method of analysis might form a basis for further research in fruit and vegetable sorting.

Cherry Problem

In the cherry processing plants, cherries are brought from storage into the plant on conveyor belts and are transferred to sorting belts where they are visually inspected. These sorting belts are approximately 22 inches in visual width and have a lighting fixture extending the entire length of the belt (Plate I). From four to ten workers or more inspect the cherries on each belt in order to locate and remove the defects.

<u>Types of defects</u>. The defects may be classified into three color categories:

1. Black defects---These defects are dark black and are commonly caused by wind whip, bird pecks, and hail damage when the cherry is nearing maturity.

PLATE I. Kodachrome Picture of Cherry Sorting Belts. Note flow regulator at bottom and worker spreading cherries at right of picture.

2. Brown defects---These defects consist mainly of brown rot and damaged cherries which have not had time to turn completely black. This is actually a range of defects from light colored brown rot to darker browns.

3. Under-color cherries and bruised cherries---This category consist mostly of immature and bruised cherries; they are usually lighter than the ripe cherries unless a considerable amount of oxidation has taken place.

Defects may be classified as major or minor. Most major defects are included in the brown and black categories; i.e. a range of defects beginning with brown rot and extending to black. Under-color, immature cherries may also be major defects, especially when the cherries are being frozen. When canned many under-color cherries, which are not too immature, will gain color in the can; however, a large percentage of under-color cherries would be detrimental to average color.

The dark brown and black defects generally reduce the grade more rapidly than lighter defects. Cherries will not make U.S. grade A if there are more than four major defects (serious blemishes) per 20 ounces (1)*. Thus, the main efforts of cherry sorting are directed toward removal of a range of defects from brown to black.

Illumination for sorting. In the past forty years many advances have been made in the economical production of light. A number of illuminants of different spectral qualities are available and researchers have advanced in producing an artifical daylight illuminant for certain color grading applications (2). This illuminant was needed because colored objects often exhibit changes in appearance under different illuminants. The question is, what causes these variations in appearance and in what way does the spectral distribution of the illuminant affect perception of the objects?

This phase of the cherry problem concerns the possibility of enhancing the perceptibility of cherry defects by changing the spectral distribution of the illuminant. In other words, what are the effects of the spectral distribution of the illuminant on the perceptibility of defective cherries?

---

* Numbers in parentheses refer to the appended references.

Viewing entire cherry surface. The size of defects range from approximately 1/16 of an inch in diameter to 1/4 or 1/2 of the entire cherry surface; only occasionally is the entire cherry defective. In order to remove these defects it appears necessary that the workers be able to view the entire cherry surface. Most of the surfaces could be brought into the worker's view by rotating the cherries. They might be rotated gradually as they move along the belt or rapidly at intervals along the belt. Either would be a considerable improvement.

The problem of seeing all surfaces of the cherry is indeed acute in many plants, especially where the cherries are placed on the belt more than one layer deep. In some plants where the cherries would cover only one layer, they pile up two layers deep as they fall onto the belt. This makes it necessary for the first worker on each belt to spread the cherries in order that one side of all cherries may be viewed. In addition, several workers along the belt usually attempt to rotate the cherries by hand. It appears that these manual operations are a waste of time; the workers could well spend their time removing defective cherries if their hands were free.

Cherry production in Michigan. The state of Michigan produced an average of 77,500 tons of red tart cherries (mainly the Montmorency variety) per year from 1949-53. In the peak year of 1950, production of 98,000 tons brought farmers a total of eighteen million dollars (3). With many new orchards being planted, the volume of cherry production is increasing rapidly. The number of bearing trees increased 32 percent from 1945 to 1953 (3). Considering the large production of cherries in Michigan and the labor involved in sorting defects from cherries, an improvement in sorting efficiency should save condiderable labor. Also, an improvement in perceptibility of defects will make it easier to produce higher grades; thus, resulting in higher cherry prices.

Tomato Problems

Some phases of the tomato problem are rather similar to the cherry problem; namely, the tomatoes should be viewed on all surfaces and the visual appearances of defects and the ripe fruit are rather similar. Rotation of tomatoes may be accomplished by roller conveyors. In processing plants where sorting belts are employed the tomatoes are rotated to some extent by hand. Mechanical rotation is desirable, but it not as critical as rotation of cherries. Since tomato defects are usually larger than cherry defects, the perceptibility of defects is not as acute.

In canning Michigan tomatoes it is desired to separate tomatoes into grades one, two, and culls. The number one tomatoes are red ripe and mellow; number two tomatoes are firmer and slightly lighter in color. The culls for canning are medium ripe and rather hard. This task would require critical color judgement if appearance were the only criterion. Actually, the workers use firmness as well as appearance for grading. The plant operators visited did not seem to be aware of any particular grading difficulties in this operation; however, it is conceivable that a better grading job could be acheived if special illuminants were to improve the perceptibility of color grades.

There is another color sorting problem for tomatoes which are shipped into the state during the winter months and marketed as they become ripe. These tomatoes are graded into four color grades (green, light pink, pink, and red). Also, defective tomatoes are removed. The green and pink tomatoes are placed in storage for ripening and the red tomatoes are delivered to market. At a later date the stored tomatoes are again color graded. It is desirable to store tomatoes which will ripen at approximately the same time in the same storage since this will reduce the amount of re-grading necessary. The problem arises from the fact that marginal color decisions between green, light pink, pink, and red are difficult to make, especially when it is required to make these decisions continously for several hours. It is desired to determine the effect of the spectral distribution of illuminants on the perceptibility difference of the various color grades.

DEFINITIONS

The terminology used in color descriptions are necessarily complicated. However, it is imperative that one knows whether the terms used represent measurable quantities in the physical sense, theoretical quantities which are based on agreed standards but cannot be measured directly, or the perception of radiant energy as reported by an observer. There is need to discuss light in all these relations. The committee on Colorimetry of the Optical Society of America has developed a system which is very helpful in establishing definite nomenclature (Table I).

The first group of terms in Table I are listed under "physics". These are measurable quantities of radiant energy without reference to the eye. The next group of terms are listed as "psychophysics". These terms refer to values which may be calculated considering the eye as a standardized light receptor. The accepted standard for the eye is that designated since 1931 by the Internation Commission on Illumination (official abbreviation, CIE).* The last group of terms, which depend on the observer's mental interpretation of radiant energy, are grouped under "psychology" and depend on wavelength sensitivity of the eye, level of adaptation and psychological factors (observer experience, attitude, etc.).

---

* ICI was used until 1951 when the Commission adopted the abbreviation of the French name, Commission Internationale de l'Eclairage.

TABLE I

System of Nomenclature for Color Terms (4)

Physics	Psychophysics	Psychology	
Visual Stimulus	Light	Visual Sensation	Visual Perception
Radiant energy Spectral Composition	Luminous energy Color	Color sensation	
Characteristics of Radiant Energy	Characteristics of Light = Color	Attributes of Color Sensation	Corresponding Modes of Appearance
Radiant flux Radiance Irradiance Radiant reflectance Radiant transmittance	Luminous flux Luminance Illuminance Luminous reflectance Luminous transmittance	Brightness	Aperture (1-5) Illuminant (1-8) Illumination (1-3) Object modes: Surface (1-11) Volume (1-9)
Spectral distribution	Chromaticity	Chromaticness	Attributes of modes of appearance:
(Relative spectral composition, Quality)	Dominant wave-length (or Complementary)	Hue	1. Brightness (or lightness
Radiant purity	Purity	Saturation	2. Hue 3. Saturation 4. Size 5. Shape 6. Location 7. Flicker 8. Sparkle 9. Transparency 10. Glossiness 11. Luster

In order to obtain a more definite understanding of the meaning of the words used, the following list of definitions are presented.

Terminology Used for Measurable Quantities, "Physics"

1. Radiance---radiant energy from a source per unit time per unit solid angle per unit projected area of source.

2. Irradiance---E, radiant energy incident on a surface per unit time per unit area.

3. Radiant Reflectance (reflectance)---R, ratio of reflected to incident radiant energy.

4. Spectral Distribution Curve---a curve showing the relative radiant energy at various wavelengths in the electromagnetic spectrum.

Terminology Used for Theoretical Calculations of Visual Phenomena, "Psychophysics"

1. Luminosity Function---L, relative spectral sensitivity of the eye considered as a standardized receptor, the CIE standard observer (see Figure 3).

2. Luminance--- $\int_0^\infty (E_\lambda L_\lambda)\, d\lambda$*, the effective stimuli from a light source. That is, evaluation of a light source as to its effectiveness in producing visual sensation, evaluated in terms of the CIE standard observer.

3. Luminous Reflectance-- $\dfrac{\int_0^\infty (E_\lambda L_\lambda R_\lambda)\, d\lambda}{\int_0^\infty (E_\lambda L_\lambda)\, d\lambda}$, the ratio of reflected to incident light evaluated in terms of the CIE standard observer when using a specified illuminant.

---

* The subscript, λ, is used in color notation to indicate that the variable is a function of λ.

4. Luminous Transmittance--- $\dfrac{\int_0^\infty (E_\lambda L_\lambda T_\lambda) d\lambda}{\int_0^\infty (E_\lambda L_\lambda) d\lambda}$, the ratio of transmitted to incident light evaluated in terms of the CIE standard observer when using a specified illuminant.

5. Luminous Reflectance Ratio (Contrast ratio)--- $\dfrac{\int_0^\infty (E_\lambda L_\lambda R_\lambda)_1 \, d\lambda}{\int_0^\infty (E_\lambda L_\lambda R_\lambda)_2 \, d\lambda}$, the ratio of the luminous reflectance of surface 1 to that of surface 2.

Terminology Used for Reporting Visual Phenomena "Psychology"

1. Hue---the range of colors; i.e. blue, green, red, purple, etc.

2. Achromatic---lacking hue; i.e. white, grey, black series.

3. Saturation---the degree of departure of a chromatic color from the achromatic color of the same lightness.

4. Brightness---apparent luminance; i.e. the estimate of luminance made by mental perception of a specified light source with a given adaptative state for the eye.

5. Lightness---apparent luminous reflectance of a surface.

6. Color Contrast---mental perception of color difference; includes hue, saturation, and lightness.

7. Lightness Contrast---mental perception of lightness difference.

8. Perceptibility Difference---total visual difference, includes lightness contrast, color contrast, shape, surface characteristics, etc.

General Terms

1. Light---radiant energy in that part of the electromagnetic spectrum capable of producing visual sensation.

2. Background---the part of the field on which objects are viewed.

3. Surround---the area around the background which falls in the field of vision.

4. Field of Vision (field)---the entire visual area perceived by the eye; this includes the background, and objects which influence the adaptation of the eye.

5. Color Constancy---the tendency of a person to perceive the daylight color of a surface regardless of the spectral distribution of the illuminant, within limits.

OBJECTIVES

In view of the foregoing statements concerning the importance of the cherry industry in Michigan and the need for improvement in the visual-manual sorting operation, the following objectives were established:

1. To find a suitable method of rotating cherries as they move along the sorting belt.

2. To determine the effect of the spectral distribution of the illuminant on the perceptibility of defective fruit in cherries and tomatoes, and on the perceptibility of the color grades of tomatoes.

3. To investigate the effect of belt speed, concentration of fruit on the sorting belt, width of view of the workers, and other factors which may influence sorting efficiency in fruit processing plants.

REVIEW OF LITERATURE

Illumination for Sorting

In 1951 Peterson (5) performed limited tests on illumination of cherry sorting belts using blue, green, gold, and red illumination. The blue, green, and gold illumination was obtained by using a light red filter over a pink fluorescent tube. Green and gold were eliminated because the green gave a dark appearance to the cherries and the gold did not show up all the defects (5).

From limited tabulated data Peterson stated that higher quality cherries were obtained by using blue fluorescent lamps than white lamps; however, he stated later:

> The blue fluorescent lights made all the cherries look slightly darker. ... Blue light increases the brightness (he intended lightness) of the brown spots making them easier to detect. The black spots on the darker cherries are found be be more difficult to see. The best testimony that can be given for blue light is that the workers say that blue lights are easier than white lights for the eyes on night work.

Concerning the use of red light, Peterson stated that major defects were easier to detect while minor defects, which often cook out in the can, were less noticeable. He showed the results by the total pounds of defective cherries removed by an equal number of workers under each illuminant. The samples were taken during the same period. Peterson's tabulated results indicated an efficiency increase from 5 to 88 percent for the red illumination. That is, according to the data, if the workers under white light removed 100 pounds, those under red light removed from 105 to 188 pounds during the same period. Eleven weight values were listed in the table.

According to his report pink lights presented a psychological problem, especially when the light source was in the worker's view. Also, the workers complained occasionally about changes in the illumination.

Linsday (6) suggested the use of colored illumination for checking color proofs. He stated, as an example, that to check a yellow proof it should be examined under saturated blue light. By this procedure the yellow ink, which absorbs blue, appears very dark if printed on white paper. That is, the white background will reflect most of the blue light while the yellow ink will absorb most of the blue light. This makes the yellow proof show up with much greater contrast under saturated blue light than under white light.

The applications presented by Linsday and Peterson depend mainly on lightness differences of a surface or surfaces. The following articles on lightness are concerned with changing the spectral distributions of illuminants in order to produce greater color contrast.

White (7) working at Stanford University considered the change in spectral reflectance and appearance as fruits and vegetables mature. His main interest was in establishing color tolerances for peaches.

Spectral reflectance curves for four grades of clingstone peaches were presented. It was pointed out that the curves were very similar between 500 and 620 Mu (millimicrons). Due to this small reflectance difference in the spectral region where the eye is most sensitive to light, White suggested that photoelectric sorting of peaches be investigated. The greatest difference in reflectance of the grades occurred at approximately 675 Mu.

White examined raw samples of products, presumably peaches, under 14 different sources of commercial light. The sources of illumination included white and colored fluorescents, incandescent with daylight correction filters, and mercury vapor lamps. The greatest differences in color were observed when using light with approximately equal energy distribution. He stated:

> The results of numerous observations with these sources, at intensities of 10 footcandles to several hundred footcandles, consistently indicated that the illuminant allowing easiest detection of color difference did not vary with the spectral reflectance curve. The greatest differences in color for any product resulted when daylight, daylight fluorescent, daylight incandescent, or any source having approximately equal energy distribution was used.

Next he used illuminant-filter combinations in order to produce light in a number of restricted areas of the visible spectrum. Thirty-six Corning filters used in the tests were listed and he stated that the various combinations of these filters gave hundreds of observations of different lighting conditions. In the conclusions he stated, "The light source best suited to the detection of color differences is one having approximately equal energy distribution (daylight) throughout the visible spectrum."

Nickerson's (8) writings are not in agreement with the conclusions drawn by White. Concerning illumination for the purpose of enhancing color differences, Nickerson stated, "The single illuminant most satisfactory for this purpose will depend upon the reflectance curve of the samples to be examined." In addition she referred to studies made by Taylor (9) which indicated that the illuminant best suited to enhancement of color difference is one rich in energy in the region of the spectrum where the samples to be examined have maximum absorption. She continued, "In other words, if yellow samples are to be examined, an illuminant rich in energy in the blue portion of the spectrum where the spectral reflectances of yellow samples are apt to differ most widely, will enable an observer to discriminate differences more easily than when using an illuminant deficient in the blue portion of the spectrum."

A review of Taylor's (9) article revealed the following pertinent quotation concerning the perceptibility of color differences. "Our tests indicate that small color differences are often most definitely revealed by an illuminant radiating energy throughout the visible spectrum, but being especially rich in energy in the spectral regions where the colored object has maximum absorption." Taylor followed with an example which illustrated that the rich portion of the illuminant should be in the region of maximum absorption for two reflectance curves which exhibit approximately the same difference in this region as in the region of maximum reflectance.

The principle of enhancing color difference stated by Nickerson and Taylor is rather well established. In a discussion with Judd (10), Head of the Colorimetry Unit, National Bureau of Standards, the writer learned that the more accurate and positive way of stating this principle is as follows: Color difference is most pronounced by use of an illuminant with radiation throughout the visible spectrum but rich in energy in the region of the spectrum where the reflectance curves of the objects exhibit the greatest percent difference. This agrees with Taylor's example but not precisely with his statements. His statements are based on the fact that for many color differences occurring in industry, the greatest percent difference in reflectance is in the region of maximum absorption.

Product Rotation and Other Factors Affecting Sorting Efficiency

Peterson (5) reported that some processing plants attempted to rotate cherries mechanically at the half-way point along the sorting belt. The methods listed were wooden pegs, trip wire, and a square roller. He explained that the pegs were mounted vertically in two staggered rows across the belt; the trip wire was a piano wire stretched across the belt below the center of gravity of the cherries; and the square roller was a wooden roller which rotated in the opposite direction to the belt travel. (Roller action was not explained further). Peterson stated, "The disadvantages of the above methods are that the first two will jam up when squashed cherries come along, and the latter method may do mechanical damage to the product." He attempted to rotate cherries with foam rubber fingers and stated that the fingers were 80 percent effective in turning the cherries; however, the term "effectiveness" was not defined and the concentration of cherries on the belt was not given.

Peterson made several counts to determine the percent of defective cherries which were visible without rotation. He stated that without rotation approximately 30 percent of the defects were visible.

Malcolm and DeGarmo (11) reported rather exhaustive laboratory tests and some field tests on factors affecting sorting efficiency in processing plants. The tests included nine variables: 1. shape of objects, 2. direction of approach to worker, 3. number of rows of objects, 4. rate of inspection, 5. rotation of objects, 6. percent defective, 7. location of defects, 8. color contrast of defect with that of object, and 9. effect of mirrors on inspection efficiency. The following account of the report only includes those items which were deemed important to this work. All comments apply to spherical shaped objects as reported.

Malcolm and DeGarmo (11) reported previous tests by Rossi (12) which showed that for three-quarter inch to two inch objects the sorting efficiency is increased from approximately 75 percent to 98 percent by rotating the product 3/4 to 2 revolutions per foot of travel on the sorting belt. The product in this test was presented to the worker in single rows. More complete tests by the authors verified the data collected by Rossi. Malcolm and DeGarmo used $2\frac{1}{2}$ inch diameter objects in their tests, but reported that the size of the product was not important in this report.

They also reported tests on rotation by DeHart (13) which showed that the direction of rotation should be such that the top surface of the product travels in the same direction as the sorting belt (forward rotation). When the rotation of the product was in the reverse direction the workers developed nausea at certain critical belt and rotational velocities.

For spherical objects of $2\frac{1}{2}$ inch diameter painted an orange color, Malcolm and DeGarmo (11) tested three speeds of rotation: 1.53, 3.0, and 4.0 revolutions per foot of translation. Slightly higher sorting efficiencies were shown for the two lower speeds of rotation.

In their tests the sorting efficiency ranged from 3 to 9 percent greater for the direct approach to the worker as compared to the side approach which is commonly used on sorting belts. As the width of view increased (greater number of rows of objects) the side approach showed an improvement in sorting efficiency. This led the authors to state, "Thus, it may be conjectured that if 6-row presentation had been tested the side approach would have equaled the inspection efficiency obtained under the same conditions for direct approach of the specimens."

Inspection efficiency was not significantly affected by the percent of defects in the samples. Samples in the tests contained 14 and 30 percent defective objects.

Following is a partial list of the conclusions and recommendations presented by Malcolm and DeGarmo (11).

> When objects are moved (translated) along a table or conveyor belt past a grader for visual inspection for defects located on a peripheral surface, the speed of rotation of the object, while it is being moved in translation, is a primary factor in obtaining greater inspection efficiency. ... Spheroidal specimens, which roll about numerous axes, should be rotated about 1.6 revolutions per foot of translation when from 3 to 5 rows are presented for simulataneous inspection.
>
> The presentation of specimens at regular intervals along the inspection belt is preferable to haphazard spacing, from the viewpoint of both inspection efficiency and operator satisfaction.
>
> For specimens that have a maximum "width" dimension of $2\frac{1}{2}$ inches, four rows of specimens appear to be the optimum number of rows that should be presented for simultaneous inspection. There is reason to believe that this number of rows might not be correct for smaller or larger specimens which would decrease or increase the width of the area over which the grader's eyes searched during the visual inspection process.
>
> For use with the side approach, the equipment should be so constructed that the grader will be stationed about 8 inches from the nearest row of objects. Defects on objects within this 8-inch range cannot be clearly seen by graders.

PERCEPTIBILITY DIFFERENCE

From Table I the eleven attributes of modes of appearance as designated by the Optical Society of America are listed as follows: brightness (or lightness), hue, saturation, size, shape, location, flicker, sparkle, transparency, glossiness, and luster. Evans (14) stated that all eleven attributes of modes of appearance can occur for the surface mode. Thus, differences between surfaces may be perceived and reported in any of these specified ways. The perceived difference is a result of the cumulative effects of the difference due to these attributes of modes of appearance and perhaps others not included in these specifications.

In considering illumination as a means of enhancing perceptibility difference between surfaces, the first three attributes are of prime importance; i. e. lightness, hue, and saturation. It is not intended to imply that changes of illuminant quality and intensity do not influence the other surface differences, but that the other factors appear to be of relatively minor importance in fruit and vegetable sorting. Specular gloss and transparency will be mentioned later with respect to cherry sorting operations.

As set forth in the definitions, the color perceived depends on lightness, hue, and saturation. From these three attributes in combination, the eye interprets the difference in color of surfaces; i.e. color contrast. In addition, the single attribute of lightness variation is interpreted as lightness difference; i.e. lightness contrast. Thus, the perceptibility difference may be discussed in terms of two variables, color contrast and lightness contrast. However, another very important factor, adaptation of the eye, must also be evaluated. Adaptation depends on the quality and quantity of the light reaching the eye from all parts of the field of vision; thus, the color and lightness of background and general surrounds must enter into the analysis of perceptibility difference. An exact relationship for the calculation of the general adaptation level is not known; however, it is considered a complex function of the average reflectance of the field of view and general illumination level (15).

In order to analyze the illumination in more detail, it is necessary to consider the visual process. Only those principles and theories by which color and lightness differences are usually explained are presented. For a more detailed explanation the reader is referred to textbooks on vision, psychology, and color. (4,15,16,17,18)

The Visual Process

Light entering the eye is focused by refraction at the surface of the cornea and by the lens to form an image at the back of the eye on the retina. From the lens to the retina, light is transmitted by a medium (vitreous humor) which absorbs part of the light. The retina is made up of approximately seven million extraordinarily small receptors (cones and rods) (15). When light strikes these receptors, each receptor absorbing enough energy initiates a nerve impulse which is transmitted to the brain via a nerve fiber. The nerve impulse takes place through electrochemical action (4). The molecular basis and chemical action of visual excitation is discussed in recently reported research (19).

In the central part of the retina there is a nerve fiber for each receptor, whereas in the outer regions of the retina a number of receptors are connected to a single nerve fiber (15). (This accounts for distinct vision at the center of the field of vision). These nerve fibers are combined into a cable (optic nerve) at the back of the eye. The optic nerve is then connected to the occipital lobes of the brain in the back part of the head. An illuminated surface reflects light to the eye and results in a pattern of excitation of the retina. This pattern is transmitted to the brain and forms a pattern of excitation on the occipital lobes of the brain which is interpreted by the brain. The resulting sensation is called visual perception.

Three-Receptor Theory of Color Vision

According to this theory there are three photopigments or photopigment-filter combinations which have different sensitivity to various wavelengths of light(17). It is not known whether these receptors or photopigments actually exist; however, the postulation of such receptors enable us to explain many observed facts of color vision (15). Helson (20) in 1938 reported that his research on adaptation indicated color vision is recorded by only one mechanism. However, the three receptor theory was applied by Evans (15) in 1948 and by Judd (17) in 1952. Indeed this theory has been developed to the extent that the approximate color, which will be perceived in simple visual situations, may be calculated. In order to make this calculation it is necessary to have a weighing function (hypothetical sensitivity) for each receptor and to know the spectral irradiance on the eye. The formulas used are as follows(17):

$$X = \int_0^\infty H_\lambda \bar{x}_\lambda \, d\lambda, \quad Y = \int_0^\infty H_\lambda \bar{y}_\lambda \, d\lambda, \quad Z = \int_0^\infty H_\lambda \bar{z}_\lambda \, d\lambda$$

where: H_λ is the spectral irradiance on the eye

$\bar{x}_\lambda$, $\bar{y}_\lambda$, and $\bar{z}_\lambda$ are presented in Figure 1 as weighing functions for the color receptors.

also: $\frac{X}{X+Y+Z}$?

$$x = X/X+Y+Z \quad , \quad y = Y/X+Y+Z \quad , \quad z = Z/X+Y+Z$$

where: x, y, and z are the trichromatic coordinates of the CIE color mixture diagram. (This is the most widely used system for color specification from spectrophotometric data. A number of systems are possible).

General adaptation. According to Evans (15) the color perceived, excluding psychological factors (attitude, intention, etc. of the observer), depends on the ratio of the output of the presumed color receptors. The output of a receptor depends in turn upon its level of adaptation as well as the amount and wavelength of light absorbed by it. The level of adaptation of each type of color receptor rises and falls with the amount of light received by each. The adaptation of color receptors is most easily presented by examples.

When the eye is adapted to radiation with approximately the intensity and distribution of average daylight the color receptors are adapted to what may be called equal sensitivities (15). If a small green object is brought into the field of view, the output of the green receptors will be greater than the blue and red receptors in the region of the retina where the object is focused. The object is then perceived as

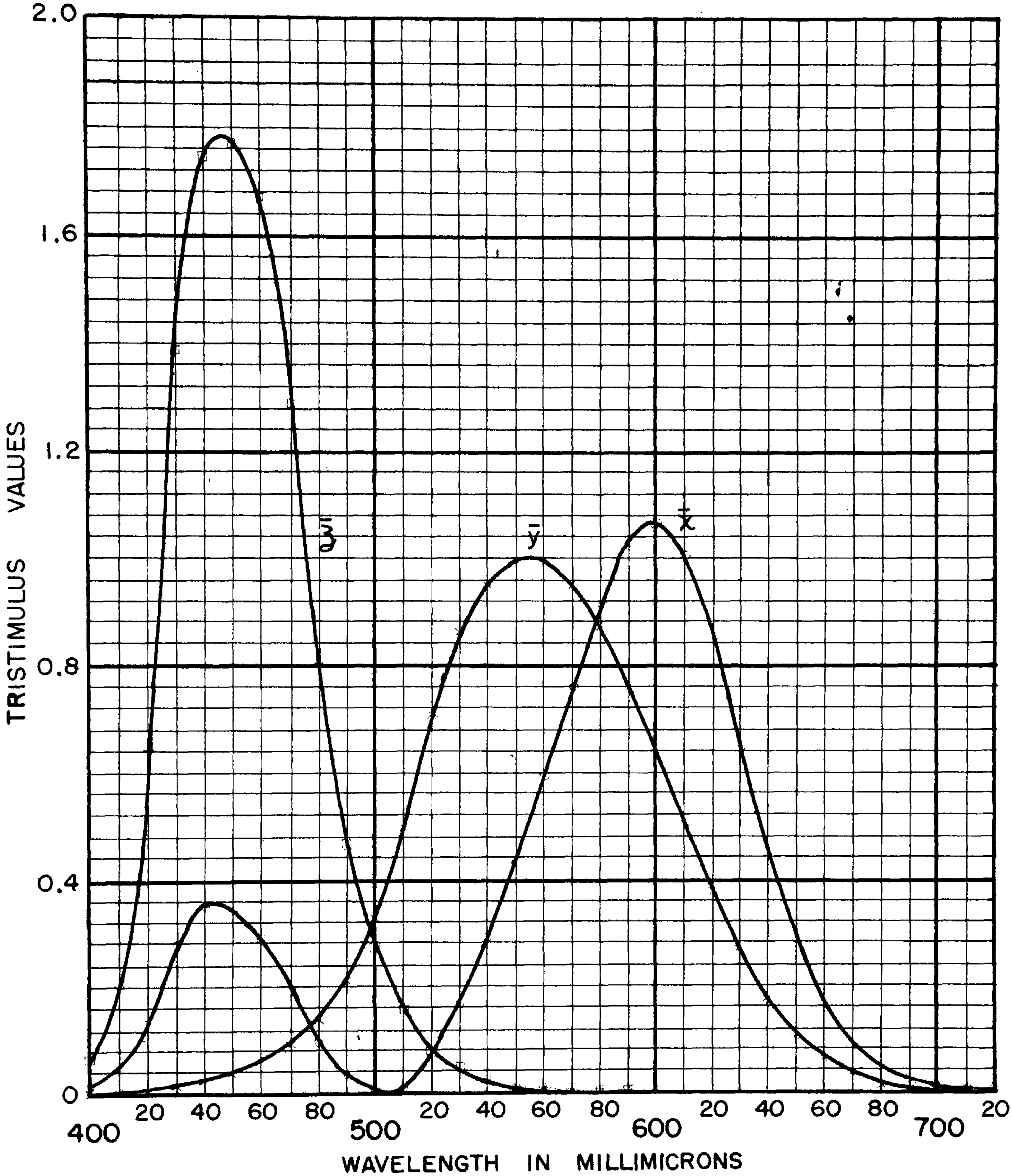


FIGURE 1. WEIGHTING FUNCTIONS USED TO REDUCE SPECTROPHOTOMETRIC DATA TO COLORIMETRIC TERMS (17)

green in color. This is a simplified illustration; adaptation due to the image of the green object is neglected. This will be discussed later.

Now suppose the eye is adapted to the spectral distribution of an incandescent lamp (Figure 2). With the eye adapted to this spectral distribution the green receptors are somewhat desensitized compared to the blue receptors since the green receptors are receiving more radiation to which they are sensitive. Likewise, the red receptors are desensitized even more than the green since the radiation is considerably greater in the red portion of the spectrum. Then, the sensitivity distribution of the eye to different colors is opposite to the spectral distribution of the radiation received by the eye (15). Receptors receiving the least radiation to which they are sensitive have greatest outputs per unit received.

Color constancy. Due to adaptation of the color receptors an observer tends to see the same color for a given object even though the spectral distribution of the illuminant is changed. This is called "color constancy" and is usually complete for object-color perceptions of ordinary changes in the conditions of illumination (4). Color constancy applies to a smaller degree for illuminants with sharp changes in spectral distribution and for saturated object colors (15). Finally, if objects are viewed under spectrally homogeneous (single wavelength) illumination color constancy is not maintained.

As an example of color constancy suppose a light red object is placed on a light gray background of equal lightness and illuminated by either an incandescent lamp (Figure 2) or by north skylight (approx. equal energy distribution throughout the visible spectrum), the object will

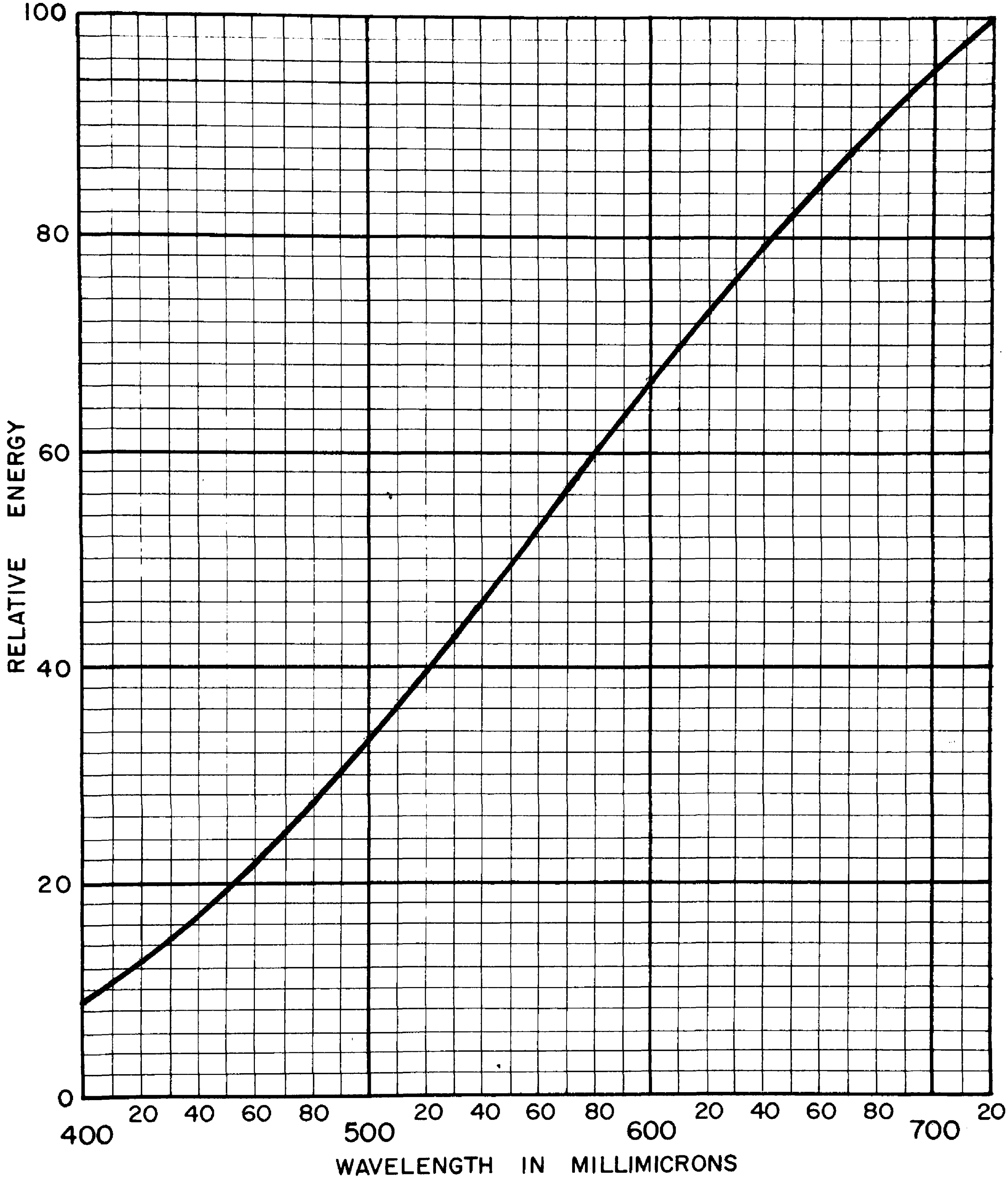


FIGURE 2. SPECTRAL DISTRIBUTION OF 2910°K TUNGSTEN (APPROX. 150 W. FILAMENT TYPE LAMP)

appear very nearly the same color under each illuminant. For the skylight illumination let us assume the energy received by the red receptors is twice that received by the blue receptors and both are adapted to the same level. Then, for the incandescent lamp the red receptors would receive a much greater ratio of the energy, perhaps four times the blue receptors, since this illuminant emits much more strongly in the red region. However, the blue receptors are more sensitive due to the adapting gray background and the ratio of the output of the red receptor to the blue is still approximately two to one. That is, blue receptors are relatively more sensitive, and the radiation received by the blue receptors results in greater output than an equal amount of radiation absorbed by the red receptors.

Color constancy is not maintained for spectrally homogeneous or strongly saturated illuminants. Observers using strongly saturated chromatic illuminants report that objects exhibit: 1. the hue of the illuminant, 2. achromaticness (no hue), or 3. the after-image complementary hue of the illuminant (20). Furthermore, the observed hue under strongly saturated illuminants depends mainly on the lightness of the object for the specified illuminant with respect to the lightness adaptation of the eye. (Lightness adaptation of the eye depends on all objects in the field of view). Daylight hue is of minor importance. However, if a small amount of light is added throughout the visible spectrum, the objects quickly regain their normal daylight hues. Nonselective objects are slower to regain their normal daylight hues than selective objects (21). The exact daylight color may not be attained until normal illumination, whatever this may be, is restored. Thus, the color of an object may be distorted by the spectral distribution of the illuminant; however, the correct hue of the object will be perceived if a small amount of radiation is present throughout the visible spectrum. This includes a host of so called white and even certain non-saturated chromatic illuminants. But the color of an object may not be precisely the same under any of these illuminants. (Note that color includes hue, lightness, and saturation).

In summary, the general adaptation of the eye makes automatic corrections for a rather wide range of spectral distributions from surfaces so that these surfaces are interpreted as the same hue regardless of the spectral distribution of the illuminant, within limits. Also, color is corrected by adaptation for ordinary spectral distributions encountered in daily living.

Local and lateral adaptation. The foregoing discussion has been concerned with general adaptation and color constancy. In addition, two other types of adaptation, local and lateral, must be considered. Local adaptation means the adjustment of sensitivity of a portion of the retina due to the radiation falling on that particular part of the retina. As the eye moves from place to place over a surface, the radiation received by any particular area of the retina will be continually changing according to the changes of the field (as in reading). For such a visual task the eye moves in small jumps from place to place and stops instantaneously to pick up the image. The focus of this image on the retina causes an initial retinal adaptation according to the pattern of the image. This is local adaptation (15). At a given task with a given illumination level, local adaptation and time contribute to the general adaptation level of the eye.

Lateral adaptation refers to the influence of receptors which are receiving radiation on adjacent receptors. It the eye adapts locally to a spot of light of a given wavelength, adjacent receptors will also be desensitized to these wavelengths through neural interactions. If a yellow-green and a green object are viewed in proximity, the former will tend toward yellow and the latter toward blue-green. The reason for the apparent shift in color is lateral adaptation and this is a very important effect in "simultaneous contrast" (15).

As an example, when two objects are viewed in proximity lateral adaptation is a maximum and the image of the first object will tend to desensitize the adjacent receptors to the color of the first light. Suppose the two objects are green but the first reflects more blue light than the second. It these objects are viewed in proximity the blue light in the first image will help desensitize the blue receptors in the region of the second image; thus, the output of the blue receptors in the second image will be reduced. This will result in an interpretation of less blue reflection for the second object than actually exist. The tendency is for the objects to be perceived as complementary. Thus, for greatest color difference the objects should be viewed in proximity (4).

Color adaptation has been discussed under three classifications: general, local, and lateral. Likewise, lightness adaptation may be considered under the same three classifications.

The Brightness Receptor

In addition to the three color receptors considered in the foregoing discussion it is convenient to assume a fourth type of receptor, the brightness receptor. For color considerations this is actually the green receptor of the CIE system but is considered separately here because of its importance in lightness contrast and simplicity of explanation. Evans (15) uses this technique. The sensitivity of this receptor to the various wavelengths of the spectrum is given by the luminosity function (Figure 3). There are many similarities between lightness and color adaptation. General, local, and lateral adaptation apply to this type of receptor as they do to any one of the color receptors. However, it should be remembered that there is only one type of receptor to be considered.

The eye is capable of adapting over a range of luminance from about 10^{-5} to 10^{5} foot-lamberts but the momentary range perceived by the eye is approximately 1000 to 1 (4). For a given level of adaptation there is an intensity level below which all stimuli appear black (15). This is called the black point and it increases and decreases with the level of illumination. On the other hand, white is perceived for non-selective surfaces which reflect 75 to 100 percent of the light striking the surface. Gray is perceived for non-selective surfaces which have reflectances between the black and white surfaces; for example, gray is perceived for non-selective surfaces in the presence of other non-selective surfaces of higher reflectance. Gray is a relative sensation depending on other surfaces in the field; i.e. on adaptation level of the eye. Because of this dependance on adaptation level, the eye cannot be depended upon to judge absolute magnitudes of intensity but it can detect very small intensity differences (15).

The ratio of luminous differences for surfaces is expressed by the contrast ratio which has been defined as follows:

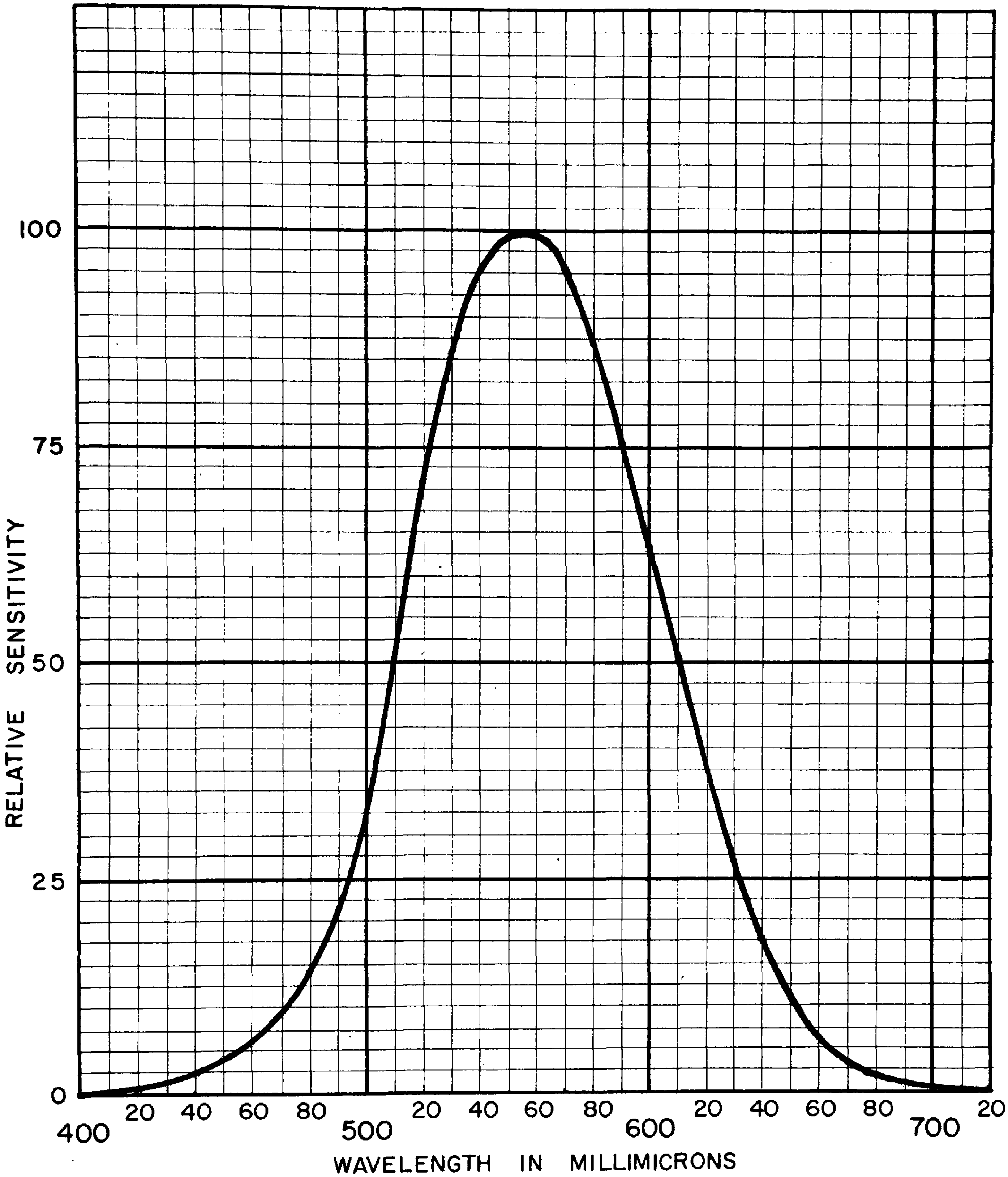


FIGURE 3. RELATIVE SPECTRAL SENSITIVITY FOR DAYLIGHT ADAPTED EYE (CIE STANDARD) (22)

$$\text{Contrast ratio} = \frac{\int_0^\infty (E_\lambda L_\lambda R_\lambda)_1 \, d\lambda}{\int_0^\infty (E_\lambda L_\lambda R_\lambda)_2 \, d\lambda}$$

A good approximation of these intergrals may be obtained by summation of $E_\lambda L_\lambda R_\lambda$ using narrow wavebands throughout the visible spectrum.

$$\text{Contrast ratio} = \frac{\sum (E_\lambda L_\lambda R_\lambda)_1 \ *}{\sum (E_\lambda L_\lambda R_\lambda)_2}$$

For calculations of this type in color determinations a waveband of 10 millimicrons (Mu) is considered sufficient for general applications (17). The numerator or denominator for the contrast ratio is calculated by multiplying, waveband by waveband, the spectral distribution of the illuminant by the spectral reflectance of the object by the luminosity function of the eye, and by totaling the products throughout the visible spectrum. It is noted again that this calculation depends only on one receptor sensitivity curve while the color calculations require the inclusion of data from three color receptors. This is important in the consideration of lightness differences.

Suppose the eye views a scene which adapts the brightness receptors to the same level when illuminated by certain intensities of either a daylight fluorescent lamp or an incandescent lamp. If two objects of different spectral reflectance are viewed under each illuminant, the objects will tend to maintain their own color since color adaptation tends to make up for color deficiencies in the illuminant. However,

* The summation limits from 400 to 720 Mu are omitted for convenience. These limits are used throughout this report and are justified since the luminosity function, L, is practically zero beyond these limits. A 10 Mu increment is used unless otherwise specified.

if one of the objects has greater luminous reflectance than the other under the incandescent illuminant the eye will make no correction for the difference in contrast ratio produced by change of illuminant. That is, there is no lightness constancy as found for color when the spectral distribution of the illuminant is changed. Thus, the lightness difference due to change in the spectral distribution of the illuminant is not corrected by adaptation of the eye since there is only one type of brightness receptor (15).

In addition to local, lateral, and general adaptation, light is reflected from the image on the retina to other parts of the retina. This is called entoptic stray light and results in excitation of these regions which increases the level of adaptation (23).

Principles of Perceptibility Difference

The following principles concerning optimium visual conditions for perception of color and lightness differences were taken from the indicated reference.

For maximum perceptibility of color differences. 1. The surfaces should be viewed in proximity (4).

2. The illuminant should radiate energy throughout the visible spectrum but should be rich in energy in the region of the spectrum where the reflectance curves of the surfaces exhibit the greatest percent difference (10).

3. Judd (17) states, "The most favorable condition for detecting chromaticity differences (Schonfelder, 1933) is to have the eye adapted to a chromaticity as closely like the two being compared as possible." This means that the color of the background should be the average color

of the product being graded.*

<u>For maximum perceptibility of lightness differences.</u> 1. The surfaces should be viewed in proximity (15).

2. According to Adams and Cobb (24), the relative fractional threshold for visual sensation is a minimum when the lightness of the background equals the lightness of the surface; i.e. uniform field lightness is the optimum adaptive condition for distinguishing lightness differences. A darker background is preferred to a lighter one in this respect.

---

* This applies only to the detection of color differences and not to judgement of daylight color as used for standards (see reference 4, p. 51).

PERCEPTIBILITY OF DEFECTIVE CHERRIES

The concern of this section is the perceptibility difference between cherry defects and red tart cherries. For the analysis of perceptibility difference it is necessary that the reflectance of the cherries and defects be considered.

Spectral Reflectance Curves

Reflectance curves for red tart cherries and for defective cherries are presented in Figure 4. These curves were taken from the original reflectance curves which are presented in Appendix I. The under-color and black defect curves were taken from samples 7 and 5, respectively. The brown defective cherry curve is an average of samples 6 and 9, and the red ripe cherry curve is an average of samples 8 and 10. Color pictures of samples 7,8,9,and 10 are shown with the original reflectance curves in Appendix I. The samples used for averages possessed comparable reflectance throughout the visible spectrum. Each of the curves of Figure 4 is considered typical for the type of cherry or defect represented.

The area between the reflectance curves of the brown and black defects is shaded and labeled as the area for dark defects. From the appearance of the cherries all defects which are darker than brown rot should have reflectance curves which lie in the shaded area. This classification includes a large majority of the major defects. The under-color cherry curve represents immature cherries. This curve may also be a fair approximation of cherries which are bruised in the lug and turn a slightly lighter color.

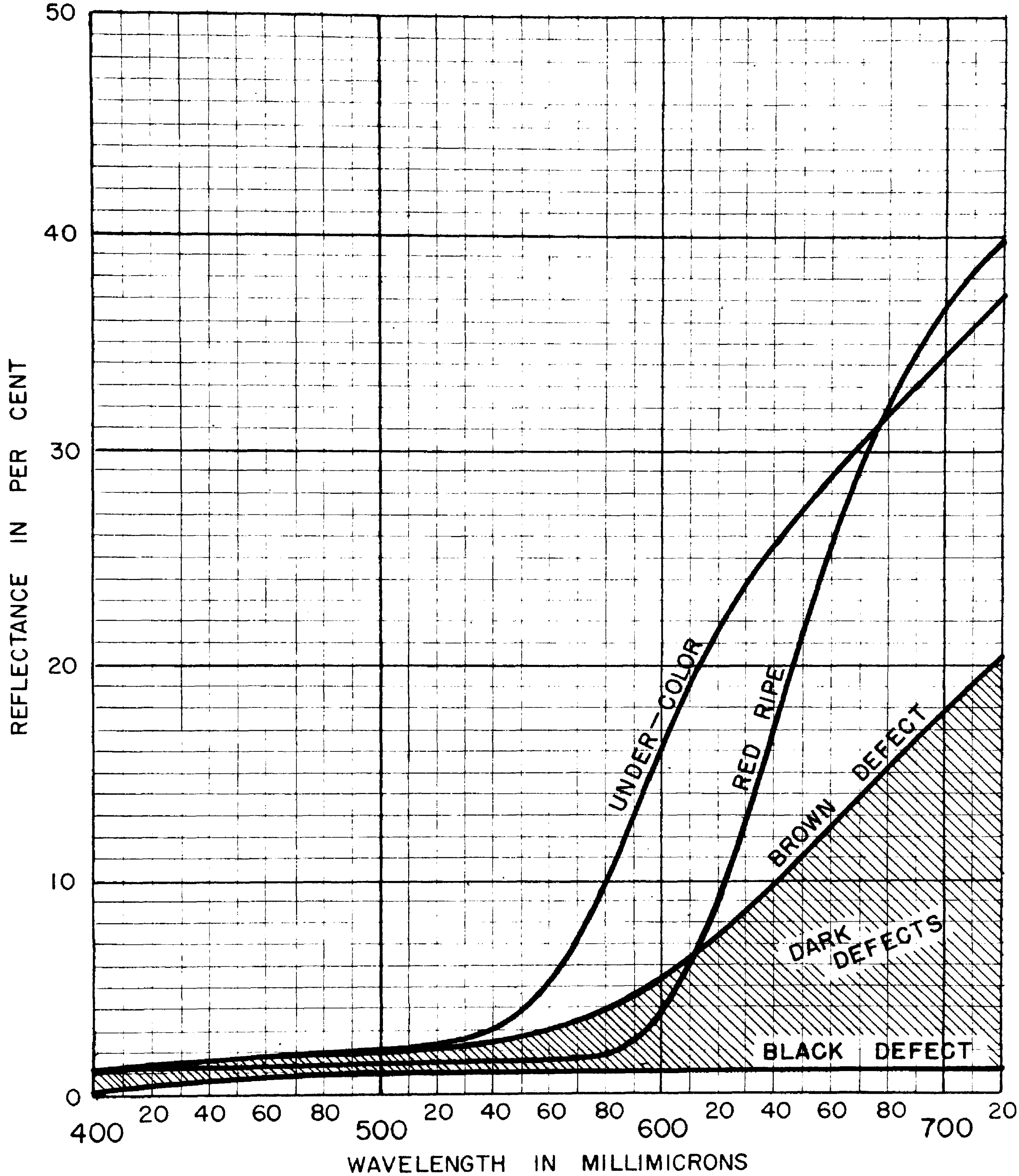


FIGURE 4. 45°-0° SPECTRAL REFLECTANCE CURVES FOR RED TART CHERRIES

Color Contrast

Color has been defined as including hue, saturation, and lightness. By observing a reflectance curve, an indication of the hue may be obtained by noting the region of the spectrum in which the peak of the curve appears, providing the reflectance curve has only one such peak. Also an indication of saturation may be obtained by the narrowness of this peak and the magnitude of reflectance in other regions of the visible spectrum. Curves with narrow peaks and little reflectance in other parts of the spectrum exhibit greater saturation. (This type of observation can be made only for reflectance curves which are simple). The lightness of an object is a function of the area under the curve obtained by multiplying (waveband by waveband) the reflectance curve, the luminosity function, and the spectral distribution of the illuminant; i. e. lightness is a function of luminous reflectance. Lightness increases with luminous reflectance for specified visual conditions.

Referring again to the reflectance curves of Figure 4, the reflectance for wavelengths shorter than 550 Mu is very low for all curves. All curves except the black defect curve show increased reflectance for the longer wavelengths. It may be surmised from these curves, as from observations of cherries and defects, that the difference in hue of the under-color, red ripe, and brown is rather small. Saturation difference is greater but a large part of the color difference may be attributed to lightness difference.

In addition to these statements concerning the relatively minor role of hue and saturation differences the change in the existing color should be small since the eye tends to maintain color constancy, especially if some radiation is admitted throughout the visible spectrum. In the cherry sorting tests discussed here some daylight was admitted to the sorting belts; thus the change in hue and saturation should be of relatively minor importance. (An exception may have been the preliminary test at Plant A). By this analysis, the problem is reduced, essentially, to the perceptibility of lightness differences.

Lightness Contrast

The contrast ratio may be used as a relative measure of the lightness contrast although the relationship between these factors is not expressed mathematically. The contrast ratio is a calculated psychophysical value depending only on the relative luminous reflectances of the two surfaces being considered. The lightness contrast is a psychological value giving an estimate of lightness difference. It depends on the relative luminous reflectances of the surfaces, the adaptation of the eyes, and psychological factors (attitude,concentration, intent, etc.). The psychological influence may be assumed to be equal for two visual situations where the observer is attempting the same task, unless contrary facts can be observed. Eliminating psychological factors for the present, the lightness contrast increases as the contrast ratio departs farther from unity. A contrast ratio of 1/2 is equivalent to 2/1, and unity contrast ratio gives zero lightness contrast.

Contrast ratio. The contrast ratio, as expressed previously, equals the luminous reflectance of surface one divided by the luminous reflectance of surface two. In this report the luminous reflectance of the cherry surface is used in the numerator and the luminous reflectance of the defect in the denominator. Thus, the contrast ratio is expressed by the following formula:

$$\text{Contrast ratio} = \frac{\sum(E_\lambda L_\lambda R_\lambda) \text{ for cherry}}{\sum(E_\lambda L_\lambda R_\lambda) \text{ for defect}}$$

In the contrast ratio equation the factor, L, represents the luminosity function as presented in Figure 3 and the spectral reflectances, R, are given in Figure 4 for cherries and defects. The reflectances and the luminosity function are assumed to be fixed and it is desired to vary the spectral distribution of the illuminant, E, in order to produce the maximum contrast ratio. In order to visualize clearly the possibility of increasing the contrast ratio, the luminosity function was multiplied waveband by waveband, by the spectral reflectance of cherries and defects. The resulting curves are plotted in Figure 5. For maximum contrast ratio of two objects, the illuminant should have strong radiation in the region of the spectrum where the curves for the objects (Figure 5) exhibit maximum percent difference. Radiation in other regions may be eliminated or reduced. This procedure was not suggested in the literature. However, it can be seen from the contrast ratio equation and Figure 5 that this is the most general approach to the problem of lightness differences. A statement to this effect should be added to the principles of perceptibility differences.

The curves in Figure 5 represent the distribution of the reflected luminous flux of cherries and defects under an illuminant which possesses equal energy distribution throughout the visible spectrum. With this assumed uniform illuminant the area under the respective curves (Figure 5) represent luminous reflectance and the ratio of the area under the red ripe cherry curve to the area under a defect curve is the contrast ratio. Since the curves exhibit differences with this

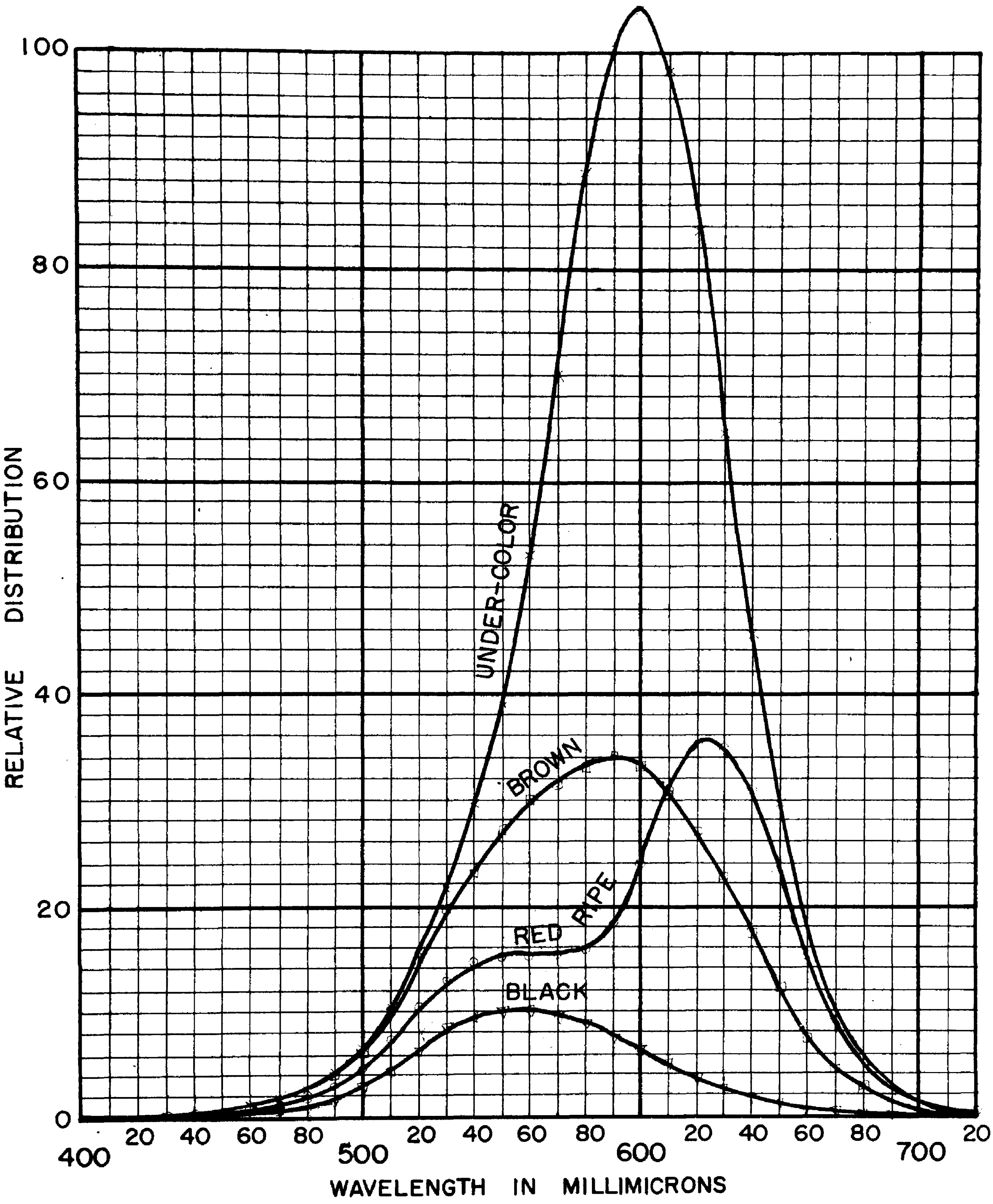


FIGURE 5. DISTRIBUTION OF LUMINOSITY FUNCTION TIMES SPECTRAL REFLECTANCE OF CHERRIES AND DEFECTS

theoretically uniform distribution of illumination, altering the distribution of the illumination would change the relative areas under the curves. Let us consider the possibility of eliminating the illumination in

Let us consider the possibility of eliminating the illumination in certain regions of the spectrum as a means of increasing the contrast ratio. It appears that the contrast ratio for the under-color and brown defects could be increased by using the short wavelengths of light up to approximately 610 Mu. This would cause these defects to appear lighter than the red ripe cherry. Likewise, the contrast ratio for the dark defects, ranging from the brown to black, should be increased by including only the long wavelengths of light from approximately 610 to 720 Mu. This would result in dark defects and light cherries. These are theoretical considerations using an illuminant with uniform spectral distribution. In practical applications it is desirable, if possible, to use commercially available illuminants. Thus, further analysis is restricted to common illuminants.

Commercially available illuminants. Three illuminants representing a wide range of spectral distribution were selected. These were: the G. E. daylight fluorescent (Figure 6), with a large part of its radiation in the green and blue regions of the spectrum; the G. E. deluxe warm white fluorescent (Figure 7), with considerable radiation in the yellow-red region of the spectrum; and the 2910° K tungsten filament lamp (Figure 2) approximately 150 watt bulb, with a large amount of its radiation in the red region of the spectrum. The spectral distribution curves for these lamps were plotted from the tabular data which are presented in Table XVI. in Appendix III. These data were used in

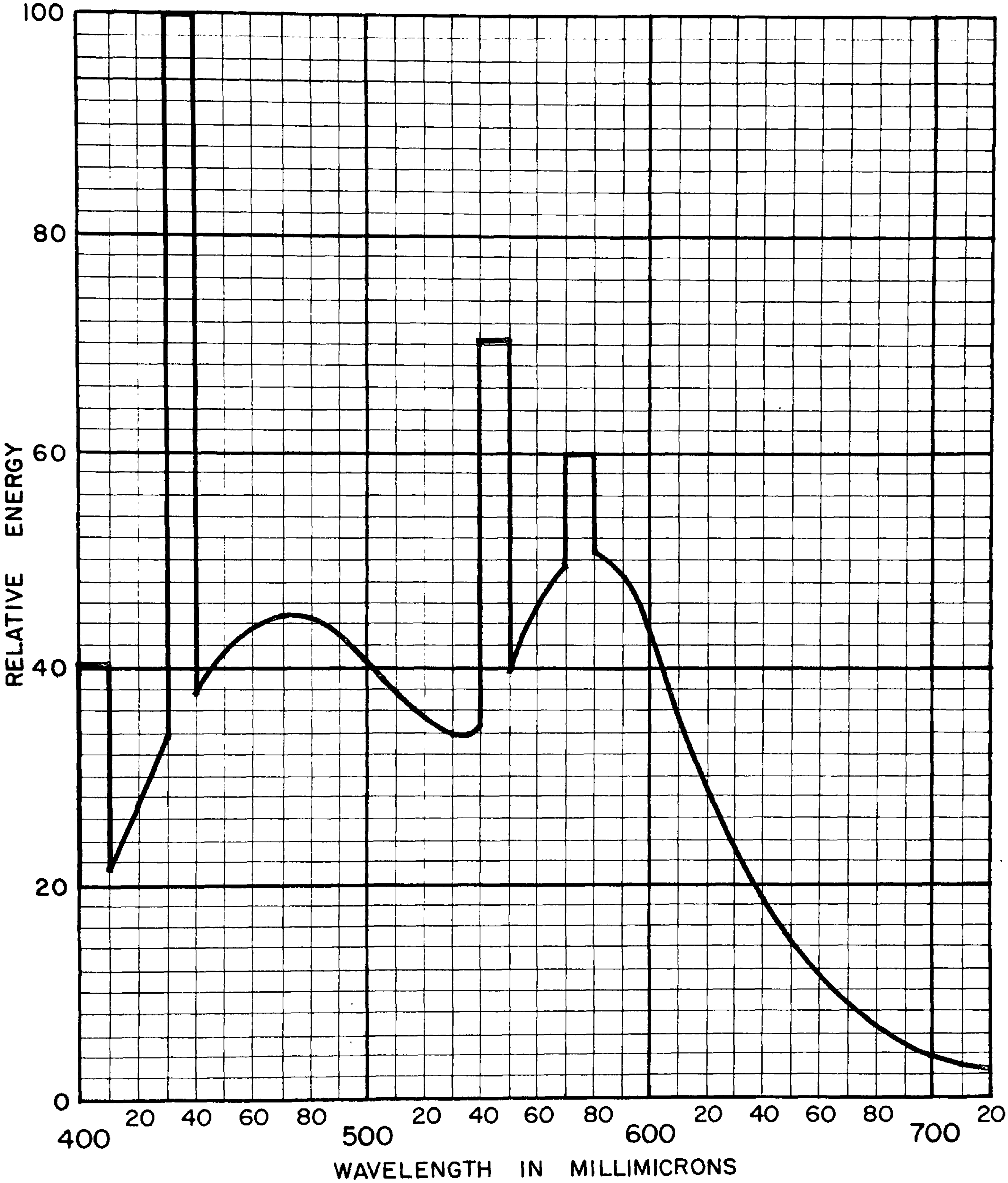


FIGURE 6. SPECTRAL DISTRIBUTION OF G.E. DAYLIGHT FLUORESCENT LAMP (BASED ON 40 W. T-12)

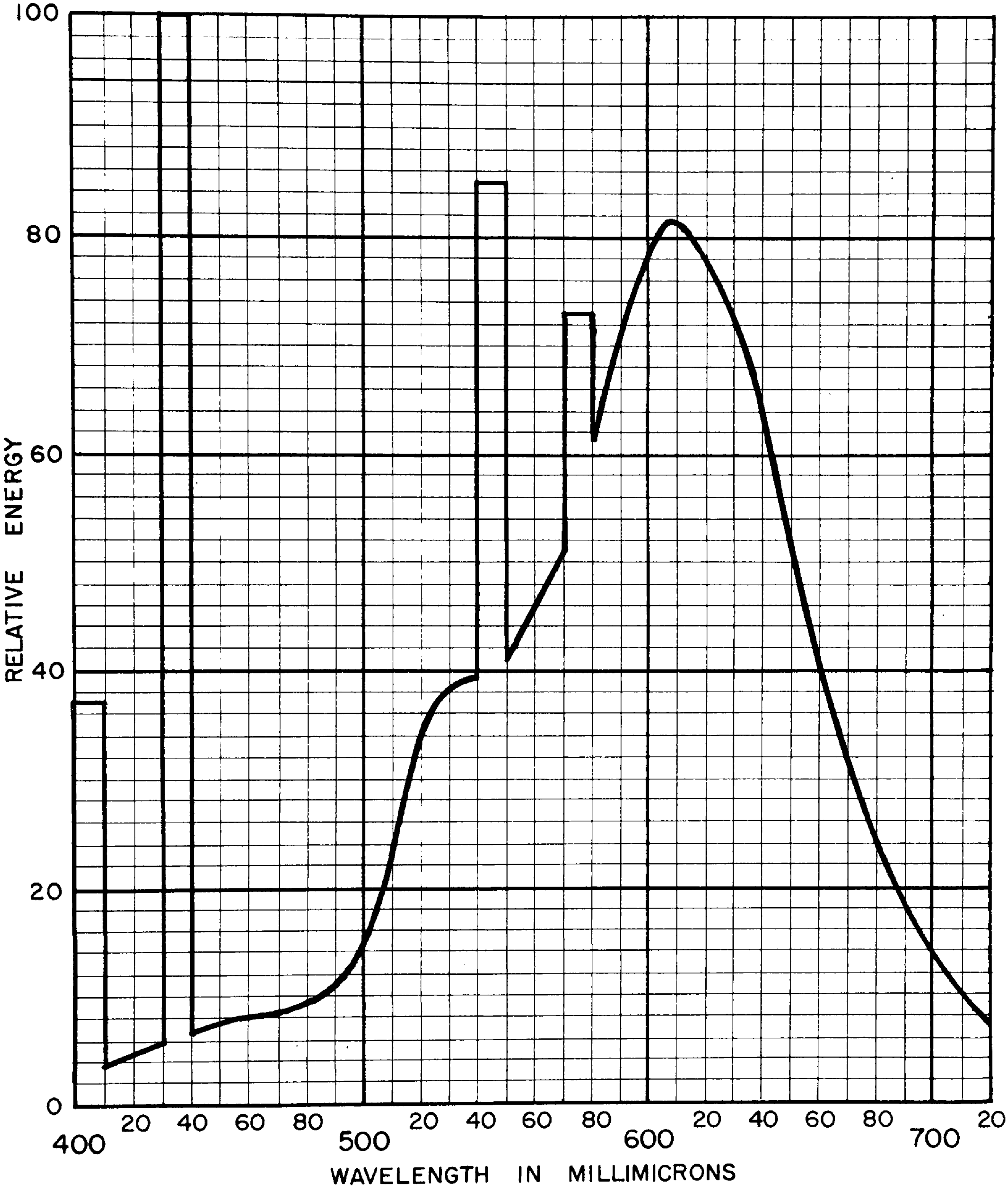


FIGURE 7. SPECTRAL DISTRIBUTION OF G.E. DELUXE WARM WHITE FLUOR. LAMP (BASED ON 40 W. T-12)

calculations for the respective illuminants and statements on spectral distribution apply to the tabular data (see Appendix III).

For an analysis of the spectral distribution of the luminous flux reflected (luminous reflectance) by cherries and defects under these illuminants, the spectral distribution of each illuminant was multiplied, waveband by waveband at 10 Mu increments, by the luminosity function and by the reflectance curves for cherries and defects. The resulting curves, which show the spectral distribution of the reflected luminous flux for cherries and the black and brown defects, are presented in Figures 8, 9, and 10. The area under these curves represent the luminous reflectance for the respective defect or cherry.

Table II gives the contrast ratio and the relative luminous flux reflected from the red ripe cherry per watt of power input for the three illuminants. The highest contrast ratio for under-color defects is obtained with the daylight fluorescent lamp and for black defects with the tungsten lamp.

The relative luminous flux reflected from red ripe cherries per watt (Table II) is used as a measure of the illuminant efficiency since maximum lightness of the cherry surface is needed for increasing the contrast ratio of dark defects. Also, this should be a better measure than lumens per watt since the reflected flux from the cherry is essential for visibility of the cherry itself. The relative luminous flux reflected per watt for the red ripe cherries was computed by multiplying $(\sum E_{\lambda} L_{\lambda} R_{\lambda})$ for cherries by the lumens per watt for the illuminant. The values L and R are both relative and E has units of microwatts per

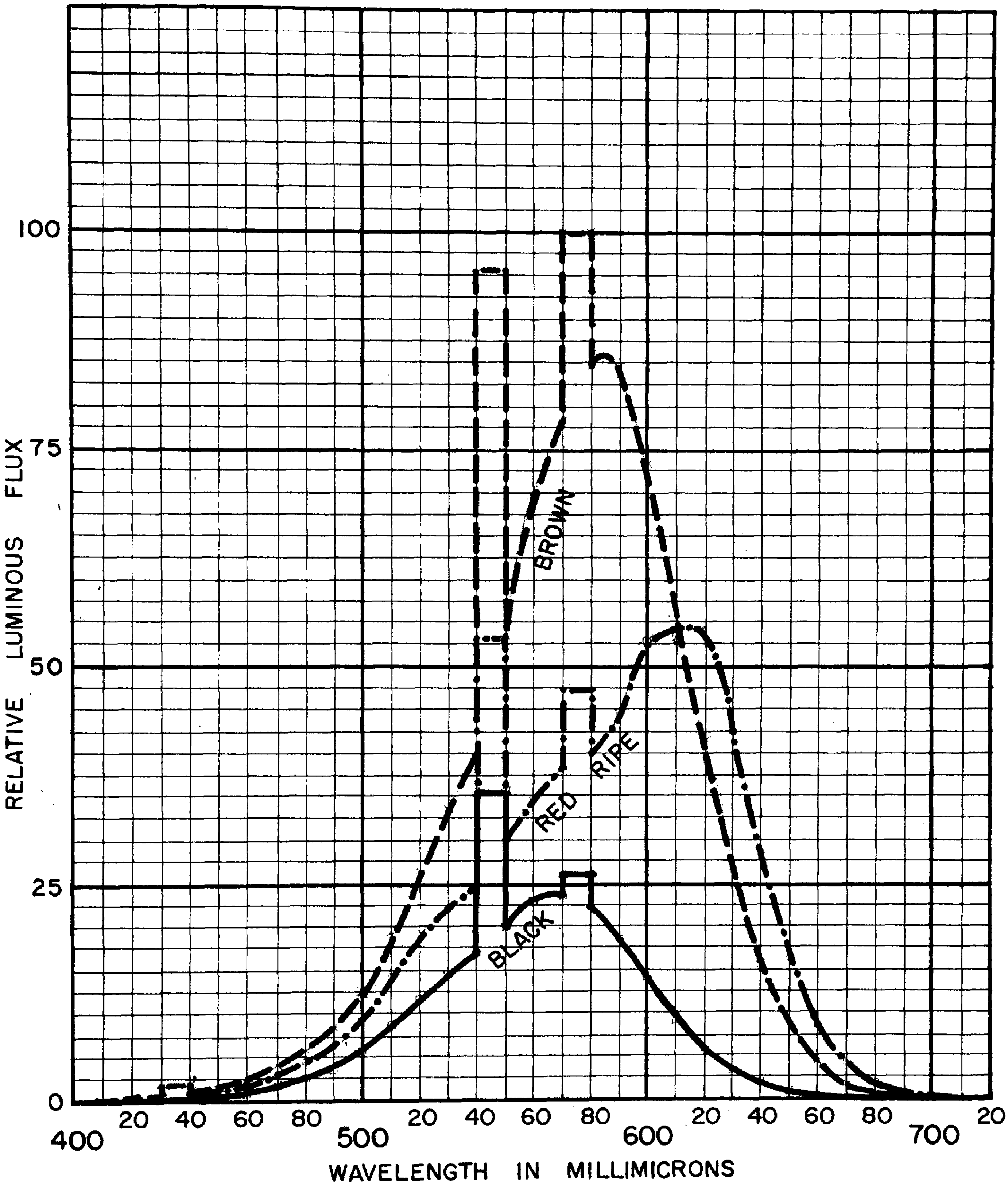


FIG. 8. SPECTRAL DISTRIBUTION OF LUMINOUS FLUX REFLECTED BY CHERRIES AND DEFECTS UNDER DAYLIGHT FLUORESCENT LAMP

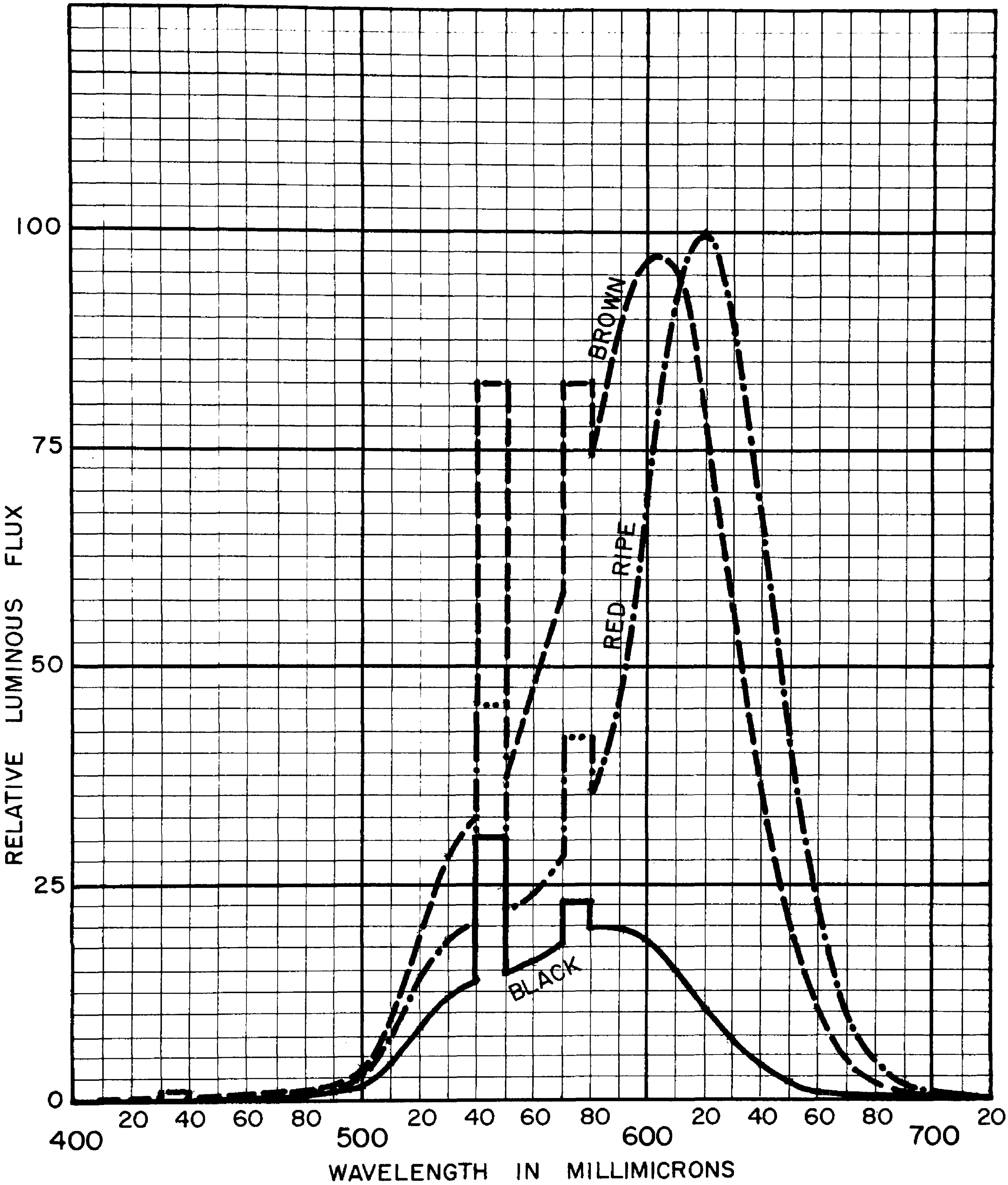


FIGURE 9. SPECTRAL DISTRIBUTION OF LUMINOUS FLUX REFLECTED BY CHERRIES AND DEFECTS UNDER DELUXE WARM WHITE FLUORESCENT LAMP

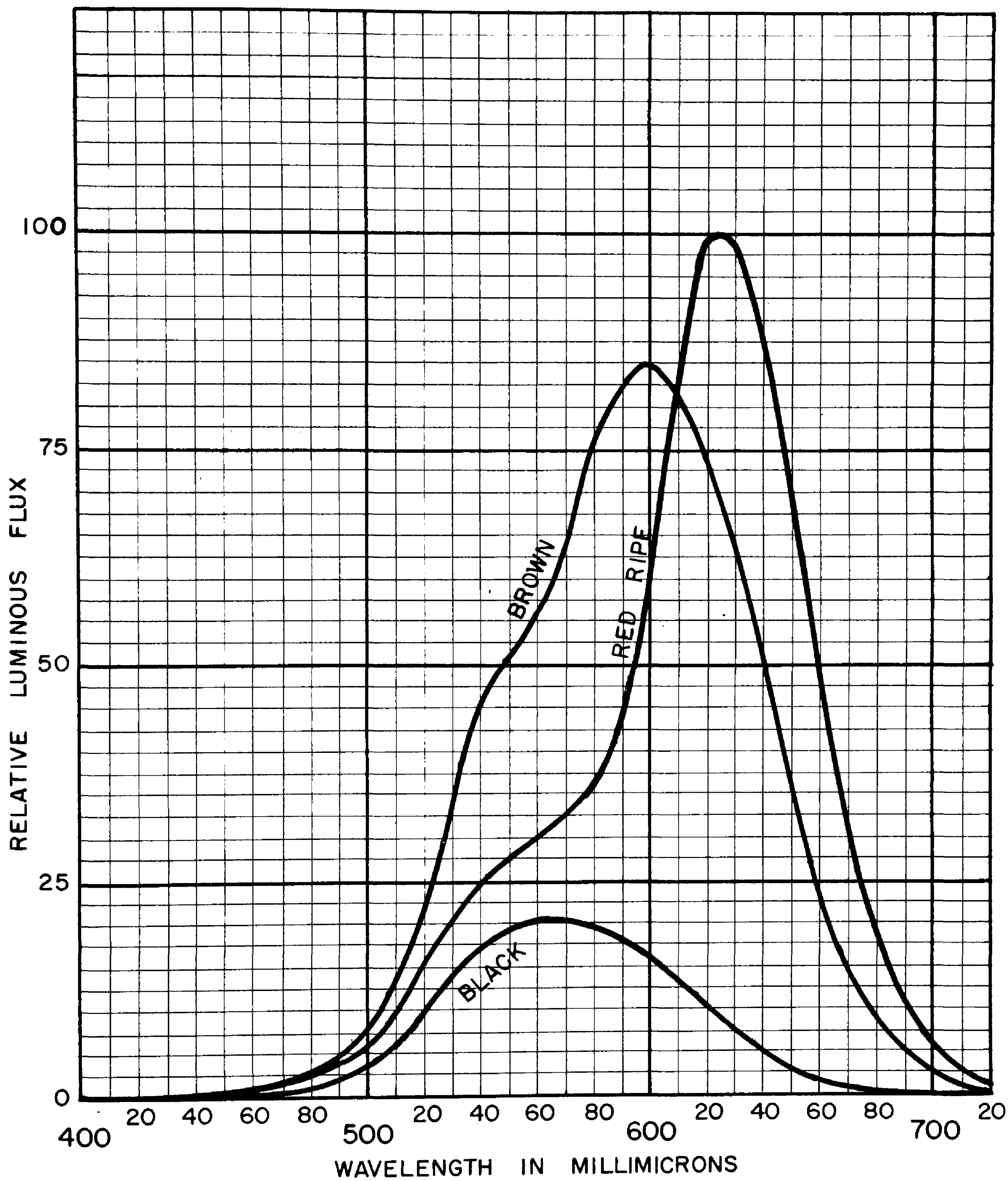


FIGURE 10. SPECTRAL DISTRIBUTION OF LUMINOUS FLUX REFLECTED BY CHERRIES AND DEFECTS UNDER 2910°K TUNGSTEN LAMP

TABLE II

Contrast Ratios and Relative Luminous Flux Reflected from Cherries Illuminated by Fluorescent or Incandescent Lamps

Illuminant	Contrast Ratio			Relative Luminous Flux Reflected from Red Ripe Cherries per Watt*
	Under-color Defects	Brown Defects	Black Defects	
G.E. Daylight Fluorescent	1/3.09	1/1.38	2.56/1	211
G.E. Deluxe Warm White Fluorescent	1/2.85	1/1.15	3.63/1	253
2910° K Tungsten (Approx. 150 Watt Filament Type Incandescent Lamp)	1/2.52	1/1.04	4.14/1	103

*This factor is used as a measure of illuminant efficiency since high luminous reflectance from the cherry surface is required to produce high contrast ratios for dark defects and for increasing visibility of the cherry itself.

10 Mu per lumen. Multiplying ($\sum E_\lambda L_\lambda R_\lambda$) by lumens per watt for the illuminant gave a value of relative luminous flux reflected per watt which can be compared for different illuminants. This comparison assumes that equal percentages of light from each illuminant is directed on the product.

Theoretical filters. Consider the elimination of particular portions of the spectrum by use of theoretical filters which absorb all the radiation in selected regions of the spectrum and transmit 100 percent of the light in other regions. There are two important factors to remember; namely, the contrast ratio should have a large departure from unity and the efficiency of the illuminant should be high. With these factors in mind let us consider the percent of the reflected luminous flux included by using only that part of the spectrum from some variable wavelength, λ, to 720 Mu. For this purpose the percent of reflected luminous flux included from λ to 720 Mu for cherries and defects are given by the curves of Figures 11, 12, and 13 for the three illuminants considered. Stated differently, these curves give the percent of the total reflected luminous flux (luminous reflectance) included by using only that part of the spectrum from λ to 720 Mu. Theoretically, the remainder of the illumination from λ to 400 Mu is filtered out completely.

For high illuminant efficiency and for increased visibility of the cherries, the wavelength, λ, on Figures 11 to 13 should be selected to include as much as possible of the reflected luminous flux from the cherry. Also, at the same wavelength, λ, it is desirable to read the black and brown curves at a minimum value of reflected luminous flux in order to maximize the contrast ratio. Since both conditions cannot be satisfied at once, a balance must be made between the reflected luminous flux from the cherry and the contrast ratio. As an aid in attaining this balance Figures 14 and 15 present the contrast ratios for black, under-color, and brown defects when the illumination from λ to 720 Mu is included. Figure 14 shows that very high contrast ratios are possible for the black defects although the luminous reflectance is reduced as more of the spectrum is eliminated (Figures 11 to 13). For brown and under-color defects the contrast ratio can be increased only slightly (Figure 15).

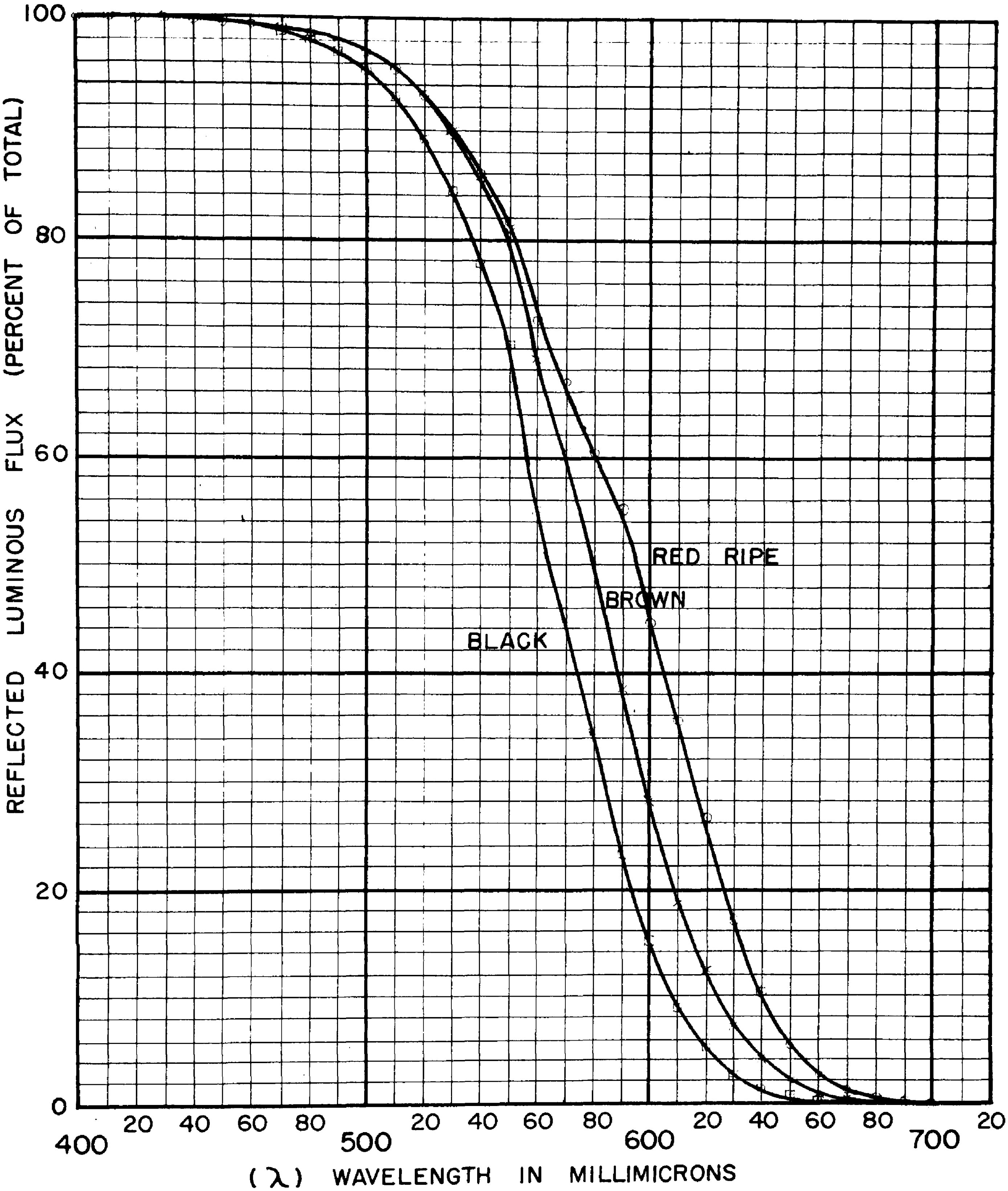


FIGURE II. PERCENT OF REFLECTED LUMINOUS FLUX INCLUDED FROM λ TO 720 Mu FOR CHERRIES AND DEFECTS UNDER DAYLIGHT FLUORESCENT LAMP

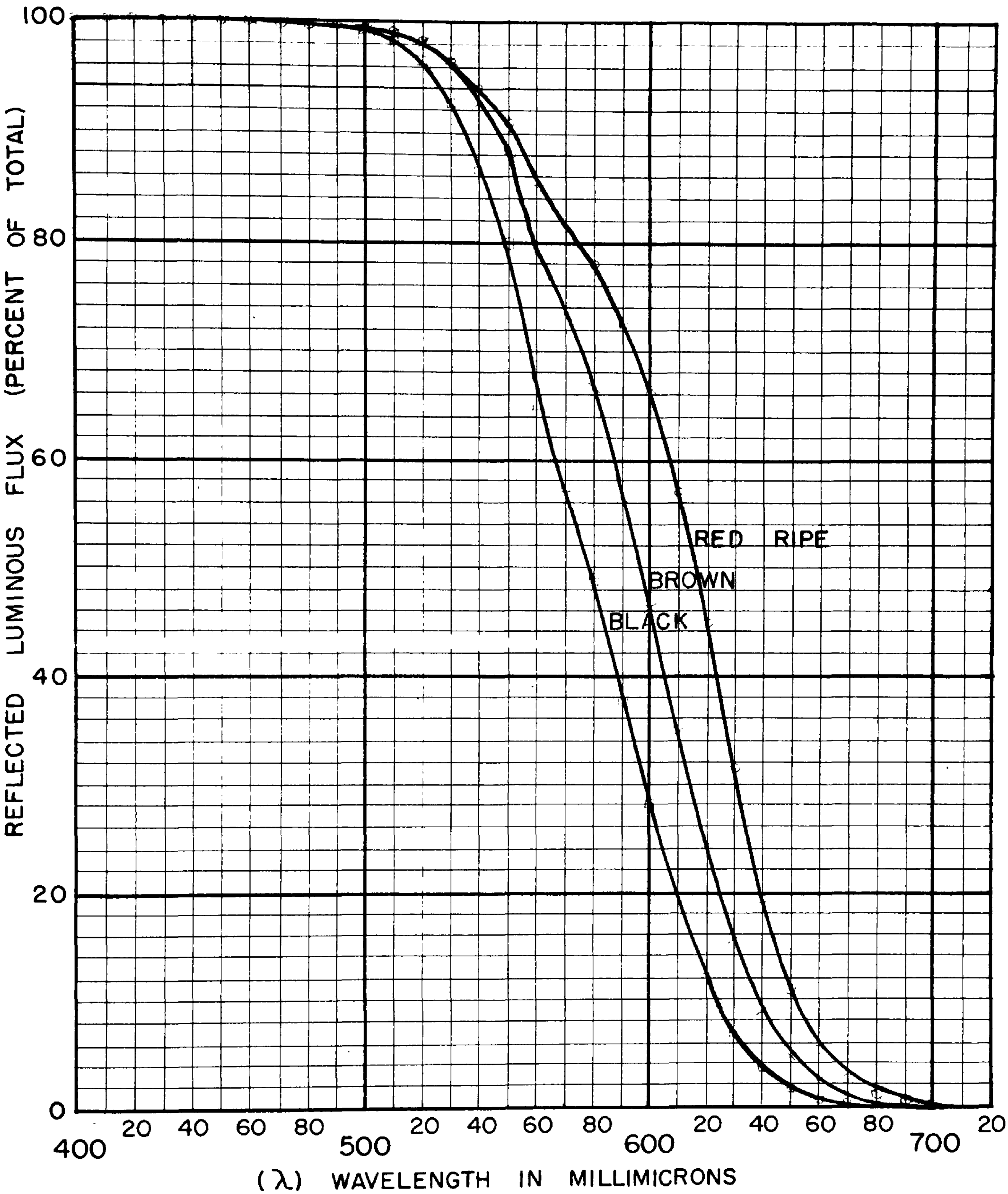


FIGURE 12. PERCENT OF REFLECTED LUMINOUS FLUX INCLUDED FROM λ TO 720 Mu FOR CHERRIES AND DEFECTS UNDER DELUXE WARM WHITE FLUORESCENT LAMP

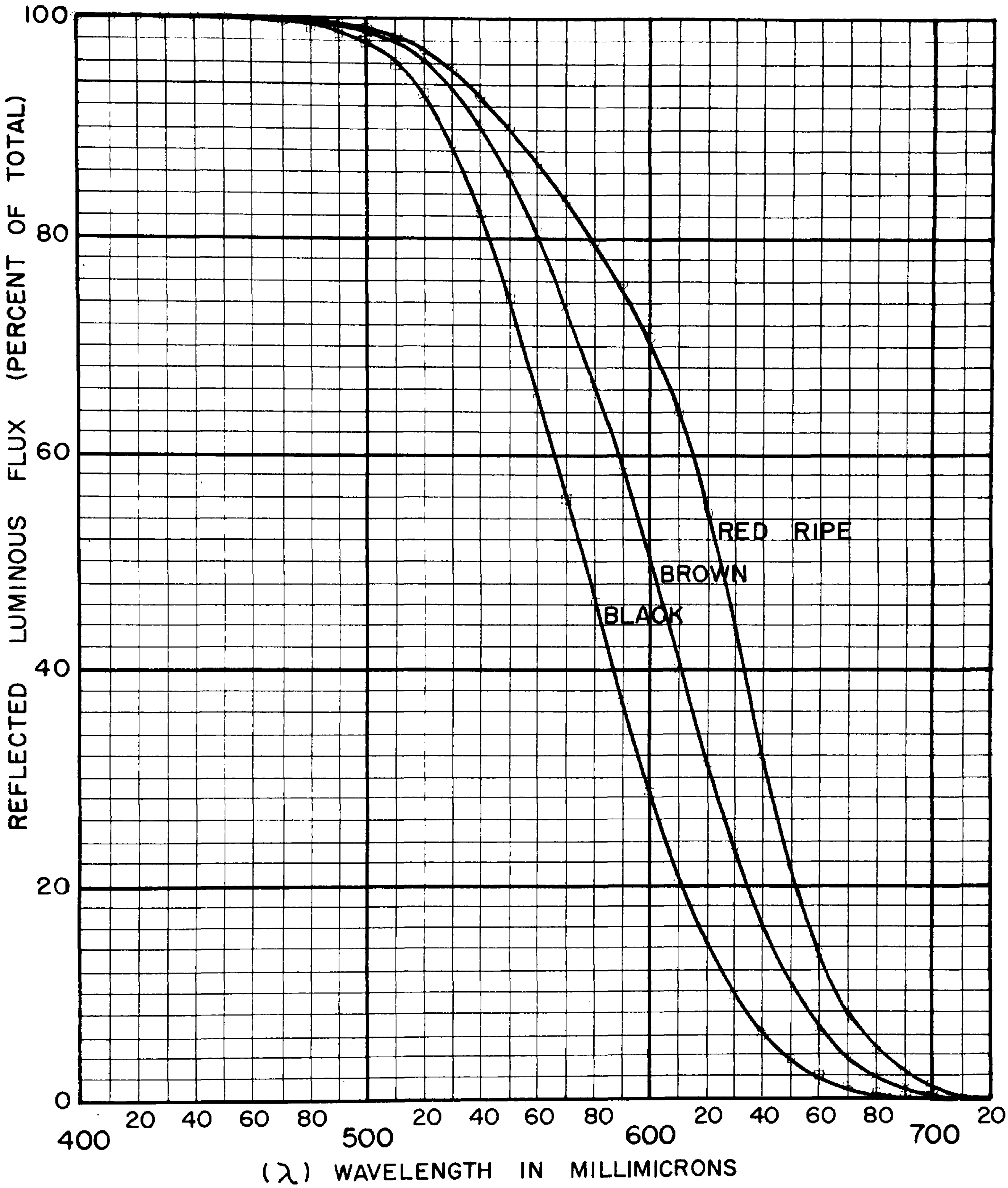


FIGURE 13. PERCENT OF REFLECTED LUMINOUS FLUX INCLUDED FROM λ TO 720 Mu FOR CHERRIES AND DEFECTS UNDER 2910°K TUNGSTEN LAMP

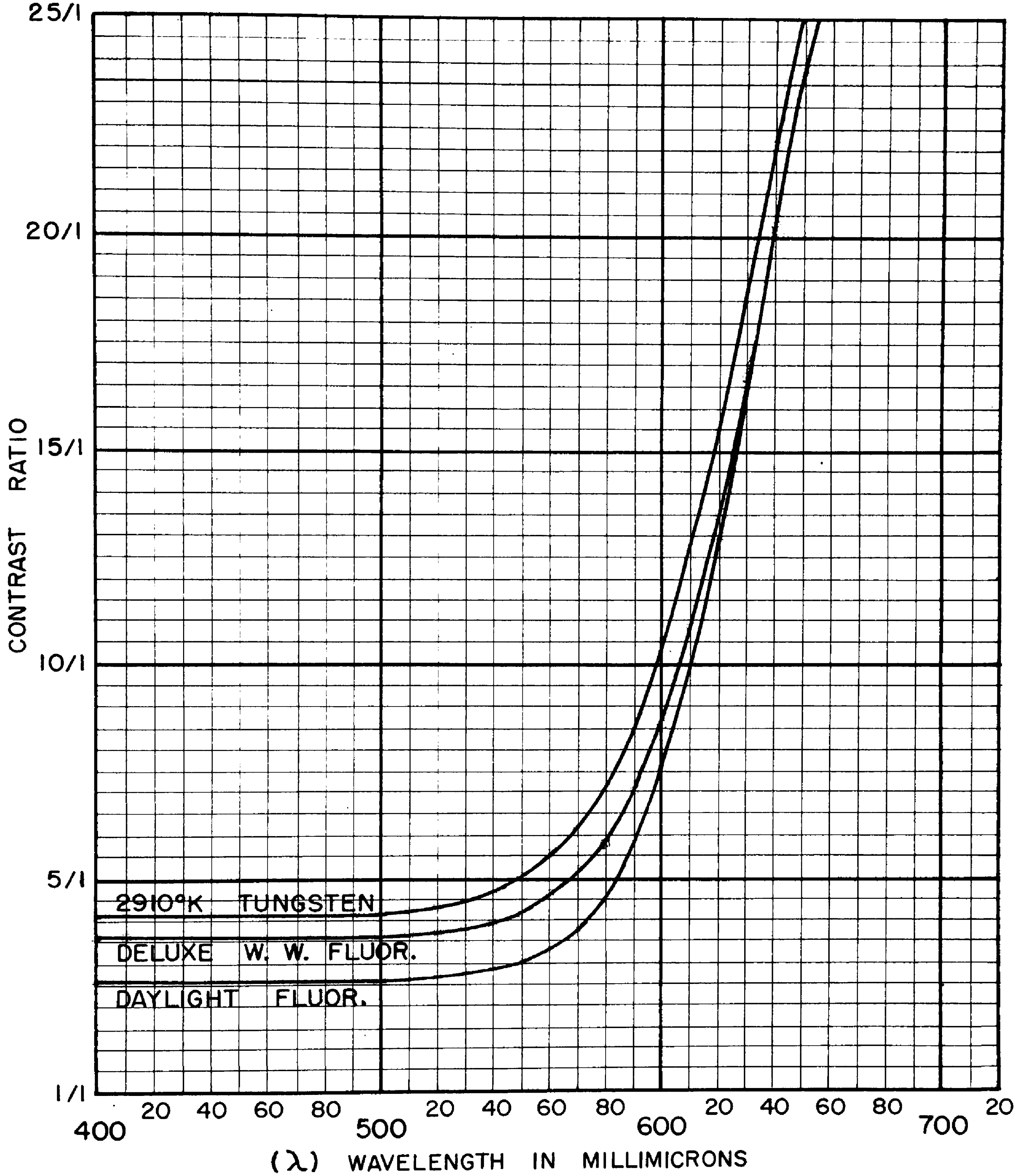


FIGURE 14. CONTRAST RATIO FOR BLACK DEFECTS WHEN INCLUDING REFLECTED LUMINOUS FLUX FROM λ TO 720 Mu

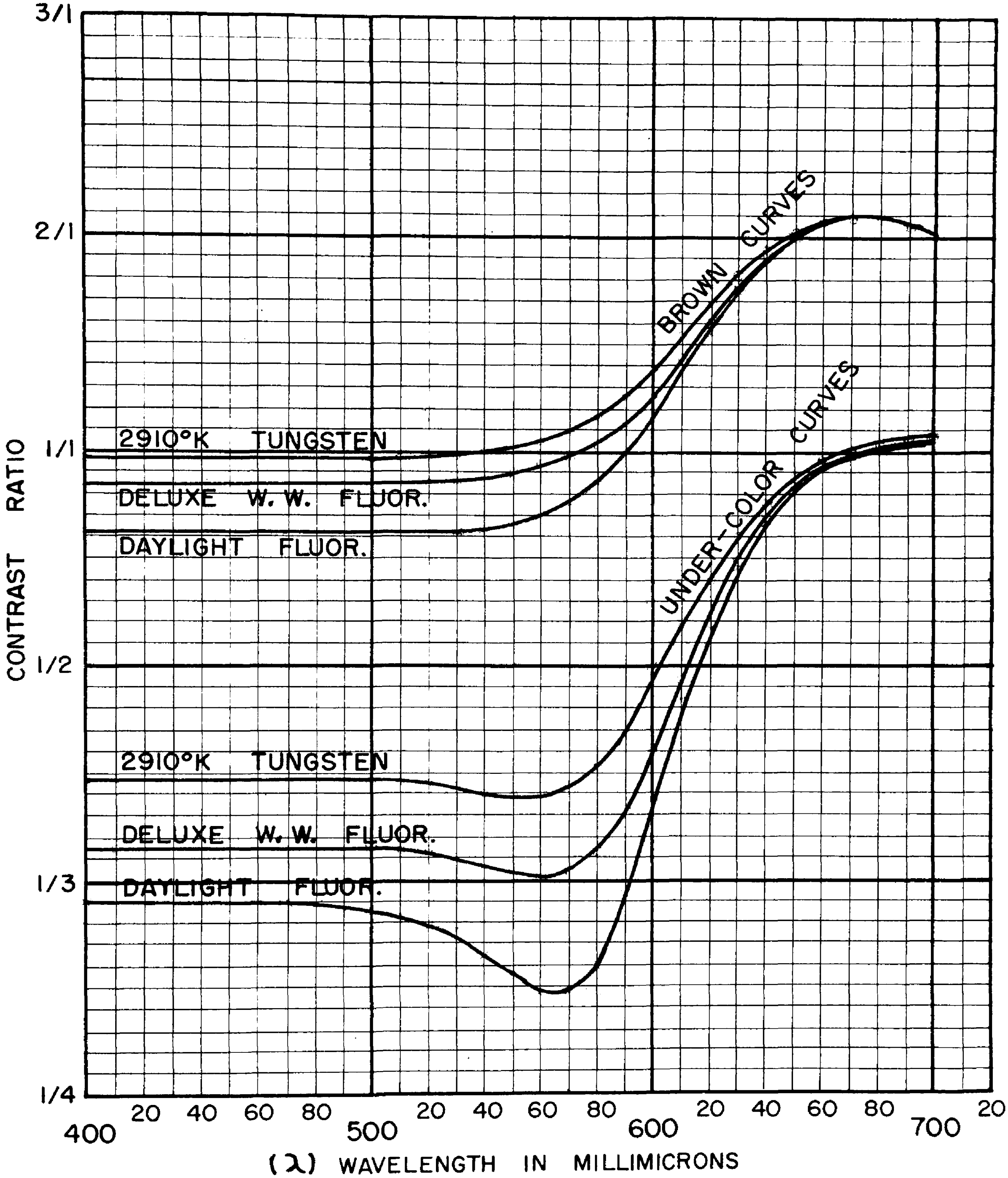


FIGURE 15. CONTRAST RATIOS FOR BROWN AND UNDER-COLOR DEFECTS WHEN INCLUDING REFLECTED LUMINOUS FLUX FROM λ TO 720 Mu

Together Figures 11 to 15 show the various combinations of contrast ratios and percent of luminous reflectance from cherries and cherry defects which are illuminated by that part of the spectrum from λ to 720 Mu with the specified illuminant. These curves show that the 2910° K tungsten lamp possesses the greatest possibility of increasing the contrast ratio of dark defects. Using the curves for the tungsten lamp, if that part of the illumination from 400 to 610 Mu were eliminated, 64 percent of the total luminous reflectance from the red ripe cherries would be included (Figure 13) and the contrast ratios for black and brown defects would be 12.7/1 and 1.55/1, respectively (Figures 14 and 15). In addition, the elimination of this portion of the spectrum would greatly reduce the adaptation level of the eyes. This lower level of adaptation should provide improved visibility of the cherries since a lower level of adaptation would be closer to satisifying the condition of uniform field lightness.

This same analysis may be applied to the fluorescent illuminants but with less success in including an equal percent of the reflected luminous flux from red ripe cherries and at slightly lower contrast ratios for the same wavelength, λ.

Since the contrast ratio for the under-color and brown defects was increased only slightly, Figure 16 is presented in order to consider the use of the portion of the spectrum from λ to 400 Mu. From these curves the maximum contrast ratio for brown and under-color defects is 1/1.8 and 1/3.9, respectively. Using the G. E. daylight fluorescent lamp without filters, the corresponding ratios are 1/1.4 and 1/3.1, respectively. Observing again Figure 5, it appears that no large

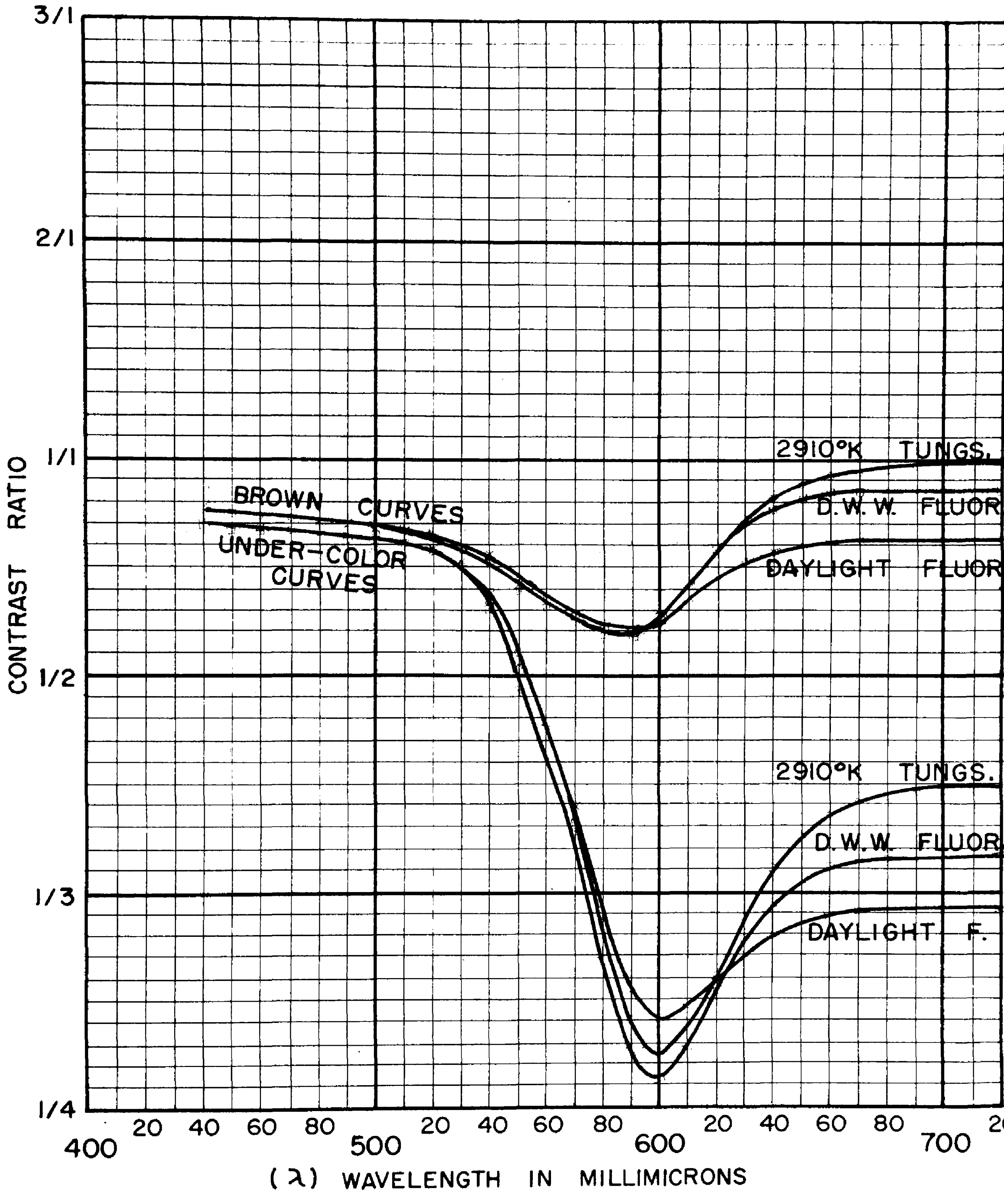


FIGURE 16. CONTRAST RATIOS FOR BROWN AND UNDER-COLOR DEFECTS WHEN INCLUDING REFLECTED LUMINOUS FLUX FROM λ TO 400 Mu

increases in contrast ratio are possible for these defects by using other portions of the spectrum.

In summary, by application of filters to fluorescent lamps, the contrast ratio for dark defects may be increased considerably and at the same time a large part of the reflected luminous flux from the red ripe cherry may be included. The 2910° K tungsten lamp shows the greatest promise in accomplishing these objectives. For the brown and under-color defects it appears that the contrast ratio may be increased only slightly by use of filters; the G. E. daylight fluorescent lamp without filters gives nearly as good results as illuminant-filter combinations.

Commerically available filters. In order to test the effect of increasing the contrast ratio on the perceptibility of cherry defects, it was necessary to obtain filters which would increase the contrast ratio for the dark defects, and compare the illumination produced in this manner with regular illuminants. It was decided to use low cost gelatine filters for this purpose and a number of filter samples were obtained from manufacturers. A sample of cherries and defects was obtained and viewed by placing various filters over the eyes and observing the apparent differences in lightness contrast. A total of seventy filters were used in the observations. Twelve filters were chosen and their spectral transmittances obtained with a spectrophotometer.* Also, four wratten filters with known spectral transmittances were provided by the Eastman

---

*Transmittance curves were run on the same spectrophotometer as discussed in the appendix for reflectance curves. Band width was maintained at 12.5 Mu or less.

Kodak Company. The brown and black defect contrast ratios obtained by applying these sixteen filters to G. E. deluxe warm white fluorescent lamps are listed in Table III. The calculations were made at 20 Mu increments. Since this increment is rather large these ratios are considered only as approximations for selection of several filters for field test.

The highest range of contrast ratios is approximately 1.6/1 for brown to 11.3/1 for black defects for filter B-29. This and other contrast ratios show that it is possible to increase the contrast ratio by use of commerically available filters. From the group of filters considered filters B-7, B-11, B-23, and B-67 were selected for field tests. In making these selections the contrast ratios, luminous flux reflected from the red ripe cherries, and the appearance of the cherries and defects by filtered light were considered.

TABLE III

Contrast Ratios and Luminous Flux Reflected from Cherries Illuminated by G. E. Deluxe Warm White Fluorescent Lamp with Commercial Filters

Filter Used to Cover Illuminant*	Contrast Ratio		Relative Luminous Flux from Red Ripe Cherries per watt **
	Brown Defect	Black Defect	
none	1/1.15	3.14/1	253
K-9, yellow	1/1.15	3.22/1	220
K-15, deep yellow	1/1.15	3.38/1	210
K-25, red	1.22/1	7.44/1	134
K-29, deep red	1.62/1	11.28/1	87.6
B-6, rose pink	1.01/1	5.05/1	161
B-7, dark rose pink	1.04/1	5.52/1	148
B-10, light magenta	1.13/1	5.70/1	117
B-11, medium magenta	1.19/1	6.60/1	114
B-13, rose	1.49/1	9.30/1	100
B-20, light purple	1.48/1	6.50/1	38.4
B-23, medium purple	1.41/1	5.90/1	52.5
B-59, amber	1/1.11	4.00/1	186
B-60, dark amber	1/1.06	4.36/1	170
B-63, spec. lt. red	1.14/1	6.35/1	133
B-65, medium scarlet	1.25/1	7.50/1	109
B-67, fire red	1.41/1	9.40/1	94

* Filter numbers are those designated by the manufacturer, Eastman Kodak Co., Rochester, N. Y.; Brigham Gelatine Co., Randolph, Vermont. "K" indicates Kodak and "B", Brigham.

** Calculations were made at 20 Mu increments.

PERCEPTIBILITY OF DEFECTIVE TOMATOES

Reflectance curves for red ripe tomatoes are presented in Figure 17. In the discussion of tomato curves (Appendix I) it is noted that considerable specular gloss entered into the measurements. Therefore, the curves actually should show lower reflectance by approximately 5 to 15 percent. The lower value applies to the short wavelengths and the higher to the long wavelengths. Laying aside this fact, the shape of the red ripe tomato curves are similar to the red cherry curves. Some of the defects are in the same range as the brown to black defective cherries. No reflectance curves were run for defective tomatoes; however, the reflectance curves for red ripe tomatoes indicate that the analysis used for dark defective cherries should also apply to dark defects on tomatoes.

Observations were made at two tomato processing plants using filters over the eyes to simulate chromatic illumination. Dark defects and green spots appeared very dark and the tomatoes much lighter when using the same filters as employed in the cherry analysis. It was noted that the green spots should have appeared darker since the filters transmitted very little green light. Thus, it is concluded that dark or green spots on ripe tomatoes may be enhanced by use of filters similar to those listed for cherries.

The problem of removing defective tomatoes is not as acute as the cherry sorting problem because fewer tomatoes pass the observers per unit time and the defective spots are usually larger.

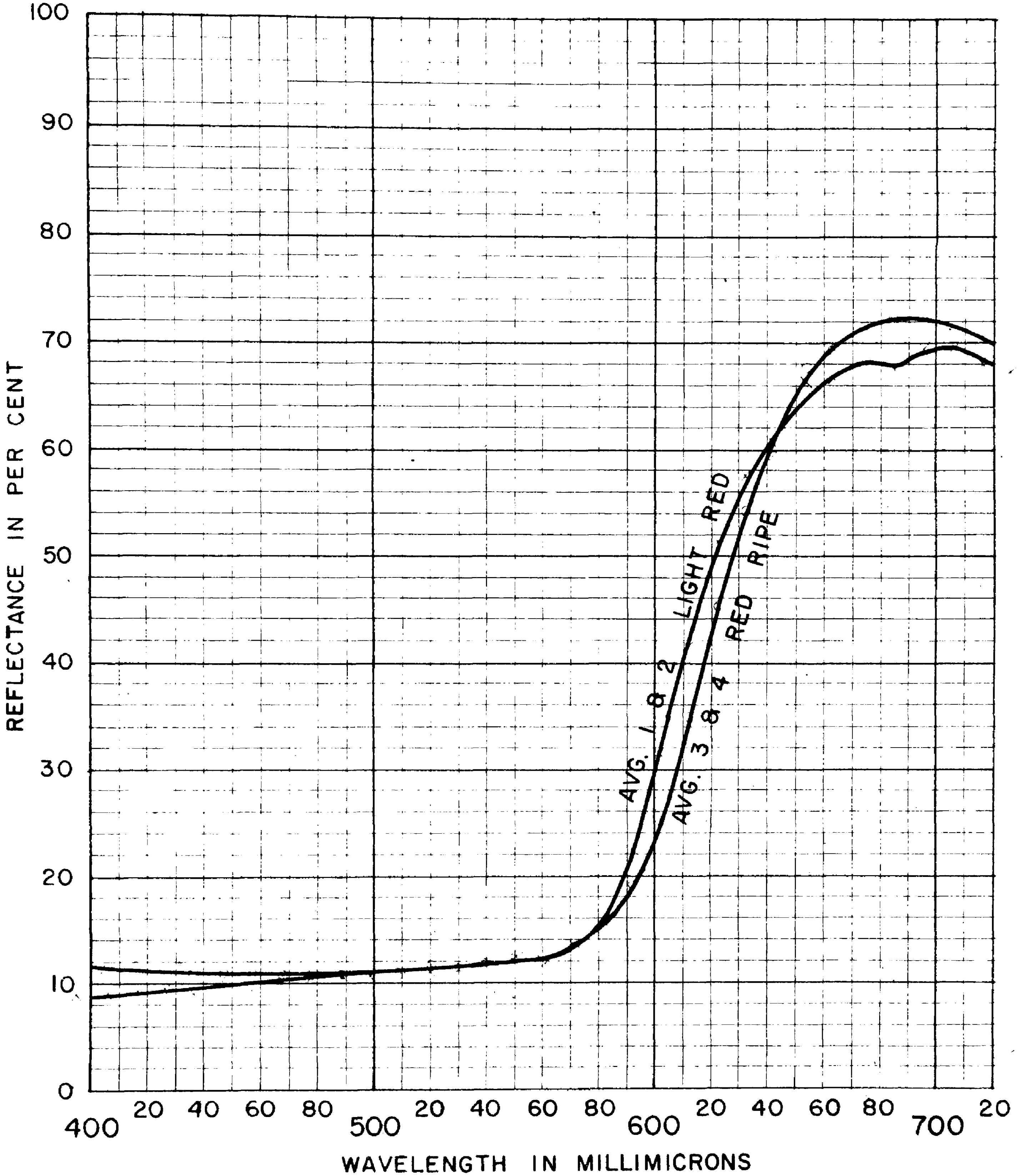


FIGURE 17. 45°-0° SPECTRAL REFLECTANCE CURVES FOR MICHIGAN GROWN TOMATOES

COLOR GRADING TOMATOES

The color grading problem for tomatoes was divided into two parts in the introduction: 1. grading tomatoes which are shipped into the state during the winter months into four color grades (green, light pink, pink, and red) and 2. grading Michigan tomatoes for canning into grades one, two, and culls.

For the former problem, observations were made of the various color grades of tomatoes by using filters over the eyes to simulate chromatic illumination. The filters were selected from the college stores supply by use of a wedge interference filter which showed the color of illumination transmitted by each filter. The filter colors were straw, medium amber, pink, light red, light magenta, dark rose purple, light blue, and green.

In general, there was little effect on color or confusion of color when filters were used over the eyes. Filters of low saturation gave only small changes in colors and those of high saturation caused confusion of certain colors. It appeared that none of the filters used would be suitable for grading tomatoes into four color grades.

After reflectance curves of tomatoes were obtained it was noted that the reflectance of the color grades varied with respect to each other in several different regions of the visible spectrum (Figure 18). Besides, the reflectance for pink tomatoes had considerable variation (Figure 40). Thus, it did not appear possible to enhance differences between four color grades by any single chromatic illuminant. It is not

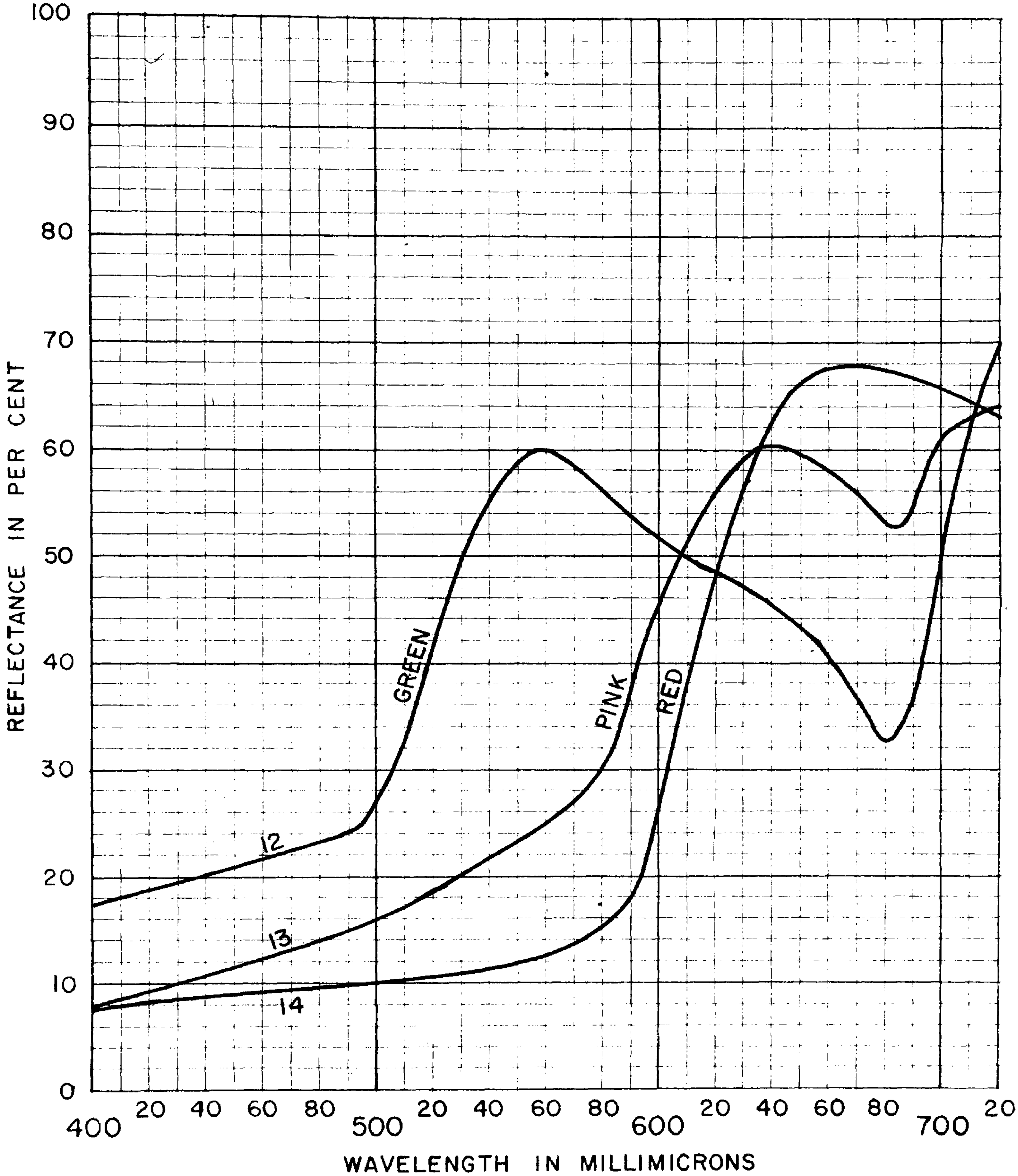


FIGURE 18. 45°-0° SPECTRAL REFLECTANCE CURVES FOR FLORIDA GROWN TOMATOES

practical to use two or three types of illumination which would specialize sorting along the belt since the relative number of each grade is quite variable. Referring to the previously mentioned color principles, an illuminant with a spectral distribution throughout the visible spectrum should be used. No conclusions can be drawn as to whether this illuminant should be rich in a particular portion of the spectrum.

For analysis of the problem of grading Michigan grown tomatoes into grades one and two, reflectance curves for the Rutger's variety were run. Two curves from tomatoes of each of these grades are presented in Appendix I. The average for each type is shown in Figure 17; red ripe represents number one tomatoes for canning and light red number two tomatoes.

From these curves it appears that the illuminant should radiate throughout the visible spectrum but may be especially rich in energy in the region of 580 to 640 Mu. However, before making any definite recommendations, additional reflectance curves should be run since these curves are based on only two samples and their difference is small. This is necessary in order to be sure that the correct reflectance curve for tomatoes of the two grades has been obtained.

It is noted that the workers use firmness as a criterion for separating these grades and that some operators are not aware of any particular grading difficulty. Perhaps the nature and need of improvements in this type of grading should be investigated.

PRODUCT ROTATION

It has already been shown that viewing the entire surface of the product is an important factor in attaining high sorting efficiency. One common method of rotating large fruit (apples, potatoes, etc.) is the roller conveyor. This piece of equipment brings most of the surface of the fruit into the worker's view and undoubtedly the sorting efficiency is higher than attained on sorting belts which only translate the product. Another method of rotating the larger fruit, spaced rods which travel at a different speed than the sorting belt, was used on a test machine by Malcolm and DeGarmo (11). Peterson (5) reported that several methods had been attempted in cherry processing plants for rotation of smaller fruit (approximately three-quarters inch in diameter) but no satisfactory solution was presented. The work presented here was performed with cherries and should apply also to berries and other small spherically shaped fruit.

Fourteen devices were considered originally for rotating cherries. A sketch and description of operation was prepared for each. These were discussed with many interested persons and four devices were chosen for preliminary tests.

Preliminary Test Using Marbles

In the laboratory four devices were tried for rotating cherries on sorting belts. Three of the devices, a rotating roller and two types of deflection plates, are shown in Figure 19. The fourth device consisted of a one inch pipe with a slit cut along one side. Air pressure was

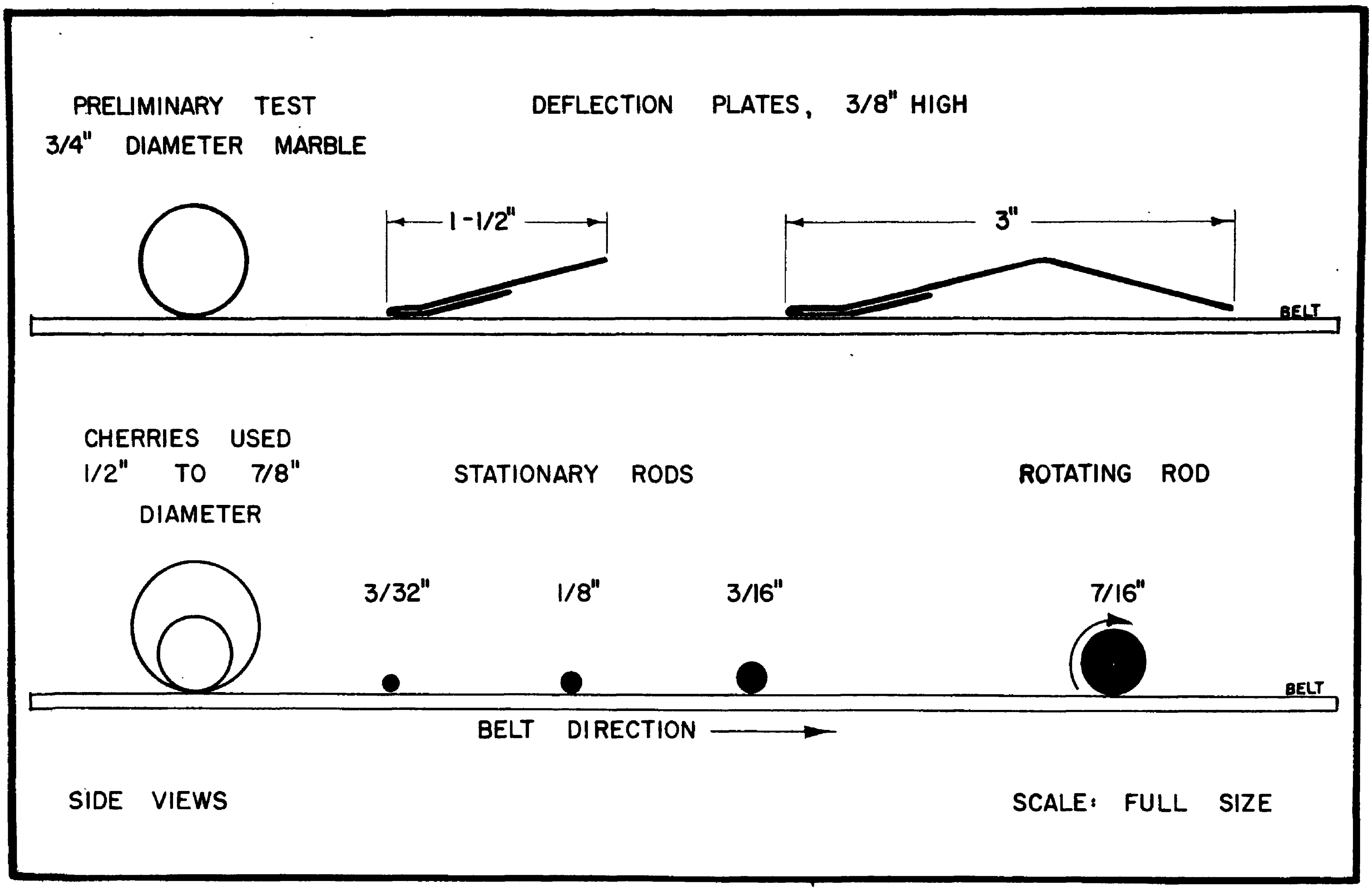


FIGURE 19. DEVICES FOR ROTATING CHERRIES ON SORTING BELT

applied to the pipe and a sheet of air directed from the slit onto the product. The impact of the high velocity air caused the marbles to roll provided there was an empty space on the belt. However, air pressure did not appear to be economically feasible and the workers would probably object to the air blast.

Preliminary tests using the first three devices to rotate 3/4 inch diameter marbles at various belt speeds are shown in Table IV. Since marbles were uniform in size and had different surface characteristics than cherries, these data were considered only as an indication of the efficiency for rotation of cherries.

Rotation of Cherries

During the cherry season two devices were tested for rotation of cherries on sorting belts and a third device was tried in the laboratory.

TABLE IV

Percent of Three-Quarter Inch Diameter Glass Marbles Rotated by Devices on Sorting Belt

Belt velocity ft./ min.	$1\frac{1}{2}$" Defl. Plate		3/8" Diameter Rotating Rod *		3" Defl. Plate	
	Rotated 90° or more	Rotated 150° or more	Rotated 90° or more	Rotated 150° or more	Rotated 90° or more	Rotated 150° or more
11.9	50	30	57	45	27	10
20.0	59	42	95	91	21	8
25.0	19	8	98	82	31	11
30.0	37	24	68	50	52	31

* Peripheral velocity of rotating rod was 37.4 ft/min.

Rotating rod. A roller was mounted across the belt and rotated to cause the cherries to go over it (see Figure 19). The roller was made of a 5/16 inch steel rod wrapped with friction tape which served as a friction coating (7/16 inch overall diameter). The friction coating turned the cherries as they were lifted over the roller. The peripheral velocity of the roller ranged from 25 to 60 feet per minute. Belt velocity was 24 feet per minute.

The procedure for tests was as follows. Cherries were placed on the belt one layer deep in front of the roller and the belt was run for 6 inches in order to minimize friction on the stationary fruit guards (sides of table) during the test. A mixture of white paint pigment and flexible collodion was used to paint two rows of 50 cherries each across the belt. This paint dried in one or two minutes and the belt was started. When both test rows had passed over the roller the belt was stopped and a count made of all cherries rotated 90° or more and those rotated 150° or more. Another count of the total number of cherries was made as the painted cherries were removed from the unpainted cherries before the next test. It should be noted that the 90° and 150° are only approximate since the writer's judgement was used to determine this factor. An effort was made to count each test in a similar manner. Plates II and III show pictures which were taken before and after rotation of cherries with the rotating rod.

Results of the tests with the rotating rod are shown in Figure 20. The efficiency of this device is shown by two curves which give the percent of cherries rotated 90° or more and the percent of cherries rotated 150° or more. The peripheral velocity of the roller was twice the belt velocity at maximum efficiency.

PLATE II. Before Test of Rotating Rod. Fifty cherries were painted in each row.

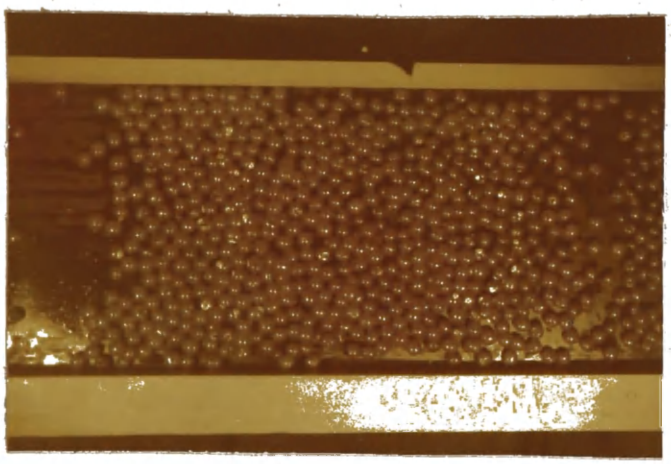


PLATE III. After Test of Rotating Rod. Many of the one hundred painted spots were turned under.

PLATE IV. Stationary Rod. Mounted on Sorting Belt in Processing Plant. This belt is lightly loaded with cherries compared to Plate I.

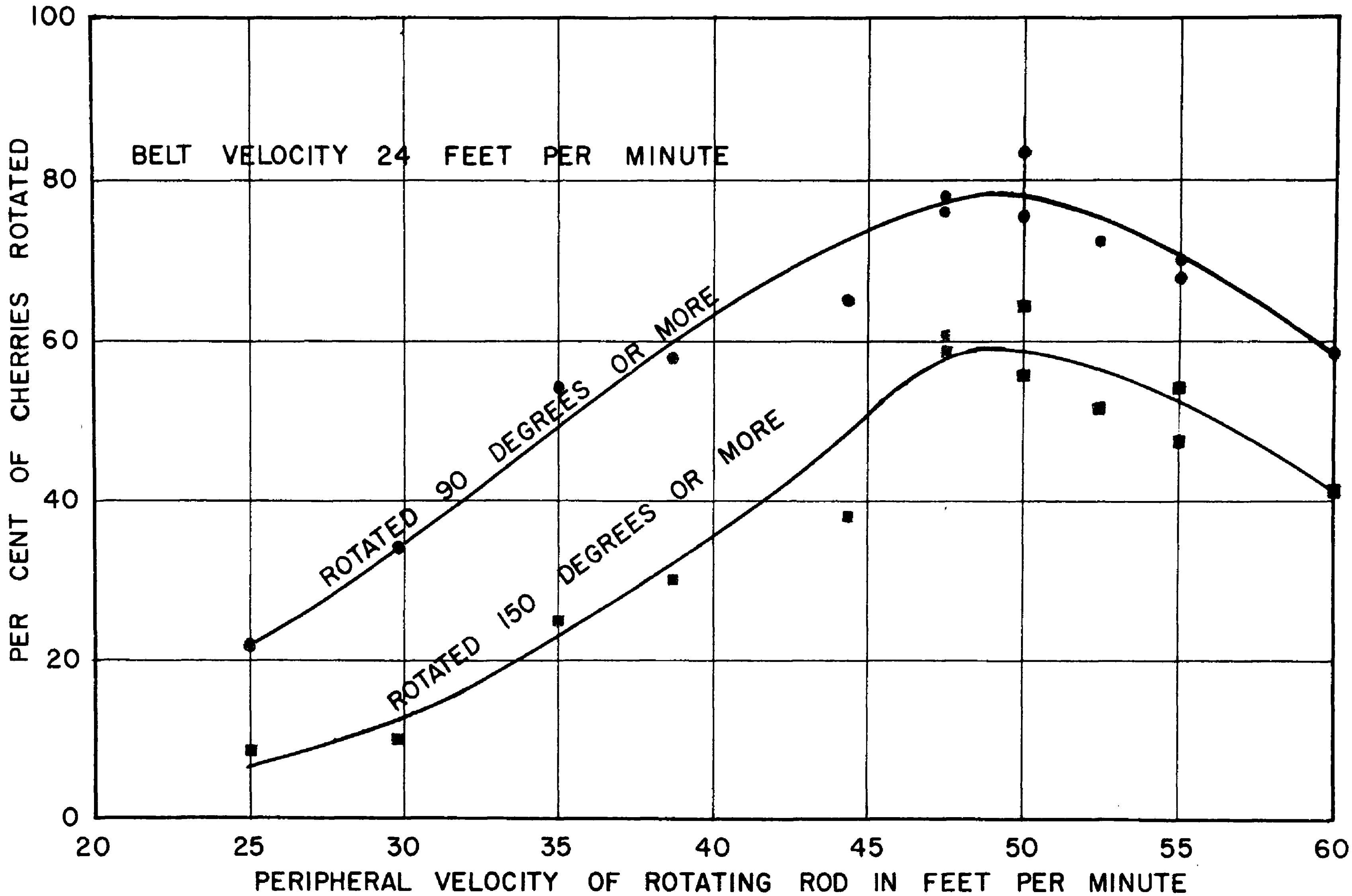


FIGURE 20. ROTATION OF CHERRIES ON SORTING BELT WITH ROTATING ROD

Stationary rods. Tests were conducted on three sizes of stationary rods (Figure 19) in the laboratory and at one processing plant using red tart cherries. At the plant the 1/8 and 3/16 inch rods were left on the belt during actual sorting operation (Plate IV.). They operated satisfactorily except for catching a small amount of trash. Cherries rotated in front of the rod until other cherries forced them over the rod. This appeared to be responsible for much of the turning action.

The procedure for testing the stationary rods was similar to that used for the rotating rod. The correct percent of the belt covered with cherries was obtained by covering one secton of the belt with one full layer and then spreading the cherries to twice or four times this area to obtain 50 percent and 25 percent cover, respectively. The rods were mounted tightly against the belt and the belt supported under the rod by a flat metal plate.

Preliminary tests showed that the 3/32 inch rod was rather inefficient; therefore, it was eliminated. The data for the 1/8 inch and the 3/16 inch rod are shown in Figure 21. Each plotted point for "variable belt speed test" represents 100 cherries and each point for the "percent of belt covered test" represents 200 cherries for the 1/8 inch rod and 400 cherries for the 3/16 inch rod.

From this data it appears that the 3/16 inch diameter rod is slightly better than the 1/8 inch rod when the belt is not fully covered with cherries. It is shown by the left group of curves that the efficiency decreases as the belt speed increases. Also both groups of curves indicate that efficiency is improved by decreasing the concentration of cherries on the belt.

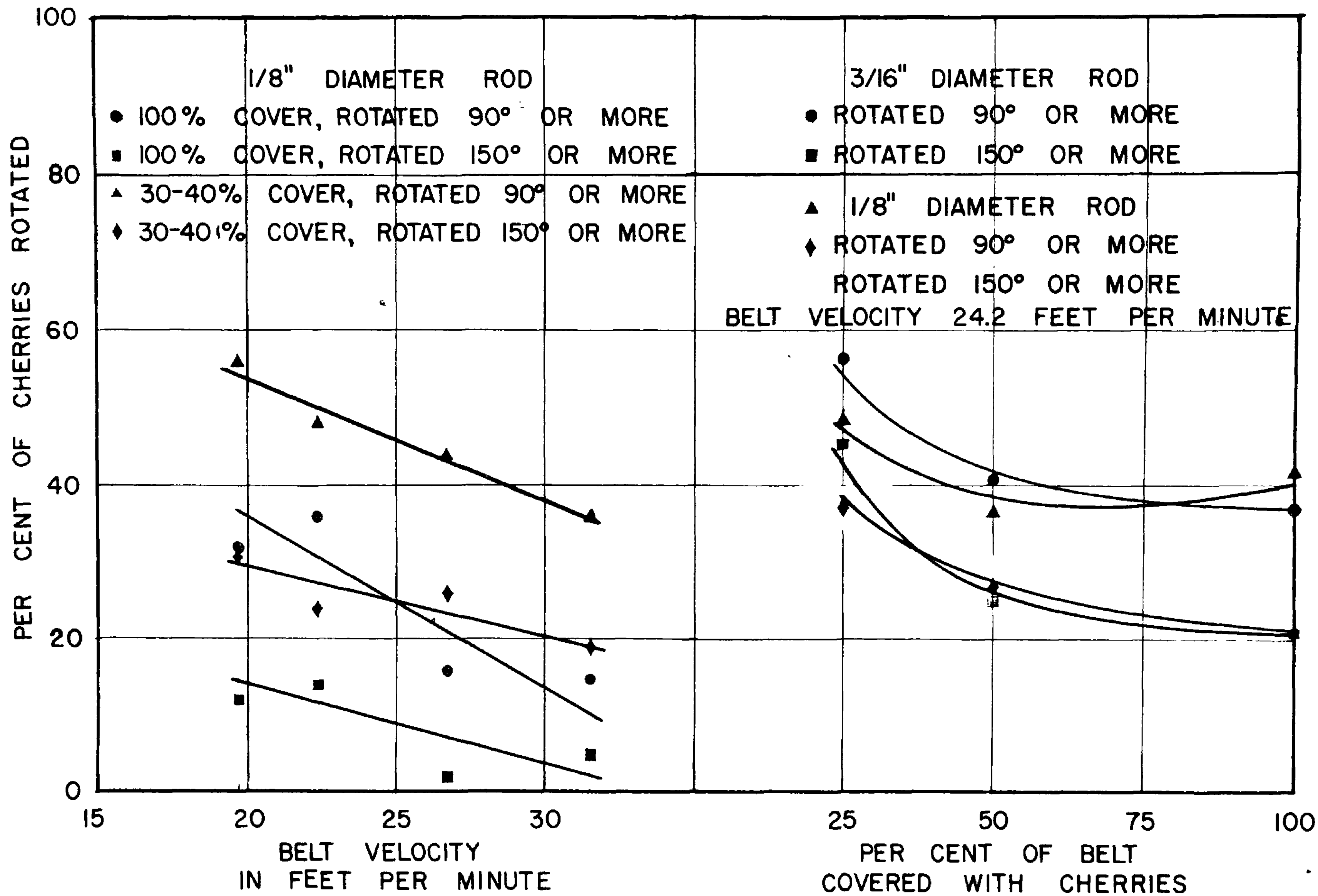


FIGURE 21. ROTATION OF CHERRIES ON SORTING BELT WITH STATIONARY ROD

The two sets of data in Figure 21 are not in close agreement, especially for 100 percent cover. This is attributed to the fact that the cherries used in the test for the left set of curves were more uniform in size. In any case, the efficiency is rather low when the belt is fully covered with cherries.

Deflection plates. No actual tests were conducted on the use of deflection plates to rotate cherries; however, a deflection plate was inserted on the belt in the laboratory and cherries run over the plate. In the limited observations, the cherries went over the plate without crushing. This type of device may have some advantage over the stationary rod since its larger friction surface should have a tendency to cause more rotation than that of the stationary rod, especially if the belt is fully covered. However, it may have greater tendency to collect trash and become objectionable from the standpoint of sanitation. Some dead cherry stems were caught under the stationary rod during regular plant operation. If the deflection plates could be mounted with hinges in order to facilitate cleaning, they may be as satisfactory in this respect as the stationary rods.

OTHER FACTORS IN SORTING EFFICIENCY

There are a number of factors other than lighting and rotation of the product which may affect the sorting efficiency of cherries and tomatoes. Malcolm and DeGarmo (11) investigated the nine factors listed in the review of literature.

Rate of Inspection

The highest rate of inspection tested by Malcolm and DeGarmo (11) was 500 specimens per minute. The inspection rate for cherries is at-least twice this value in many plants. This is expected since cherries are smaller. However, it appears that a better standard for the rate of inspection would be the area of fruit passing a worker per minute. Such data would have more general application since the size of fruit would not be included in the measure of rate. It seems that this measure should be in agreement with the idea of cone of distinct vision and/or pattern of eye movement.

Another basis for rate of inspection might be the number of defective specimens passing a worker per unit of time. If this factor were defined, the processor, knowing the approximate quality of the fruit from inspection at the receiving station, should be able to regulate the flow of the product according to percent of defective fruit. The advantage of this procedure would be that the workers could be provided with enough fruit to keep their hands busy removing defective fruit. This should increase labor efficiency, and future research might well consider these possibilities.

Viewing the Entire Surface of Product

In addition to rotating fruit as it moves along the sorting belt, some cherry processing plants have a problem of spreading the fruit on the belts and preventing it from riding too close to the fruit guards which obstruct the view. One plant in which the writer worked used a splitter at the head of the belt to divide the cherries into two groups. This appeared to help some in spreading the cherries. Also, the devices developed for rotation of fruit helped spread the cherries over the belt. The two rows formed by a splitter and the spreading effect of the stationary rod may be seen in Plate IV. This sorting belt is rather lightly loaded (perhaps 20 percent cover).

For fruit which rides too close to the fruit guards baffles may be used to force it away from the sides.

Some processors have noted that workers often reach to the far side of the belt to remove defective fruit. It appears that a partition down the center of the belt may be useful for limiting the width of view and preventing workers from watching the other side of the belt. A center partition has been used in some plants but it is not known whether its use improves sorting efficiency. Perhaps this factor could be included in future research.

Sorting Cherries by Transmitted Light

Looking to the future it appears that cherries, due to their transparency, may be sorted by transmitted light. Some observations were made in the laboratory using pitted and unpitted cherries on a glass plate with two to four 150 watt incandescent bulbs underneath. A picture of the arrangement is shown in Plate V. Unpitted cherries are shown on the left, under-color cherries in the center, and dark defective cherries on the right of the picture.

When the cherries were viewed normal to the surface of the glass, perceptibility of defects was greatly reduced due to glare caused by the lamp bulbs even though defusers were used over the bulbs. Therefore, viewing at such an angle that the bulbs would not come into the field of vision was absolutely essential. Perceptibility of dark defects was increased when the bulbs were not in the field of vision. Perceptibility of dark defects was increased slightly more by placing filter B-23 under the glass plate or over the eyes.

It occurred to the writer that viewing the cherries by transmitted light, at such an angle that no direct radiation is received from the lamp bulbs, gives to some extent the same effect as eliminating a large part of the blue and green portions of the spectrum. This follows by reasoning that the glass will transmit a large part of the radiation but that some diffuse rays will be reflected and reach the observer's eyes indirectly. For the rays which strike the cherries most of the green and blue wavelengths are absorbed and only the red wavelengths are transmitted. The red light is then diffusely scattered by the cherry and received by the eye. Where a dark spot occurs most of the radiation in the visible spectrum is absorbed. Thus, the eye receives some radiation throughout the visible spectrum but receives only long wavelengths of light from the cherry itself. It is believed that the principle of sorting by transmitted light is rather similar to using a filter with transmittance similar to the cherry reflectance curve from

PLATE V. Kodachrome Picture of Arrangement for Observation of Cherry Defects by Transmitted Light. This sample was illuminated from above by two photoflood lamps.

approximately 600 to 720 Mu and with a small amount of transmittance from 400 to 600 Mu.

The level of illumination necessary to increase perceptibility of defective cherries by transmitted light is rather high. It appears from observations that the perceptibility of dark defects in cherries is equally enhanced by reflected light if an equal intensity of illumination is used with a filter eliminating the green portion of the spectrum as discussed previously. This statement is based on rather limited observations and perhaps further investigation of sorting by transmitted light would be justified.

Fluorescence of Defective Cherries

It is known that certain types of organic decay will fluoresce if irradiated with ultraviolet energy. The writer used a high pressure mercury arc lamp which has a group of spectral lines near 365 Mu to irradiate brown and black defective cherries. However, with the eyes dark adapted, there was no visible fluorescence from the defective cherries.

Specular Gloss

Due to the smooth surface of cherries and tomatoes, non-selective specularly reflected light (specular gloss) produces an image of the light source on each piece of fruit. Point sources of light will cause these images to be quite distinct. Diffuse illumination minimizes effects of specular gloss and improves perception of glossy surfaces. This should be easier on the eyes.

CHROMATIC ILLUMINATION TESTS IN CHERRY PROCESSING PLANTS

Field tests were conducted at three cherry processing plants. Procedure for the tests was as follows. Two sorting belts which were as nearly alike with respect to color, speed, location, etc. were selected. An equal number of workers inspected the cherries on each belt. Filters were placed over the illuminant on one belt and the other belt was operated with the same type of illuminant without a filter. On the test with fluorescent lamps, the number of tubes was tripled where filters were applied. For incandescent lamp tests, the number of bulbs was doubled for the belt with the filter.

In operation, a cherry sample was taken before the cherries were sorted. Another sample was taken from the same batch of cherries, after sorting, at the end of each sorting belt. In order to take samples from the same batch, the time required for a cherry to travel from the first sampling location to the end of each sorting belt was obtained with a stop watch. An ordinary watch was used to time the spacing of samples. Samples were marked with code letters to indicate their locations and given to a sample inspector to separate and classify the defects.

The U.S.D.A. inspector at the plant helped train the sample inspector to properly classify the various types of defects. Checks were made with the U.S.D.A. inspector when doubt arose, until the sample inspector was throughly familiar with the defects. Code markings eliminated any chance of prejudicial opinions on the part of the sample inspector who had to make the critical decision of the classification of major and minor defects.

An effort was made to eliminate any effects due to differences in worker efficiency and differences due to belts. In order to accomplish this, the chromatic illuminants were used on each of the test belts for one-half of each test. It is believed that belt and worker differences were successfully eliminated in the tests at the last two plants. Complications at the first plant will be explained later.

Another variable was the variation in the percent of defects and the type of defects. Since the sample was taken from the same batch of cherries from both belts, it is assumed that these factors had negligible effects on the results.

At times the flow of cherries to the plant fluctuated. This caused the flow of cherries to various sorting belts to be uneven. Usually the flow smoothed out soon or the operator changed the regulators to adjust the flow. No corrections were possible for this variable but the flow into the plant on the main belt was observed before taking a sample in order to avoid taking samples during any noticable fluctuation.

The plant was allowed to operate at least 15 minutes before any samples were taken. This permitted the flow regulators to be adjusted and allowed time for the eyes to adapt to the prevailing visual conditions.

Illumination was measured with a Weston Model 614 light meter (AE-763) which compared closely with the recently calibrated General Electric type P-12 light meter (AE-1567) and an approximate correction factor for chromatic illumination produced by each illuminant-filter combination was calculated and applied. The correction factor (F) was determined from the following ratio:

$$\frac{\sum(E_\lambda L_\lambda T_\lambda)}{\sum(E_\lambda L_\lambda)} = (F)\,\frac{\text{Meter reading (with filter)}}{\text{Meter reading (without filter)}}$$

The ratio on the left-hand side of the equal sign is the luminous transmittance of the filter. The ratio on the right-hand side (omitting F) is the luminous transmittance of the filter as determined by the meter. The correction factor (F) is a multiplying factor to be used for correction of Weston light meter readings, specifically readings of meter AE-763 which is not corrected for color. It should apply approximately to other uncorrected light meters.

Tests at Plant A

The arrangement of the sorting belts in plant A and the sampling locations are shown in Figure 22. This plant was chosen mainly because there was very little interference from outside daylight. With all lamps turned off the illumination falling on the sorting belts was less than one foot-candle. The belt illuminant consisted of 40 watt T-12 standard cool white fluorescent tubes mounted end to end approximately 16 inches above the belt. A curved piece of sheet metal served as a reflector above each tube.

The reflectors were painted with a good grade of white paint and the standard cool white tubes were replaced with G. E. deluxe warm white tubes. On one belt two extra tubes were mounted on the flanges of the reflector; this gave almost three times as much illumination as one tube. The filter was mounted over the three tubes of the illuminant.

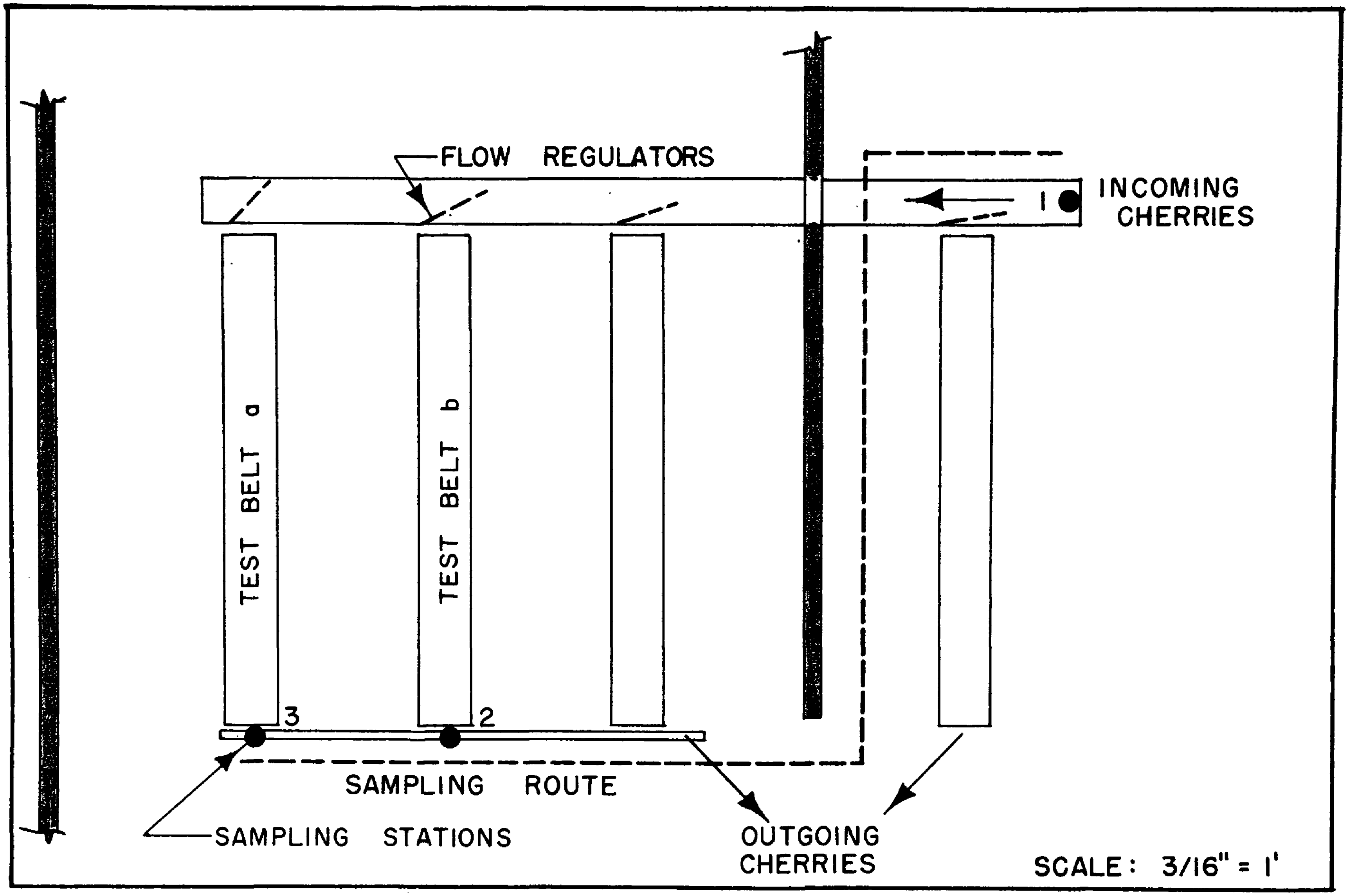


FIGURE 22. FLOOR PLAN AT PLANT A

As explained previously four filters were chosen from the calculations and observations. The statistical arrangement of the tests were planned as follows:

Four filters: 1,2,3, & 4
Two belts: a & b
Two crews: A & B

Period of day	1st day	2nd day	3rd day	4th day
1	1 a A	2 a B	3 b A	4 b B
2	3 a B	4 a A	1 b B	2 b A
3	4 b A	3 b B	2 a A	1 a B
4	2 b B	1 b A	4 a B	3 a A

The filters used and the approximate illumination on the belt are shown in Table V. (Spectral transmittance curves for these filters are presented later). Black belts were used and the belt speed was 20.4 feet per minute. Eleven workers were used on each belt.

TABLE V

Filters and Illumination for Tests Using
Deluxe Warm White Fluorescent Lamps at Plant A

Filter	Factory Designation	(F) Approx. Meter correction factor*	Range of Illumination on belt(foot-candles)
1	B-23, Medium purple	0.4	28-41
2	B-11, Medium magenta	0.5	53-41
3	B-7, Dark rose pink	0.6	85-125
4	B-67, Fire red	0.5	33-48
none	comparsion illuminant	0.9**	80-120

* Estimated 10 percent accuracy
** Reference (25)

During the first day, samples of approximately 100 cherries were taken at each sampling station. With this size sample the variation in percent defects was so great that occasionally there were more defects in the sorted cherries than in the unsorted cherries; samples taken thereafter consisted of 300 to 400 cherries.

The tests were continued for two days taking the larger samples. The results from these tests were inconclusive since only one-half of the test block was completed. The summary of totals for the number of cherries and for the number and percent of major defects (both brown and black) in samples are shown in Table VI. Theoretically, all filters should have improved the perceptibility of the black defects and any brown defects which were darker than brown rot. Actually, the results of the incomplete tests (Table VI) indicate sorting efficiency was improved for both brown and black defects when using filters B-11 and B-67 but that sorting efficiency was decreased by use of filter B-7. Results for filter B-23 indicate that sorting efficiency was increased for the black defects and decreased for the brown defects.

In addition to this inconclusive data, opinions of the worker's were taken. It was evident from their comments that filter B-67 would not be successful even though the produced illumination indicated merit for enhancing the defects. Some workers complained of eye strain and headaches when this filter was used over the illuminant. About the same complaints, except not as severe, were leveled against filter B-7. This filter had indicated no merit in the test. Thus, it was decided to eliminate these two filters from further tests and to move to a different plant with a new set of workers who would not be influenced

TABLE VI

Summary of Test at Plant A Using Deluxe Warm White Fluorescent Lamps and Filters as Indicated

Illuminant	Total cherries in samples	Total Brown Defects		Total Black Defects		Percent Sorting Efficiency*	
		No.	%	No.	%	Brown	Black
Before Sorting	3180	136	4.28	94	2.95		
No Filter	3183	69	2.16	51	1.60	49.6	45.8
Filter B-7	2977	67	2.25	63	2.12	47.4	28.1
Before sorting	2658	119	4.48	99	3.72		
No Filter	2576	94	3.65	50	1.94	18.4	47.7
Filter B-11	2658	51	1.92	41	1.54	57.0	58.6
Before Sorting	2623	138	5.25	79	3.01		
No Filter	2821	77	2.72	65	2.30	48.1	20.3
Filter B-23	2680	122	4.55	40	1.49	11.5	50.5
Before Sorting	3058	138	4.52	91	2.98		
No Filter	2932	89	3.04	51	1.74	32.7	41.7
Filter B-67	3069	64	2.08	39	1.27	54.0	57.3

* Sorting efficiency is defined as 100 percent if all defects are removed.

by the adverse comments concerning filters B-? ... .

Tests at Plant B

The arrangement of the sorting belts and the sampling locations for this plant are shown in Figure 2?. Incandescent filament lamps were used in an inverted trough fixture which was approximately ten inches across the opening and extended the entire length of the sorting belt.

Illumination from three spectral distributions are given below. The appropriate correction factors were applied.

1. Skylight varied with the time of day and location on the sorting belt from 3 to 30 foot-candles. (30 foot-candles was the maximum from measurements at beginning and end of tests).

2. Light from 6-100 watt bulbs varied with location on the sorting belt from 40 to 80 foot-candles.

3. Light from 12-100 watt bulbs with filters were:
   Filter B-11; 20 to 40 foot-candles (F= 0.6)
   Filter B-23; 12 to 25 foot-candles (F= 0.5)

4. Other pertinent information is as follows:
   Belt speed: 30.1 feet per minute
   Belt color: white
   Number of workers: six per belt

Each sorting belt had an individual feeder. With this arrangement it was necessary to take a sample before and after sorting for each belt. Thus, four samples instead of three were taken. The belt was timed as before and samples were taken from the same batch of cherries before and after sorting. Each cherry sample was taken in three parts with 100 to 150 cherries in each part. This prevented taking too many cherries from one location on the belt, which would disrupt even flow, and distributed the time of taking the samples over a longer period.

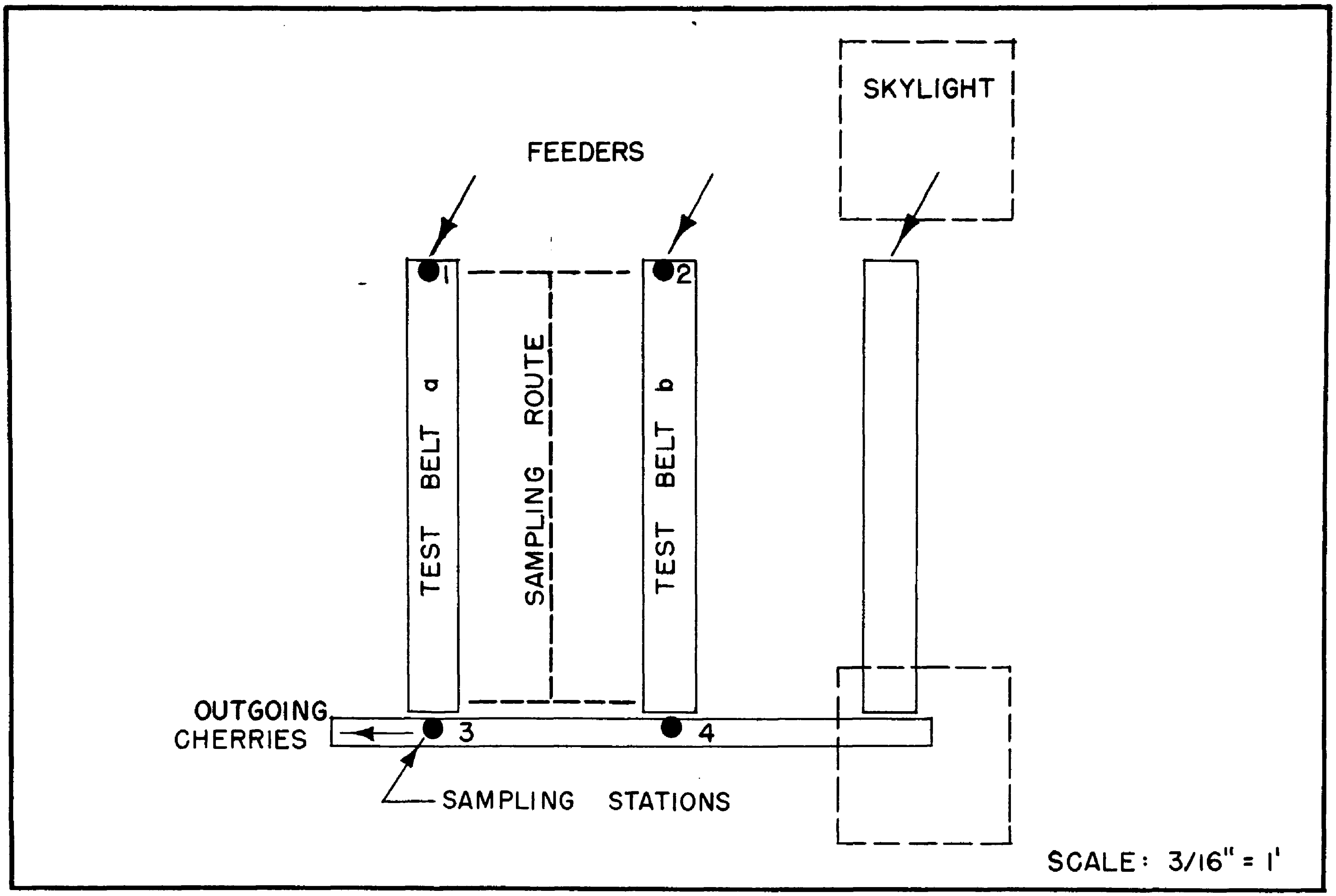


FIGURE 23. FLOOR PLAN AT PLANT B

The test time for each filter was four hours. At the end of the first two hours the extra bulbs and filter were switched to the other belt. The workers remained in their positions. Thus, each crew of workers and each belt were used with the chromatic illumination for one-half of the test. Four samples were taken from each sampling location during each two hour period of the test (one-half the test). That is, for the four hour test for each filter, eight samples were obtained for each illuminant.

The totals of all samples and percentages of major defects are shown in Table VII. Only the major defects were counted in the test. For determining the percent removed, each belt was considered independently since each belt had an individual feeder. (Actually the cherries came from the same large storage tank). The percent sorting efficiency was considered 100 percent if all defective cherries were removed. The results shown in Table VII were not statistically significant at the 95 percent confidence interval.

There was one complaint about the illumination produced by filter B-11. The worker stated that the illumination caused dizziness; however, there was no general dislike of the illumination. The illumination produced by filter B-23 was well liked by the workers. Several workers made favorable comments concerning the improved perceptibility of defects and some stated that this illuminant was easier on their eyes than the regular illuminant. There were no complaints of dizziness or headaches when using filter B-23.

Since the illumination produced by using B-23 showed promise of being superior to the regular illumination provided by incandescent

TABLE VII

Summary of Tests at Plant B Using 100 Watt Filament Type Incandescent Lamp and Filters as Indicated

	Total Cherries in Samples	Major Defects				Percent Sorting Efficiency*	
		Total Brown		Total Black			
		No.	%	No.	%	Brown	Black
No Filter						27.3	32.0
Before sorting	2657	105	3.96	50	1.88		
After sorting	2739	79	2.88	35	1.28		
Removed			1.08		0.60		
Filter B-11						27.4	41.7
Before sorting	2771	131	4.74	57	2.06		
After sorting	2590	89	3.44	31	1.20		
Removed			1.30		0.74		
No Filter						40.1	39.8
Before sorting	2835	124	4.38	82	2.89		
After sorting	2818	74	2.62	49	1.74		
Removed			1.76		1.15		
Filter B-23						48.2	41.3
Before sorting	2795	128	4.58	69	2.47		
After sorting	2825	67	2.37	41	1.45		
Removed			2.21		1.02		

*Sorting efficiency is defined as 100 percent if all defects are removed.

lamps, both from the standpoint of sorting efficiency and workers' choice, further tests were desirable.

Tests at Plant C

The arrangement of the sorting belts and the locations of sampling stations are shown in Figure 24. Incandescent filament lamps were used on the test belts. The lighting fixtures were similar to those at plant B. All the bulbs were changed to new 150 watt bulbs and double sockets were used to mount twice as many bulbs in the fixture with the filter.

Illumination of three different spectral distributions falling on the belts were as follows:

1. Skylight varied with the time of day and location on the belt up to 15 foot-candles.

2. Light from 6-150 watt bulbs varied with location on the belt from 53 to 130 foot-candles with an average, from 18 readings at selected locations on the belts, of 78 foot-candles.

3. Light from 12-150 watt bulbs covered with filter B-23 produced from 15 to 37 foot-candles at various locations on the belts with an average of 26 foot-candles from 18 readings at the same locations as for 2. (F = 0.5)

During the first test light rain was falling and the skylight illumination was very low.

Additional plant information is as follows:

Belt speed: belt "a" 20.4 feet per minute
belt "b" 21.8 feet per minute
Belt color: white, but stained tan
Number of workers: 4 to 6 (same number on each belt)

Filter B-23 was tested for six five-hour periods. The chromatic illumination was used on each belt for one-half of each five-hour period. During each five-hour test, six samples of approximately 400 cherries

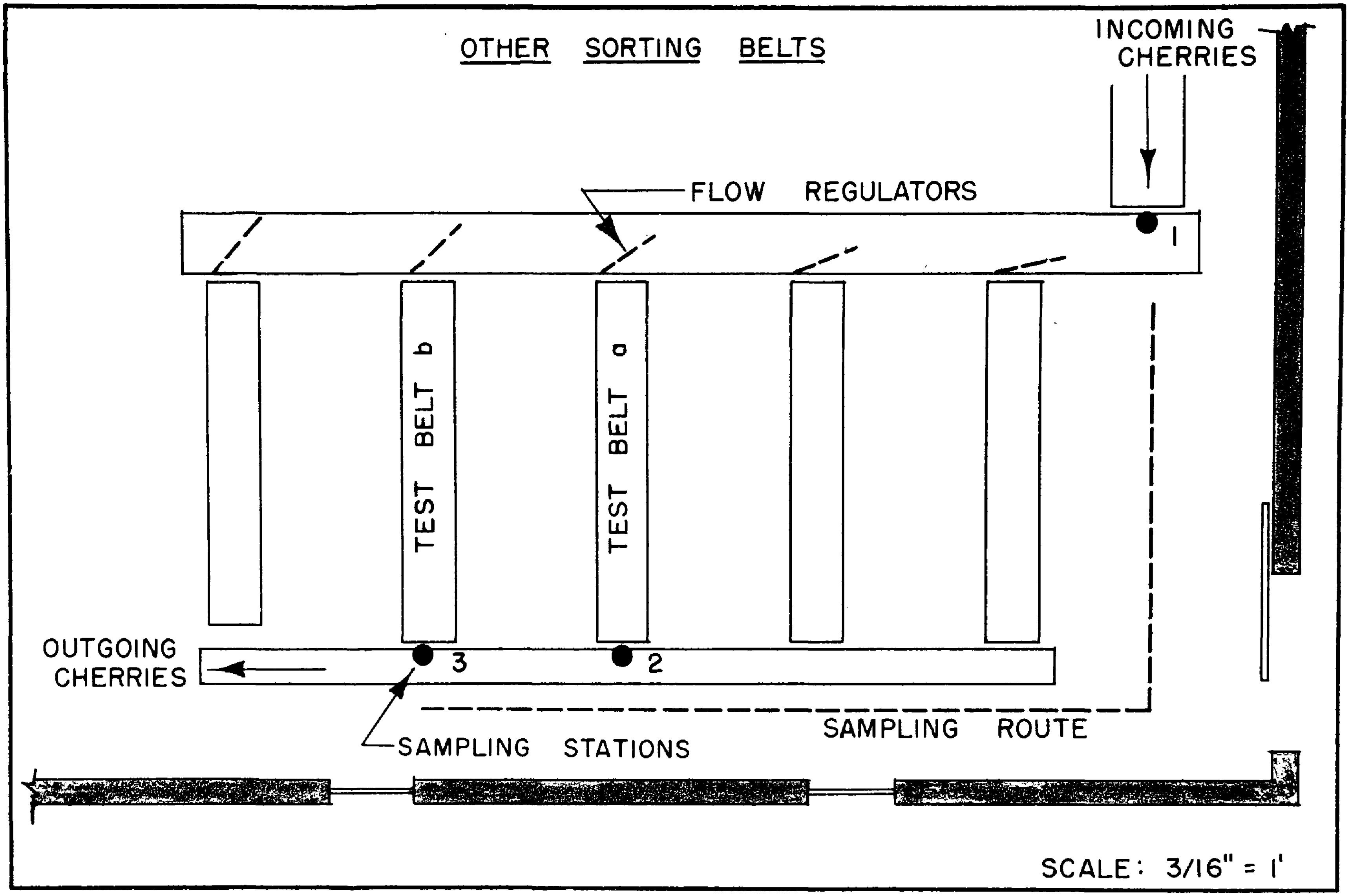


FIGURE 24. FLOOR PLAN AT PLANT C

each were taken at each sampling station (see Figure 24). Each sample was taken in four parts, approximately 100 cherries each. This distributed the sampling over a longer period and resulted in sampling a larger batch of cherries.

The results of the tests are shown in Table VIII. One five-hour test period was eliminated from the results because the defects were so numerous that all workers could locate more defects under either illuminant than they could possibly remove. It might be noted here that there are two conditions for which an improved illuminant would show no increase in sorting efficiency; namely, when there are so many defects that the workers can see more defects than they can possibly remove, and when the defects are so few that the workers have extra time to look for the next one to pick out. The latter may have been true for some of the samples at the previous plant. All samples and the defects counted for each are listed in Appendix II for the reader's inspection.

The results of the tests compare rather favorably with the theoretically calculated contrast ratios. For the minor defects there was a decrease in sorting efficiency of 1.[illegible] percent (not statistically significant) and if we consider the reflectance curve of the under-color cherry as represensive of these defects, this contrast ratio is decreased from 1/2.52 to 1/1.53 by use of filter B-23 (Table XI). For brown defects, the increase in sorting efficiency amounted to 7.8 percent (not statistically significant) and the contrast ratio increased from 1/1.04 to 1.50/1 for the filter. Actually the brown defects counted at the plant were a range of browns which in general covered defects

TABLE VIII

Summary of Test at Plant C Using 150 Watt Filament Type Incandescent Lamps and Filter B-23 as Indicated

	Minor Defects	Major Defects		Total Major Defects	
		Brown	Black	By count	By weight
% defects in field cherries before sorting	4.34	6.65	2.48	9.13	8.61
Sorted under regular light					
% removed	0.76	0.93	0.78	1.71	1.57
% sorting efficiency	17.5	14.0	31.4	18.7	18.2
Sorted under filtered light					
% removed	0.70	1.45	1.14	2.59	2.44
% sorting efficiency	16.1	21.8	46.0	28.4	28.3
% removed filtered light minus % removed, regular light	-0.06	0.52	0.36	0.88	0.87
% sorting efficiency filtered light minus % sorting efficiency, regular light	-1.4	7.8	14.6	9.7	10.1
% improvement in sorting efficiency using regular light as 100%	-8	56	46	51	55
*Statistical t-values for samples	1.18	1.65	2.21	2.19	2.47

* For statistical significance at the 95 percent confidence interval t= 2.04.

much darker than the defects used to obtain the reflectance curves for brown. Thus, the brown defects for the calculations were not the same as the range of brown defects counted at the plant.

The type and percent of brown defects varied considerably during the test. During the first two five-hour tests the dark brown defects were rather numerous and the filtered light showed a considerable advantage over the regular light. At other times, especially when mutilated cherries were prevalent, the regular light seemed to show an advantage. Not enough samples were obtained to establish this observation. Also, the indication for plant A was negative for filter B-23 where mutilated cherries were noted. This clearly indicates that filter B-23 is poor for perceptibility of mutilated cherries and good for perceptibility of dark brown defects.

For the black defects there was an increase in sorting efficiency of 14.6 percent (statistically significant at the 95 percent confidence interval) and the contrast ratio was increased by use of the filter from 4.14/1 to 8.72/1. Apparently, the results for each type of defect compares well with the calculated contrast ratios.

Totals of major defects (i.e. black plus brown defects) are also shown in Table VIII. The increase in sorting efficiency for the totals was 9.7 percent (statistically significant at the 95 percent confidence interval). The total defects were also obtained by weighing the black and brown defects. This is the measure used by U.S.D.A. inspectors at the plant. The data shows that the percent of defects are slightly less measured by weight. The difference is probably due to a decrease in weight for defective cherries either from drying or mutilation. The results show an increase in sorting efficiency of 10.1 percent for the totals by weight (statistically significant at the 95 percent confidence interval).

In the final analysis there may be some question as to what measure should be used for illustrating the improvement brought about by use of chromatic illumination. Referring to Table VIII there are several measures given: 1. the difference in percent of total cherries removed under each illuminant, 2. the difference in sorting efficiency, and 3. the improvement in sorting efficiency using the regular illuminant as 100 percent. The first criterion shows how many more defective cherries were removed in percent of total cherries moving across the belt; for example, 0.88 percent of the total cherries (column 4). The second shows increase in percent of the defects removed; e.g. 9.7 percent more of the major defects were removed (column 4). The third shows the magnitude of improvement in percent. For example, a sorting efficiency of 28.4 percent is an improvement of 51 percent over a sorting efficiency of 18.7 percent.

A survey of the workers using the chromatic illuminant yielded the following information:

1. Did the chromatic illumination bother your eyes? yes-3, no-8, better-5. The five who stated that the chromatic illumination was better than the regular illumination stated so without being asked.

2. Can you see the defects better with the chromatic illumination?
For black defects: yes-14, equal-4, no-0
For brown defects: yes-3, equal-9, no-6

3. Do you like the chromatic illumination? yes-11, equal-2, no-4.

From as objective a view as possible, the writer would omit three of the workers' statements which tended to disqualify the chromatic illuminant on questions 1 and 3 because these workers did not appear to be sincere in their answers.

FURTHER ANALYSIS OF CHERRY SORTING

Since the field test proved to be statistically significant, it was decided to investigate several additional illuminant-filter combinations in an effort to find a satisfactory combination with higher illuminant efficiency. Such a combination must have at least an equivalent contrast ratio and be psychological acceptable to the workers. Also, the reflectance of the sorting belt and its effect on adaptation remains to be discussed.

Psychological Reactions to Chromatic Illumination

During the field test the workers made definite complaints against the use of red illumination (filter B-67). The following two accounts support this finding. Mr. Lloyd Phillips (26) of Michigan Fruit Canners Inc. used pink fluorescent lamps over cherry sorting belts. He stated that the workers on the belt objected to this illuminant even though it did show up the defects better. Also, Mr. R. A. Rice (27) of the Northport Cherry Factory, Inc. wrote the author as follows, "We tried pink fluorescent lighting through red filters on one of our four belts in our Port Clinton Plant. Although this lighting definitely emphasized the defects on the fruit we were forced to discontinue its use because of objections on the part of the ladies working on the belt; they claimed the lighting was hard on their eyes, as it was difficult for their eyes to adjust whenever they looked up from the belt." It appeared, then, that red illumination was definitely unsatisfactory; whether the reason for the workers' complaints was psychological or physiological was not established.

The transmittance curves for the filters which registered complaints from the workers are shown in Figure 25. The filter used to produce red illumination, B-67, transmits practically no energy at wavelengths shorter than 570 Mu. The strongest complaints were leveled against this illuminant. The next illuminant to be eliminated, partially because of workers' complaints, was filter B-7 which transmits the short wavelengths of light only slightly. Finally, filter B-11 was eliminated with only one worker's complaint against it. This filter transmits considerably more of the short wavelengths than B-7. No actual complaints were registered against the medium purple filter, B-23, although four workers stated that they preferred the white illuminant when asked to express an opinion. Figure 26 shows that B-23 transmits almost as well in the blue region of the spectrum as in the red. Although one cannot say definitely, it appears that some illumination from 400 to 500 Mu must be included with strong illumination in the region of 600 to 720 Mu in order for the illuminant to be acceptable to the worker.

In an effort to show the appearance of cherries and defects under the different chromatic illuminants, Plate VI is presented. The pictures do not show the true colors and lightnesses because of differences in the spectral response of the eye and the film, and because the adaptation of the eye could not be included. The pictures were taken by using two photoflood lamps for illumination and placing the filter indicated over the lens of the camera. The increase in contrast does not appear in the pictures nearly as clear as for viewing with each chromatic illuminant; however, it is noted that the cherries do appear lighter where the filters were used. The differences in pictures can best be distinguished by

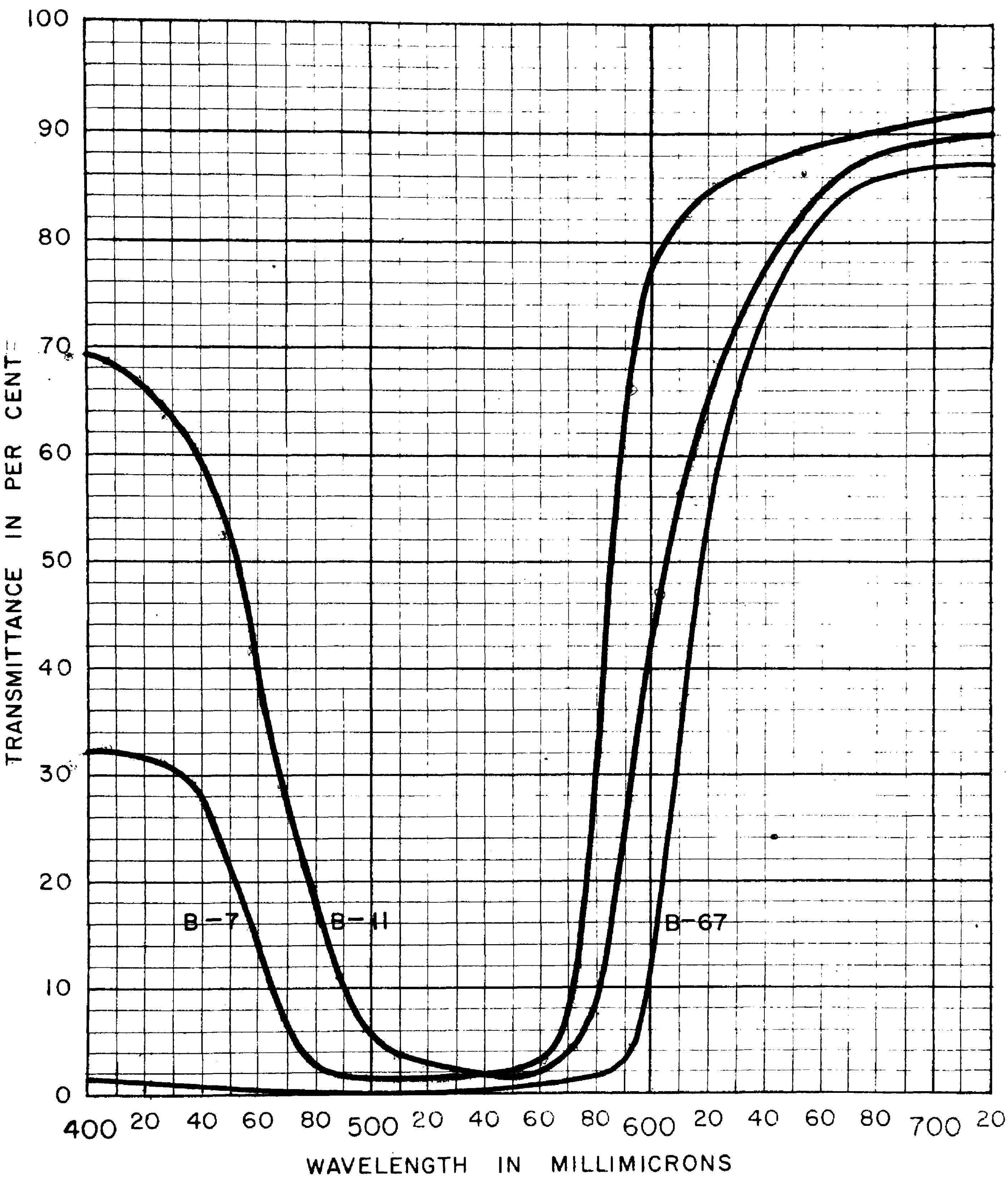


FIGURE 25. SPECTRAL TRANSMITTANCE CURVES FOR GELATINE FILTERS

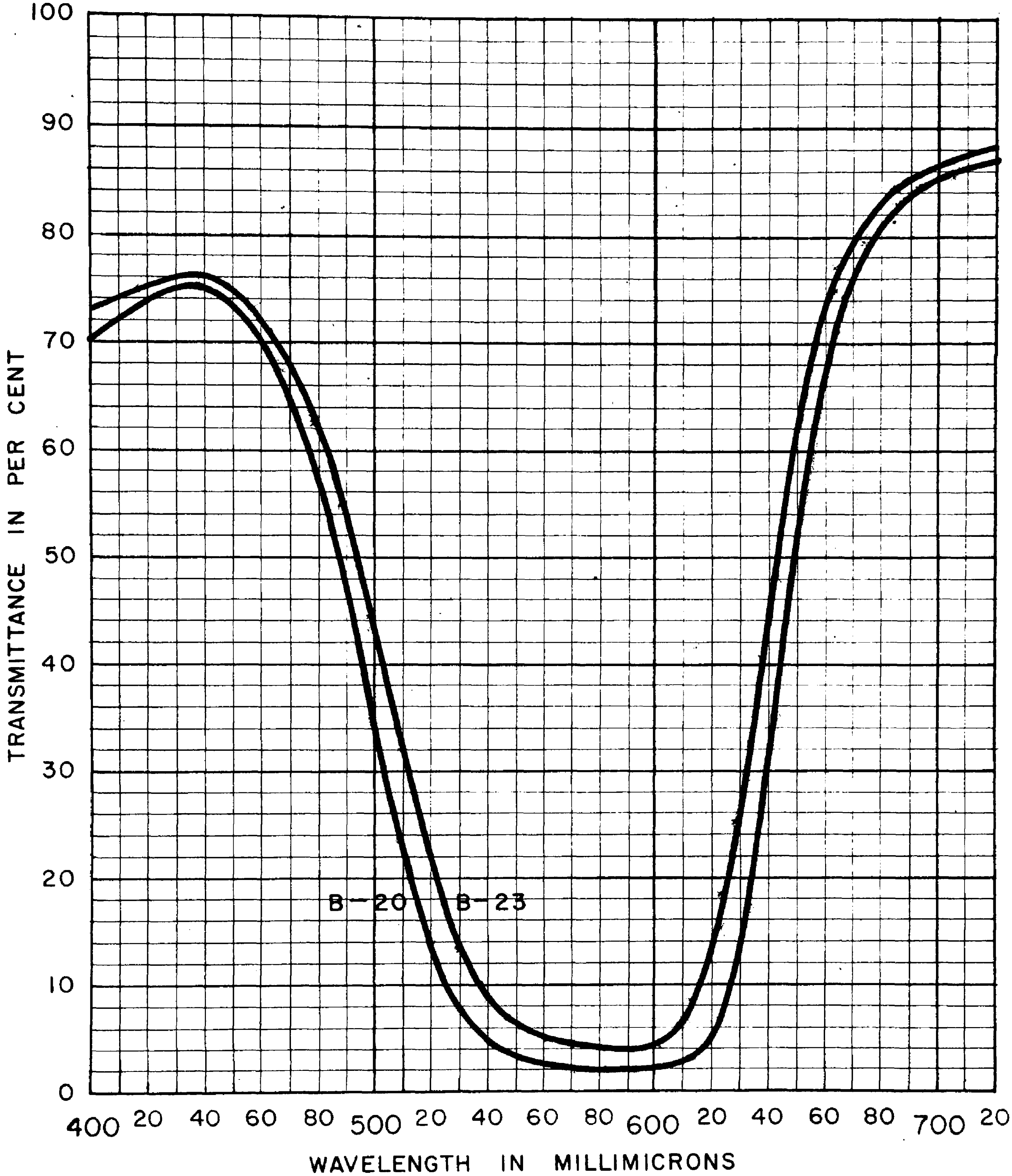
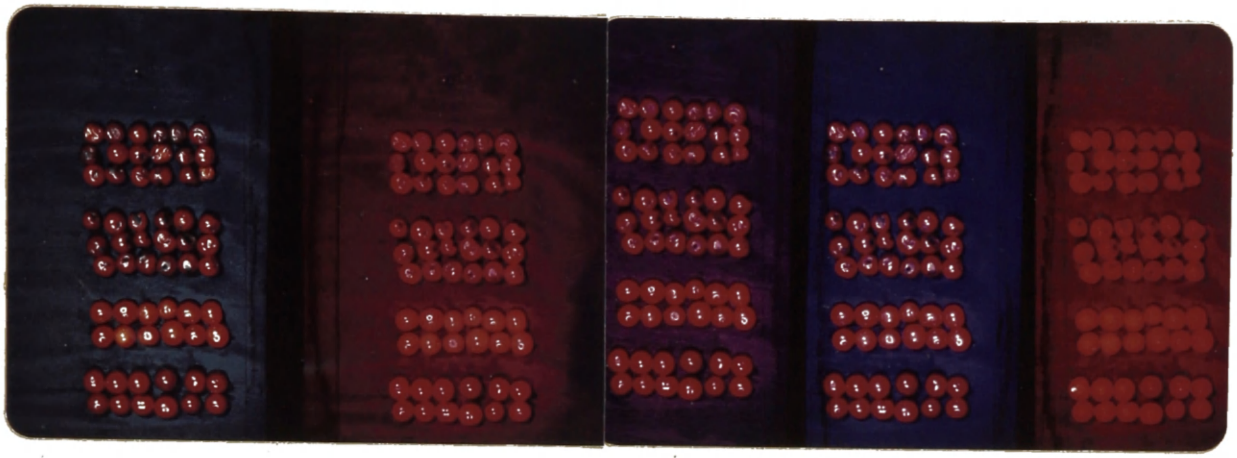


FIGURE **26.** SPECTRAL TRANSMITTANCE CURVES FOR GELATINE FILTERS



No Filter B-7 B-11 B-23 B-67

PLATE VI. Kodachrome Pictures of Cherries and Defects Using Various Spectral Distributions of Illumination. The filter indicated was used over the lens of the camera. From bottom to top: red ripe cherries, light red cherries (not defects), black defects, and a range of brown defects.

following one defect through all pictures. The color reflected from the background indicates somewhat the color of the filter.

Recognizing the psychological difficulties, additional filters which transmit radiation from 400 to 500 Mu were considered. These were filters B-18, B-19, B-20 (Figure 26 and 27) and four theoretical filters (Table IX and X). It appears that these filters should satisfy the requirement of including radiation in the blue portion of the spectrum. However, only filter B-23 has been tested in the field and found to be free of any serious criticism on the part of the workers.

Contrast Ratio and Illuminant Efficiency

The contrast ratio and the relative luminous flux reflected from the red ripe cherry per watt for the illuminant-filter combinations, which appear to be psychologically acceptable and those which were rejected,

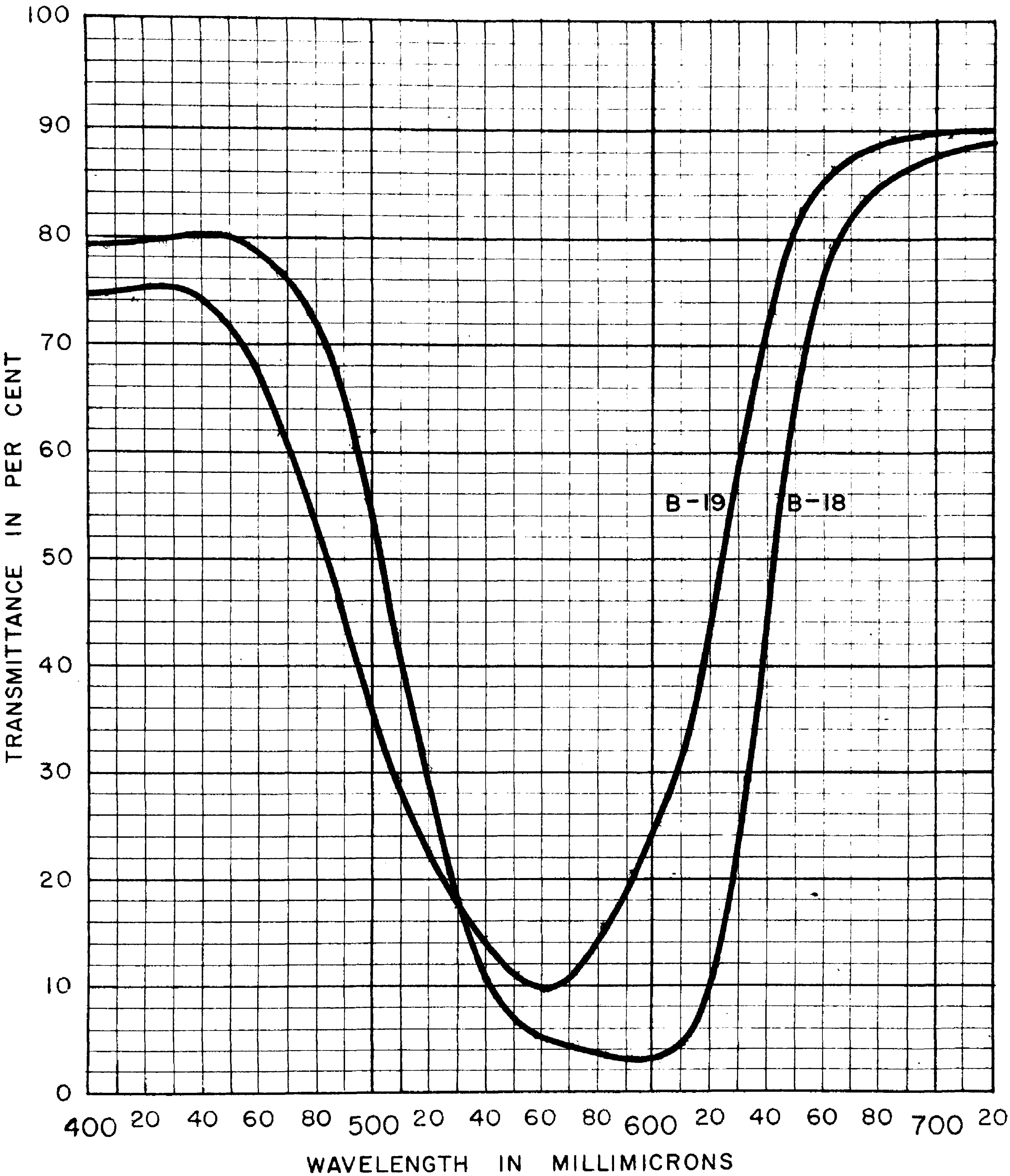


FIGURE 27. SPECTRAL TRANSMITTANCE CURVES FOR GELATINE FILTERS

TABLE IX

Contrast Ratios and Relative Luminous Flux Reflected from Cherries Illuminated by 2910° K Tungsten Lamp with Theoretical Filters

Filter	Range of Wave-lengths (inclusive) Mu	Contrast Ratios		Relative Luminous Flux Reflected from Red Ripe Cherries per Watt
		Brown Defect	Black Defect	
A	400-500 & 600-720	1.36/1	9.3/1	74.4
B	400-500 & 610-720	1.50/1	11.0/1	67.3
C	400-500 & 620-720	1.63/1	12.6/1	57.7
D	400-500 & 630-720	1.74/1	13.9/1	46.2

TABLE X

Contrast Ratios and Relative Luminous Flux Reflected from Cherries Illuminated by G. E. Deluxe Warm White Fluorescent Lamp with Theoretical Filters

Filter	Range of Wave-lengths (inclusive) Mu	Contrast Ratios		Relative Luminous Flux Reflected from Red Ripe Cherries per Watt
		Brown Defect	Black Defect	
A	400-500 & 600-720	1.24/1	8.2/1	170
B	400-500 & 610-720	1.40/1	10.0/1	147
C	400-500 & 620-720	1.56/1	12.0/1	115
D	400-500 & 630-720	1.70/1	13.7/1	81.6

are shown in Table IX, X, XI. Calculations for these values were made at 10 Mu increments. The problem is to obtain a balance between contrast ratio and illuminant efficiency. (Note the illuminant efficiency is measured by luminous flux reflected from the red ripe cherry per watt input to the lamp). From the standpoint of illuminant efficiency and contrast ratio the G. E. deluxe warm white fluorescent lamp with theoretical filters as listed in Table X was the best illuminant-filter combination found in analysis. For the commercially available filters, Table XI shows that the deluxe warm white fluorescent lamp has the highest efficiency but possesses slightly lower contrast ratios than the 2910°K tungsten lamp. There are several possible illuminant-filter combinations which might be chosen from this table. Filter B-19 offers an advantage in illuminant efficiency, especially for the G. E. deluxe warm white fluorescent lamp. On the other hand, B-20 produces a much greater contrast ratio when used with the tungsten lamp but its efficiency is rather low. Thus, for high illuminant efficiency with some increase in contrast ratio the G. E. deluxe warm white fluorescent lamp with filter B-19 may be satisfactory. If a higher contrast ratio is desired filters B-20 or B-23 with the tungsten lamp would be a better choice.

Since no definite decision could be made on the choice of an illuminant-filter combination, it was decided to compare the appearance of cherries and defects using filter B-23 with both illuminants. A tungsten filament (150 watt bulbs) and a G. E. deluxe warm white fluorescent lamp source were set up in the laboratory. Each was adjusted to provide a level of illumination of 250 foot-candles. With filter B-23 over the eyes, samples of cherries were viewed. It appeared that the cherries possessed

TABLE XI

Contrast Ratios and Relative Luminous Flux Reflected from Cherries Illuminated by Fluorescent or Incandescent Lamp with Commerical Filters

Illuminant	Filter*	Contrast Ratios**			Relative Luminous Flux Reflected from Red Ripe Cherries per Watt
		Under-color Defect	Brown Defect	Black Defect	
Daylight Fluorescent	none	1/3.09	1/1.38	2.56/1	211
	B-7,Dk.Rose pink	1/3.03	1/1.04	5.11/1	95.6
	B-11,Med.Magenta	1/2.64	1.07/1	5.89/1	68.5
	B-18,Med.Lavender	1/1.44	1.24/1	4.03/1	45.5
	B-19,Dk.Lavender	1/2.46	1/1.04	3.93/1	65.0
	B-20,Light Purple	1/1.73	1.05/1	3.54/1	23.0
	B-23,Med. Purple	1/1.92	1.01/1	3.52/1	35.6
	B-67,fire red	1/2.20	1.32/1	8.18/1	44.1
Deluxe Warm White Fluorescent	none	1/2.85	1/1.15	3.63/1	253
	B-7,Dk.Rose pink	1/2.63	1.11/1	6.73/1	156
	B-11,Med.Magenta	1/2.35	1.23/1	7.90/1	118
	B-18,Med. Lavender	1/1.70	1.33/1	6.50/1	50.5
	B-19,Dk. Lavender	1/2.22	1.19/1	6.43/1	99.6
	B-20,Light Purple	1/1.61	1.43/1	7.80/1	35.1
	B-23,Med. Purple	1/1.78	1.33/1	6.96/1	52.4
	B-67,fire red	1/1.95	1.47/1	11.3/1	90.0
2910° K Tungsten Approx. 150 Watt Filament Type Lamp	none	1/2.52	1/1.04	4.14/1	103
	B-7,Dk.Rose Pink	1/2.27	1.25/1	8.20/1	67.0
	B-11,Med.Magenta	1/2.01	1.33/1	9.74/1	53.5
	B-18,Med.Lavender	1/1.47	1.49/1	8.20/1	29.6
	B-19,Dk.Lavender	1/1.89	1.28/1	7.90/1	47.9
	B-20,Light Purple	1/1.38	1.60/1	10.00/1	22.4
	B-23,Med.Purple	1/1.53	1.50/1	8.72/1	29.7
	B-67,fire red	1/1.70	1.68/1	13.8/1	44.5

*Filter numbers are those designated by the manufacturer: Brigham Gelatine Co., Randolph, Vermont.

**Calculations were made at 10 Mu increments.

a more luminous character when viewed under the tungsten lamp and the black defects seemed to have a slightly greater contrast with the cherry. Considering both calculated values and observations, the G. E. deluxe warm white fluorescent lamp is more efficient for producing reflected luminous flux from the red ripe cherries but for equal levels of illumination the tungsten lamp produces greater contrast ratios for dark defects.

Brightness Adaptation

Each of the filters, which appear to provide illumination acceptable to the worker, absorb a large part of the radiation from 500 to 600 Mu. This includes the green region of the spectrum where the eye is most sensitive to light (Figure 3). The red ripe cherry reflects very little light in this region. Thus, eliminating this part of the illumination will decrease the luminous reflectance of the cherry only slightly. If the background reflects energy from 500 to 600 Mu, the filters would reduce the level of adaptation bringing it closer to the desired level which is obtained by uniform field lightness as discussed previously. This lower level of adaptation causes the cherries to appear lighter and should result in improved perception of the cherries.

One of the poorest adaptative conditions for sorting dark defects from red ripe cherries is presented by use of a daylight fluorescent lamp with a white belt as a background. Under these conditions a large amount of the energy from the lamp is in the blue and green regions of the spectrum. With the white background the eye is adapted to a high level of illumination and the relatively small amount of luminous flux reflected from the cherry causes very little visual response. That is, the cherry is dark in appearance and dark defects are difficult to locate.

Reflectance of Background

There are three colors of belt materials used for sorting belts in cherry processing plants; namely, white, tan, and black. Samples of these three materials were obtained and reflectance curves were run on the spectrophotometer (Figure 28). In running these curves it was necessary to use a very wide band width (50 Mu). For this reason any sharp deviation in the belt reflectance would not show up in the reflectance curve. However, they should give a good approximation of the belt reflectances.

Considering the previously discussed theory and the reflectance curves, the black belt should be the most desirable for sorting dark defects from red tart cherries when using a white illuminant. If the tan, or in particular the white belt, is used with a white illuminant the reflectance from the belt would be much higher than the reflectance from the cherries or defects. This would cause the eyes to be adapted to a high intensity level, as already explained, and would be detrimental when attempting to sort dark defects from cherries.

When using an illuminant with a filter such as B-23, which absorbs much of the energy in the green region of the spectrum, the tan belt appears to be as desirable as the black belt. With this illuminant the eyes would not be adapted to nearly as high an intensity level as with the white illuminant. Thus, it appears that the black belt should be recommended for sorting dark defects from red tart cherries when using white illumination but that the tan belt is satisfactory if much of the radiation in the green region of the spectrum is eliminated.

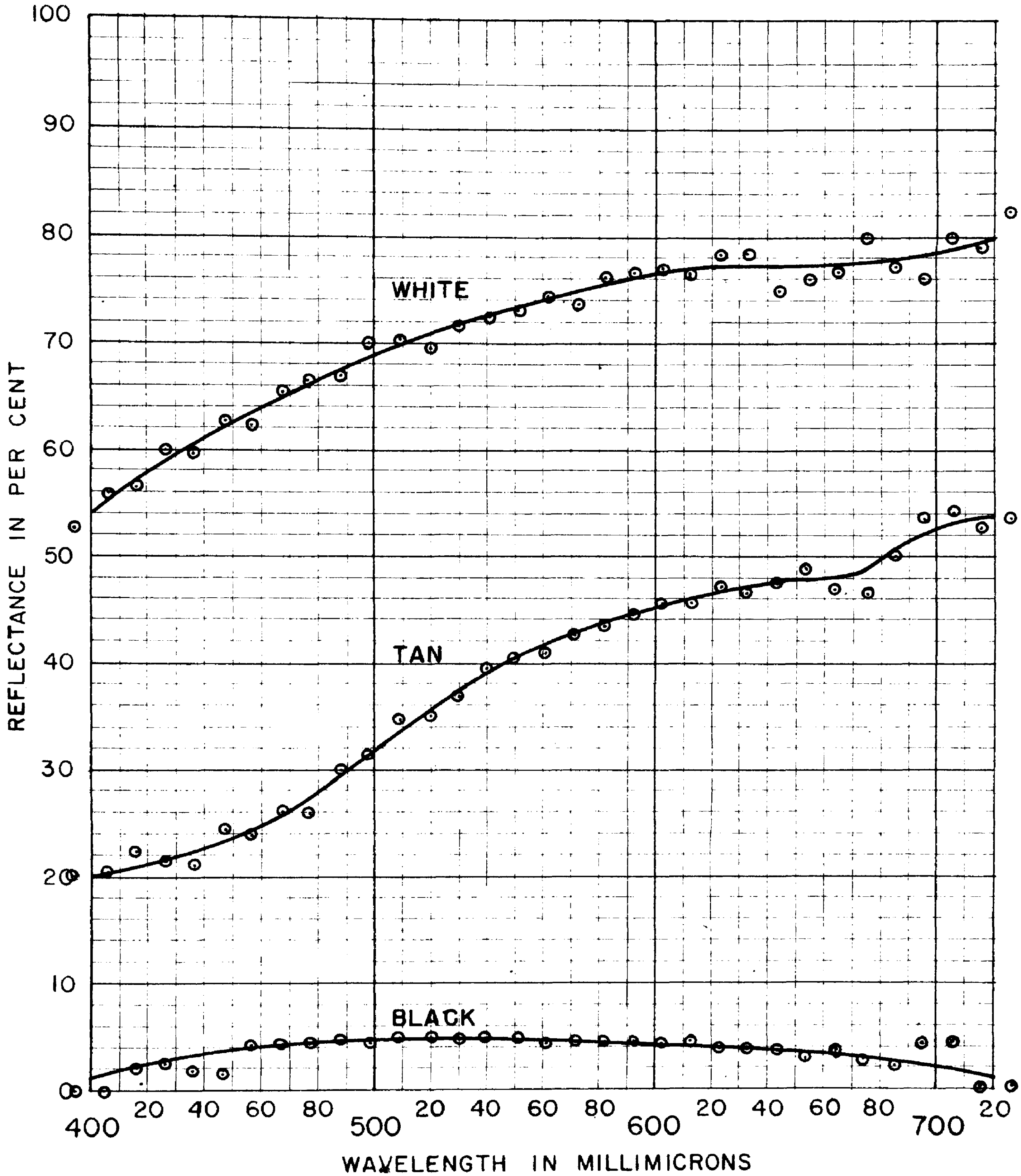


FIGURE 28. 45°-0° SPECTRAL REFLECTANCE CURVES FOR CHERRY SORTING BELTS

For sorting under-color cherries or other defects, which are lighter than brown rot, from red tart cherries, the reflectance of the background with white illumination should be between the reflectance of the tan and black belts in order to satisfy the condition of uniform field lightness.

SUMMARY AND CONCLUSIONS

There are a number of factors which may affect the sorting efficiency in fruit processing plants. A list of such factors may include the following: 1. rate of inspection, 2. width of sorting belt, 3. direction of approach, 4. belt velocity, 5. rotation of product, 6. movement of hands to discard defective fruit, 7. illumination (amount, diffuseness, and spectral distribution), 8. reflectance of product and background and, generally, the enviromental conditions.

This report discusses the investigation of two factors which were estimated to be very important in present day fruit processing plants. The first is the spectral distribution of the illuminant and reflectance of objects in the field of view. The second concerns the viewing of the entire surface of the product as it passes the workers on sorting belts.

Principles of Perceptibility Difference

The review of literature and an analysis of lighting for detection of surface differences revealed the following information concerning the optimum visual conditions for perceptibility of color and lightness differences.

For maximum perceptibility of color differences. 1. The surfaces should be viewed in proximity.

2. The illuminant should radiate energy throughout the visible spectrum but should be especially rich in the region of the spectrum where the reflectance curves of the objects exhibit the greatest percent

difference.

3. The color of the background should be the average color of the objects being separated.

For maximum perceptibility of lightness differences. 1. The objects should be viewed in proximity.

2. The lightness of the background should equal the lightness of the objects being separated. In this respect a background which is darker than the objects is preferred to a lighter one.

3. The spectral distribution of the illuminant for maximum lightness differences may be found as follows. Multiply at suitable wavelength intervals the luminosity function and the spectral reflectance of each of the objects concerned and plot the resulting curves. Use an illuminant which is especially rich in energy in that region of the spectrum where the resulting curves for two objects to be separated exhibit the greatest percent difference (See Figure 5). If the curves for the two objects intersect and cross, the lightness differences may be enhanced by providing an illuminant rich in energy in that region of the spectrum where the curves differ by the greatest percent and by reducing the light in the portion of the spectrum where the curves are reversed in magnitude.

Illumination for Cherry Sorting

Analysis of perceptibility of cherry defects revealed that the main color difference between red tart cherries and their defects was due to lightness contrast. Thus, only lightness differences were considered in the analysis. The analysis and field tests led to the following statements.

A. For sorting dark defects (ranging from brown rot to black) from red tart cherries:

1. The lightness contrast between dark defects and red tart cherries may be increased by using chromatic illuminants which have strong radiation in the red region of the spectrum (Table XI).

2. For dark defects the 2910° K tungsten lamp (approximately 150 watt incandescent bulb) produces the greatest lightness contrast of illuminants considered when used without a filter (see Appendix III for illuminants).

3. The G. E. deluxe warm white fluorescent lamp without a filter is the most efficient of lamps considered in producing reflected luminous flux from the cherry surface; that is, it possesses the highest efficiency when using lightness of the cherry surface as the measure of efficiency.

4. Statements "2" and "3" apply when using certain low-cost gelatine filters over the illuminants (Table XI).

5. For theoretical filters, which perfectly absorb or transmit, the G. E. deluxe warm white fluorescent lamp possesses considerable advantage in illuminant efficiency for the same lightness contrast as obtained with the 2910° K tungsten lamp (Table IX and X).

6. Red illumination proved to be unsatisfactory because of worker complaints. Whether these complaints were due to psychological reactions or to physiological effects was not determined.

7. In general, illumination provided by covering the illuminant with a purple filter, B-23, was favorably received by the workers.

8. An estimate of a satisfactory illuminant for producing high lightness contrast for dark defects on cherries is as follows: a. produce at least 180 foot-candles on the belt by use of tungsten lamps or 300 foot-candles by use of G. E. deluxe warm white fluorescent lamps, and

b. cover with filter B-23; other filters may also be satisfactory (See section on FURTHER ANALYSIS OF CHERRY SORTING). From laboratory observations it appears that increasing the illumination beyond these limits will increase somewhat the perceptibility of dark defects.

9. There should be some general illumination in the room although if this illumination is too high it will decrease the lightness contrast and adapt the eyes to a higher level of illumination. An estimate of a satisfactory level of illumination in the plant is approximately 10 foot-candles.

10. The most favorable adaptive condition is to have the eye adapted to a field of uniform lightness; i.e. lightness of product, background, and surround should be equal. In this respect a background darker than the product is preferred to a lighter one.

11. Reflectance curves of the common belting materials used in cherry processing plants show that the black belt most nearly satisfies the requirement for uniform field lightness for white illumination. However, when filters are used which absorb much of the radiation between 500 and 600 Mu, the tan belt may be as satisfactory. The fruit guards and the workers' clothing should not have high reflectance and no bright illuminants should be in clear vision of the workers.

B. For sorting under-color cherries or other defects which are lighter than brown rot from red tart cherries:

1. The lightness contrast for under-color defects is increased only slightly by changing the spectral distribution of the illuminant.

2. From the standpoint of illuminant efficiency and lightness contrast the daylight fluorescent lamp is the most satisfactory of the illuminants considered.

3. The reflectance of the background should be between the reflectance of the tan and black belts; therefore, the belt chosen for dark defects (part "A") should be acceptable.

4. Fruit guards and workers' clothing should not have high reflectances.

5. An estimate of general illumination for the room would be from 10 to 20 foot-candles.

6. If the processor desires to remove these light defects, the daylight fluorescent illuminant may be placed at the end of the sorting belt and a partition placed between it and the chromatic illuminant.

Sorting Dark Defects from Red Tomatoes

From the shape of the reflectance curves for red ripe tomatoes and from observations using filters over the eyes, the statements under numbers 8, 9, 10, and 11 of part "A" for cherry sorting should apply to sorting dark defects from red tomatoes.

Color Grading Tomatoes

The illuminant for color grading of tomatoes should possess radiation throughout the visible spectrum. If possible, color of the background should be the average color of the product. For grading tomatoes into four grades (green, pink, dark pink, and red) no additional recommendations were indicated by the analysis.

For grading tomatoes into light red and dark red, as in Michigan canning plants, it appears that the illuminant should possess radiation throughout the visible spectrum but should be especially rich in energy from approximately 580 to 640 Mu. Further research is needed on this point before definite recommendations can be made.

Viewing the Entire Surface of the Product

The literature shows that viewing the entire surface of the product is essential to high sorting efficiency. Since rotation of fruit brings most of its surface into view, two devices were developed and tested for rotating cherries as they move along the sorting belt. These were a small, smooth, stationary rod mounted across the belt and a friction-coated rod which rotated to lift the cherries over it. The merits and application features of these devices are listed as follows:

1. The stationary rod must be mounted closely against the belt in order to prevent cherries from being caught underneath it. On most sorting belts it appears necessary to support the belt underneath the rod in order to insure contact.

2. The stationary rod had the disadvantage of interferring with the passage of the belt lacing. It may be necessary to provide endless belts if this device is employed.

3. The maximum efficiency obtained with the stationary rod was approximately 55 percent of the cherries rotated 90° or more and 45 percent rotated 150° or more. The efficiency of this device decreases as the belt velocity increases and as the percent of the belt covered with fruit increases.

4. The efficiency of the rotating rod may reach 80 percent of the cherries rotated 90° or more and 60 percent rotated 150° or more. These efficiencies were obtained with the belt completely covered with cherries.

5. The rotating rod requires a driving mechanism.

6. The rotating rod was mounted approximately 1/16 inch above

the sorting belt. It did not interfere with the belt
the tests.

7. With a coating of black friction tape on the rotating rod, the maximum efficiency for rotating cherries was reached when the peripheral velocity of the rod was about twice the belt velocity.

8. These devices might be located between the workers along the belt. With this arrangement each successive worker would see many different cherry surfaces. In addition to rotating the cherries these devices have some beneficial effect in spreading the cherries across the sorting belt.

The literature provided the following statements:

1. Products, which are rotated continuously as they move along the belt, should rotate so that the top surface of the product moves in the same direction as the belt (forward rotation); otherwise, the workers may develop nausea at certain critical belt and rotational speeds.

2. For continous rotation, the product should rotate at least 3/4 of a revolution per foot of translation.

3. Smooth continous flow of the product is preferred to irregular flow and haphazard spacing.

<u>Other Factors</u>

1. Black and brown defective spots on cherries do not fluoresce when exposed to radiation of a high pressure mercury vapor lamp which possesses a group of spectral lines near 365 Mu.

2. It appears that cherries may be sorted by transmitted light. However, the intensity of illumination required is rather high.

3. Specular gloss from cherries may be minimized by using diffuse illumination. This should improve perception and be easier on the eyes.

APPENDIX I

REFLECTANCE CURVES

All reflectance curves for cherries, tomatoes, and belt samples were run with a Cenco-Sheard spectrophotometer at the Michigan State Highway Department's Research Laboratory. A picture illustrating the use of the spectrophotometer and the arrangement is presented in Plate VII. The sample and a reflectance standard were mounted on a disk which could be rotated and were illuminated with an airplane landing lamp at an angle of incidence of 45 degrees with the surface of the standard. The entrance slit of the spectrophotometer was positioned at zero degrees to the surface of the standard (perpendicular viewing). This arrangement avoids the main beam of specularly reflected light by 45 degrees and is recommended for use when visual appearance is the main objective (28). The reflectance standard and the samples were

PLATE VII. Kodachrome Picture of Spectrophotometer. The sample and the white reflectance standard in the background were rotated alternately into viewing position to take readings.

2.9 inches in diameter.

The standard of comparison (reflectance standard) consisted of magnesium oxide smoked on an aluminum plate. A fresh standard was prepared for each set of curves by collecting the smoke from burning magnesium ribbon in air. This standard is used almost universally as a color standard for spectrophotometric work (28). When the magnesium oxide is freshly prepared its reflectance varies less than one percent throughout the visible spectrum and its total reflectance in the visible range is 97 to 98 percent (29). The apparent reflectance of this standard, when illuminated at 45 degrees and viewed at the normal, has been adopted by the Internation Commission on Illumination as 1.00 (29).

The band width used for reflectance curves was 12.5 Mu or less except for curves of the sorting belts. In this case it was necessary to use 50 Mu band width due to lack of sensitivity of the available galvanometer. Thus, any sharp deviations in the reflectance curves for the belts would not be shown. However, they should represent a fair approximation for the purpose served.

After running curves for Florida tomatoes, the wavelength scale of the spectrophotometer was calibrated and a correction made for the scale readings. Different corrections were necessary for the wavelength scale readings after making adjustments. Appropriate corrections for the scale readings before and after calibration are shown in Table XII.

With the wavelength scale corrected and using the magnesium oxide standard with recommended angular conditions, the only other major source of error appeared to be the specularly reflected light from the

TABLE XII

Corrections for Wavelength Scale of
Cenco-Sheard Spectrophotometer

Scale Reading Mu	Corrected Wavelength for Plotting Before Calibration* Mu	Corrected Wavelength for Plotting After Calibration Mu
400	392	396
10	402	406
20	413	416
30	423	427
40	433	437
50	444	447
60	454	458
70	464	468
80	475	478
90	485	489
500	495	499
10	506	509
20	516	520
30	526	530
40	537	540
50	547	551
60	557	561
70	568	571
80	578	582
90	588	592
600	599	602
10	609	613
20	619	623
30	630	633
40	640	644
50	650	654
60	661	664
70	671	675
80	681	685
90	692	695
700	702	706
10	712	716
20	723	726

* This column applies only to the reflectance curves for Florida Tomatoes.

outside curved surface of the fruit. However, since specularly reflected light is directly proportional to the spectral distribution of the illuminant (i.e. non-selective reflection), it is possible to estimate the maximum specularly reflected light, especially if the reflectance curves have very low reflectance in some region of the spectrum. For the cherry curves given in the following pages it is noted that several of the red ripe cherry curves possess as little as one percent reflectance from 400 to 500 Mu. Therefore, it appears that the specularly reflected light should be less than 1 percent for this region of the spectrum and should not exceed 2 or 3 percent for the longer wavelengths of light where the intensity of the incandescent illuminant is considerably greater.

For the tomato curves, however, it appears that the specularly reflected light was much greater. An estimate would be in the vicinity of 5 to 10 percent for the short wavelengths with a maximum of 15 to 20 percent for long wavelengths. It was noted that rotation of the sample sometimes changed the reflectance of a sample as much as 5 percent.

The reflectance curve of cherry sample 5 (black defect) increased slightly from 620 to 720 Mu. This increase was attributed to a small edge of red which projected from the side of the cherry; thus, the slight increase in reflectance from 620 to 720 Mu was neglected and the curve was drawn straight at one percent for the red region of the spectrum (Figure 33).

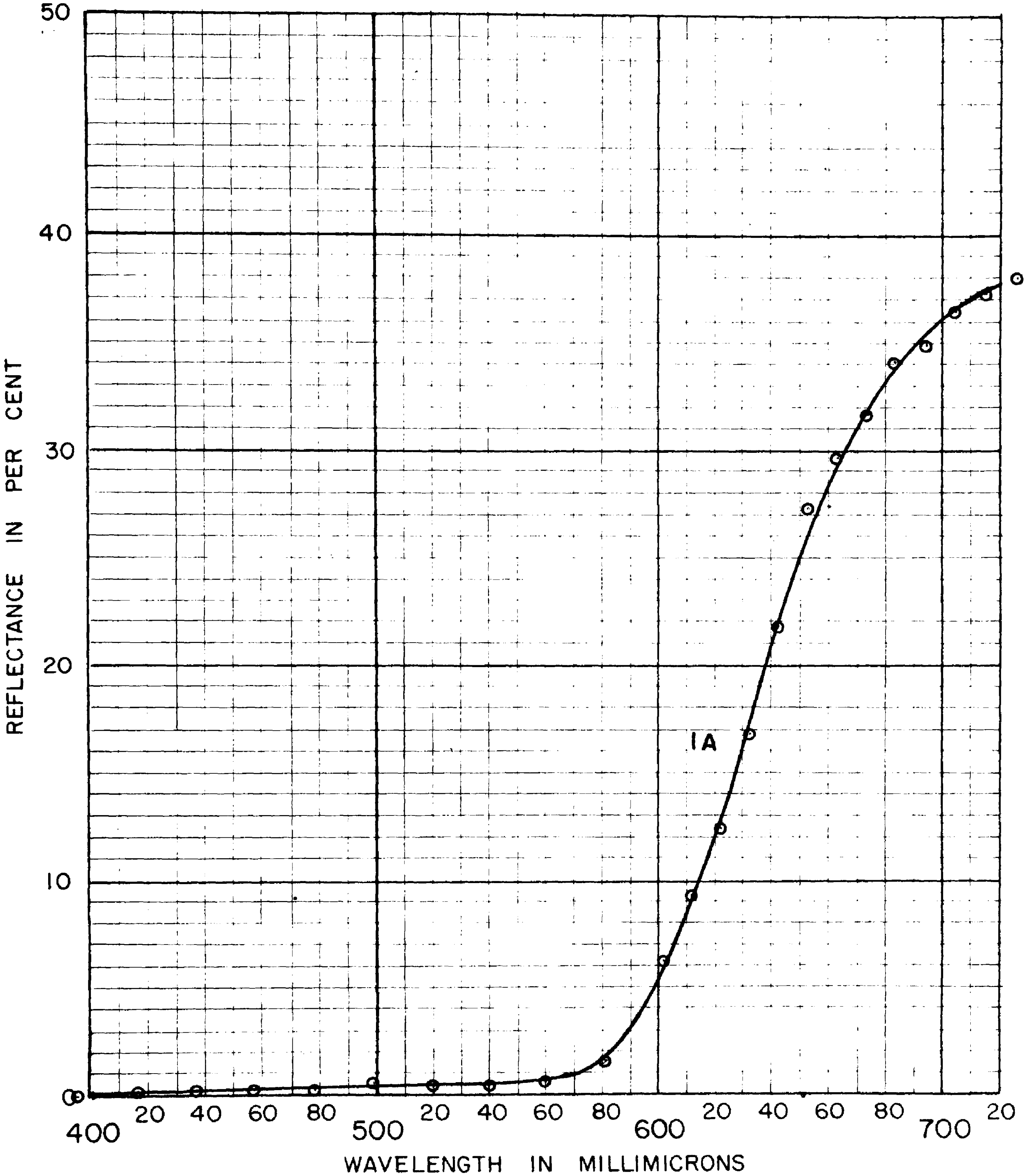


FIGURE 29. 45°-0° SPECTRAL REFLECTANCE CURVE FOR RED RIPE EARLY RICHMOND CHERRIES

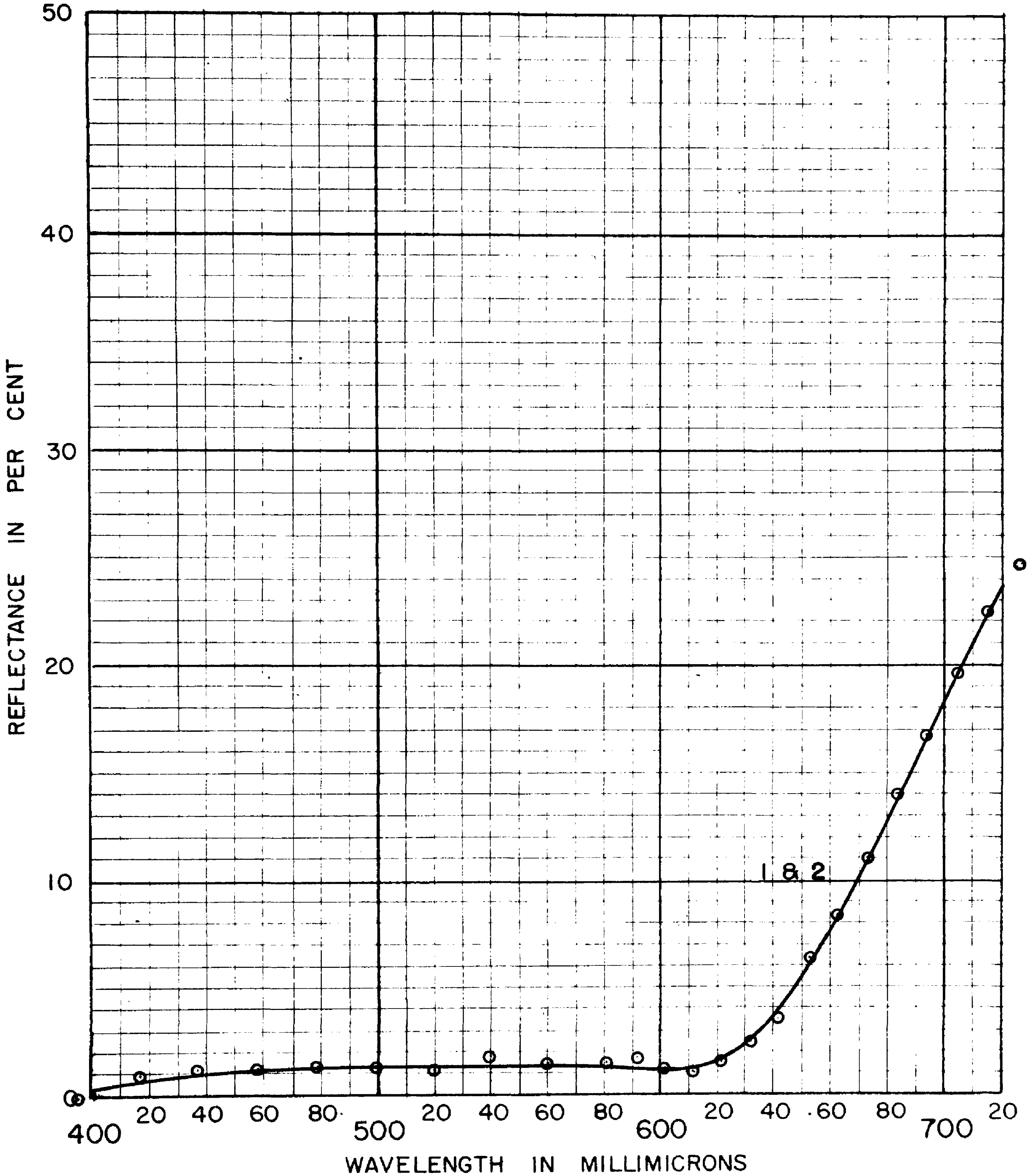


FIGURE 30. 45°-0° SPECTRAL REFLECTANCE CURVE FOR RED RIPE SCHMIDT CHERRIES

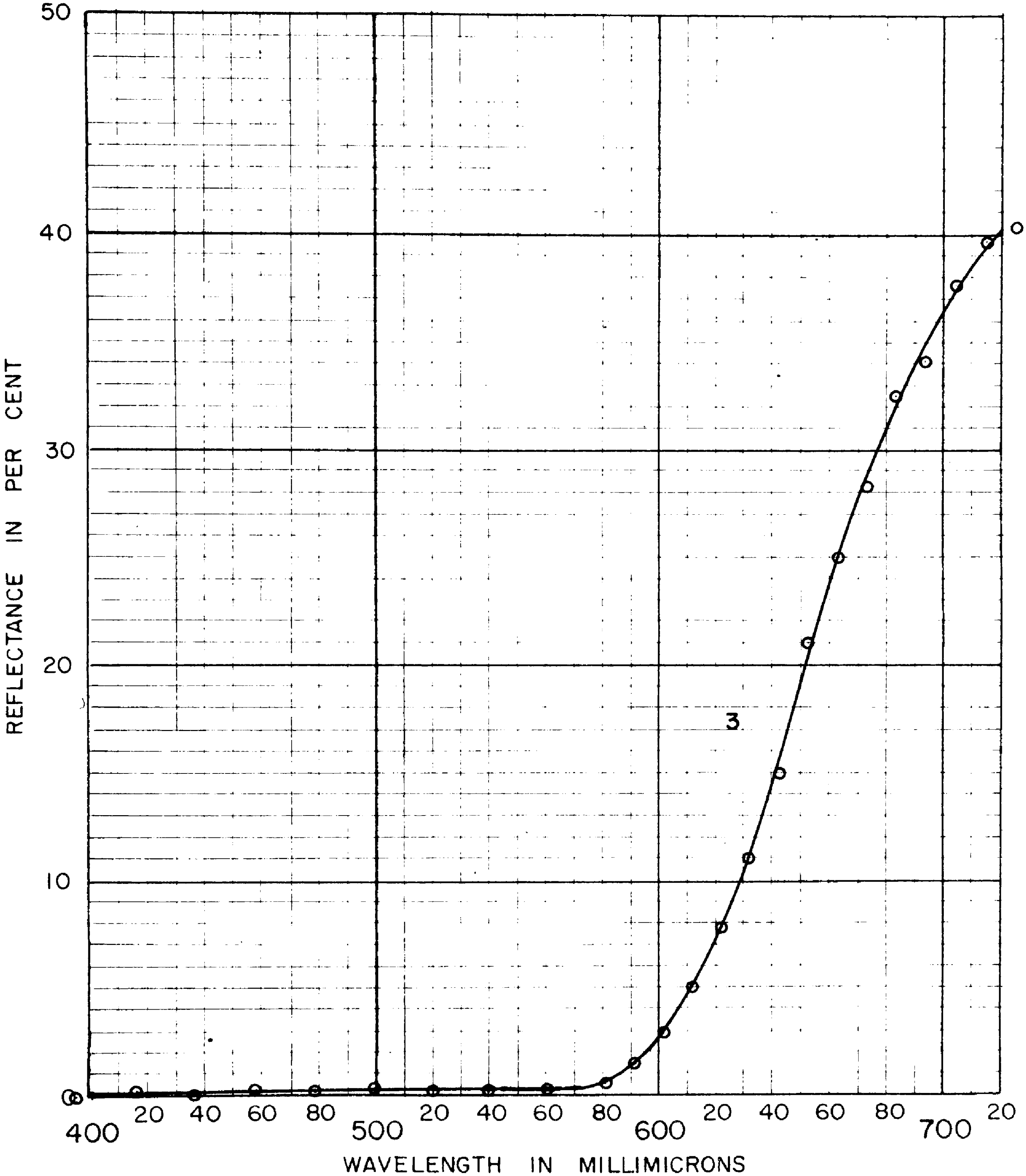


FIGURE 31. 45°-0° SPECTRAL REFLECTANCE CURVE FOR LIGHT COLORED SCHMIDT CHERRIES

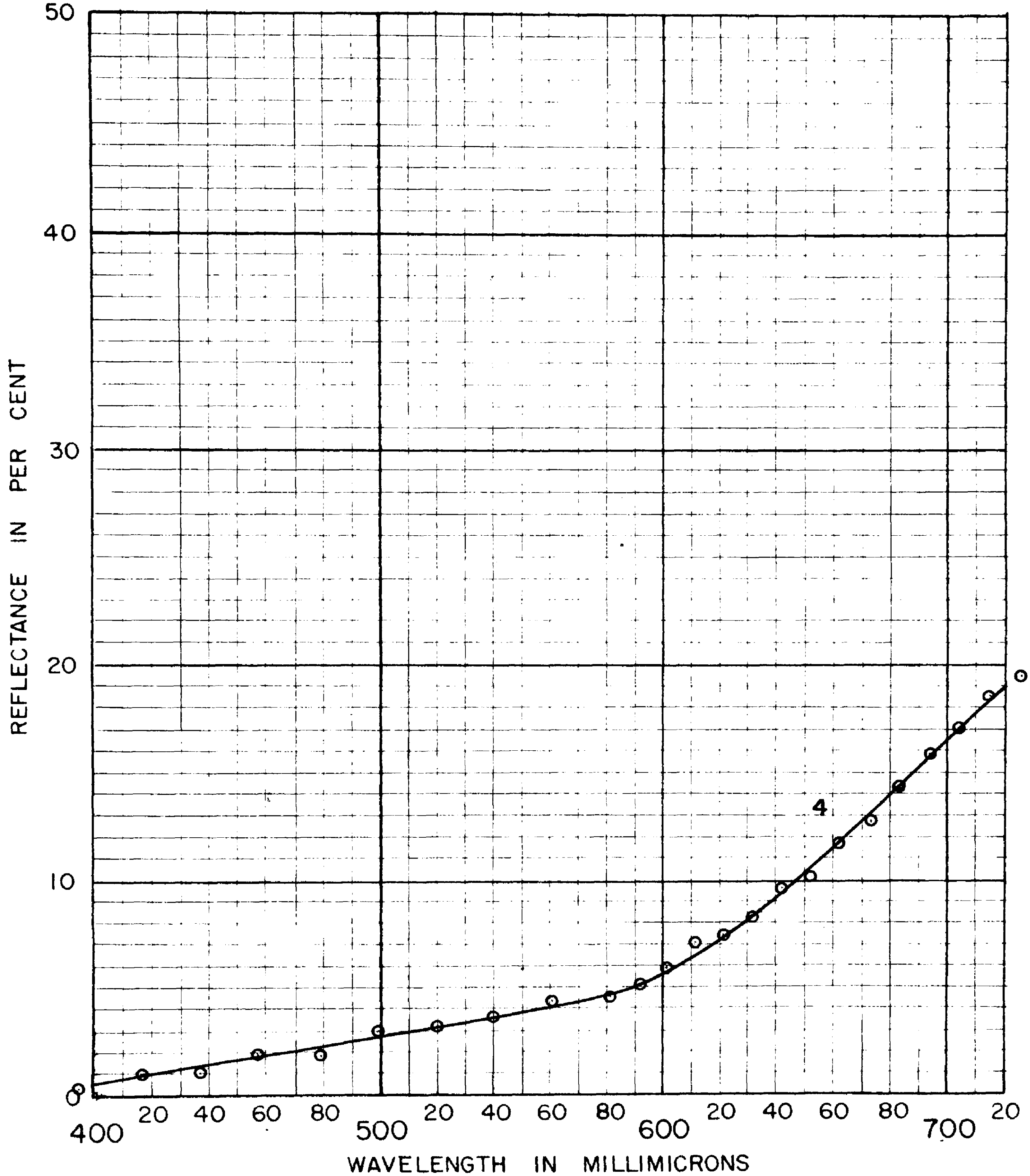


FIGURE 32. 45°-0° SPECTRAL REFLECTANCE CURVE FOR BROWN DEFECTIVE SCHMIDT CHERRIES

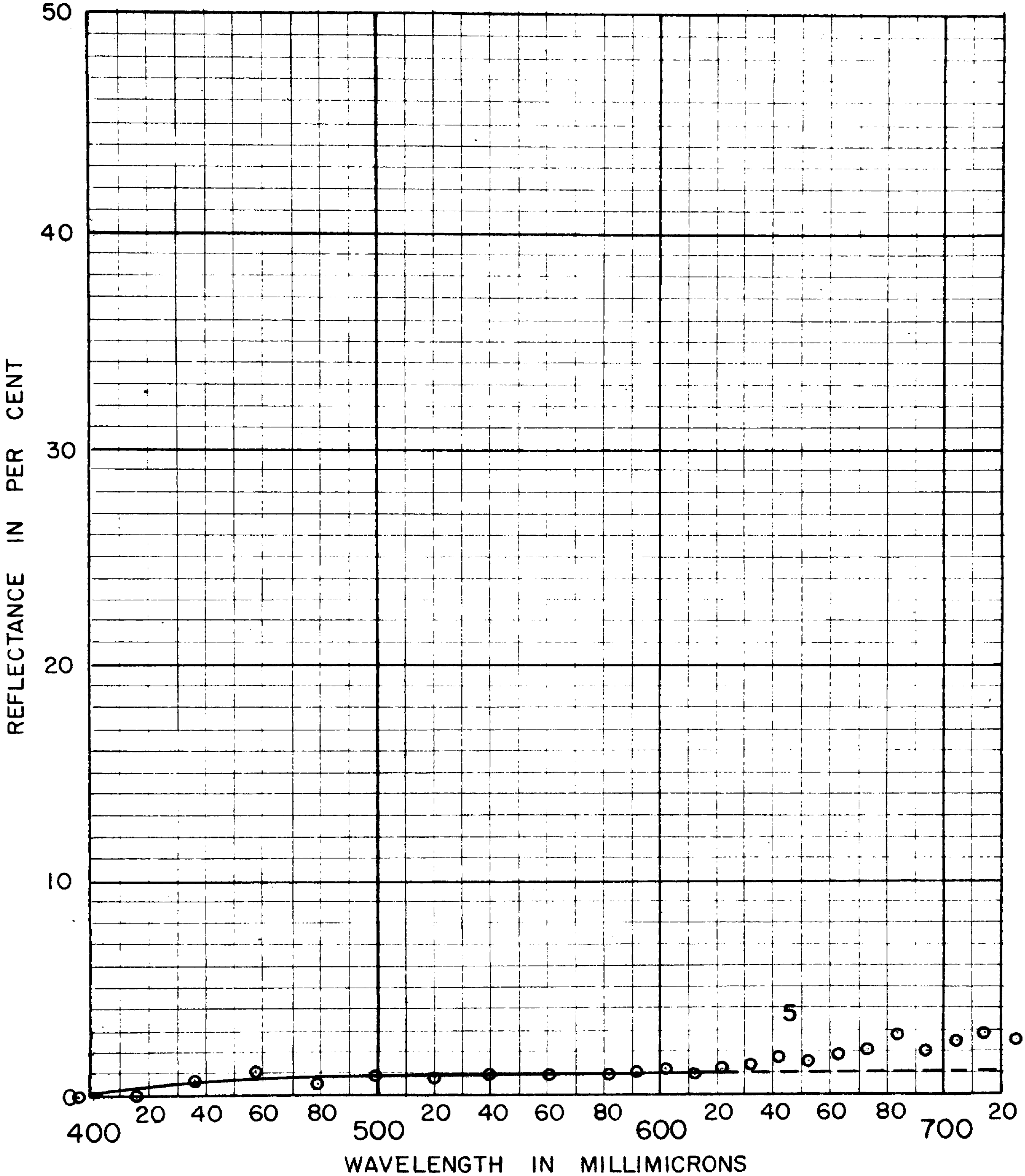


FIGURE 33. 45°-0° SPECTRAL REFLECTANCE CURVE FOR BLACK DEFECTIVE SCHMIDT CHERRIES

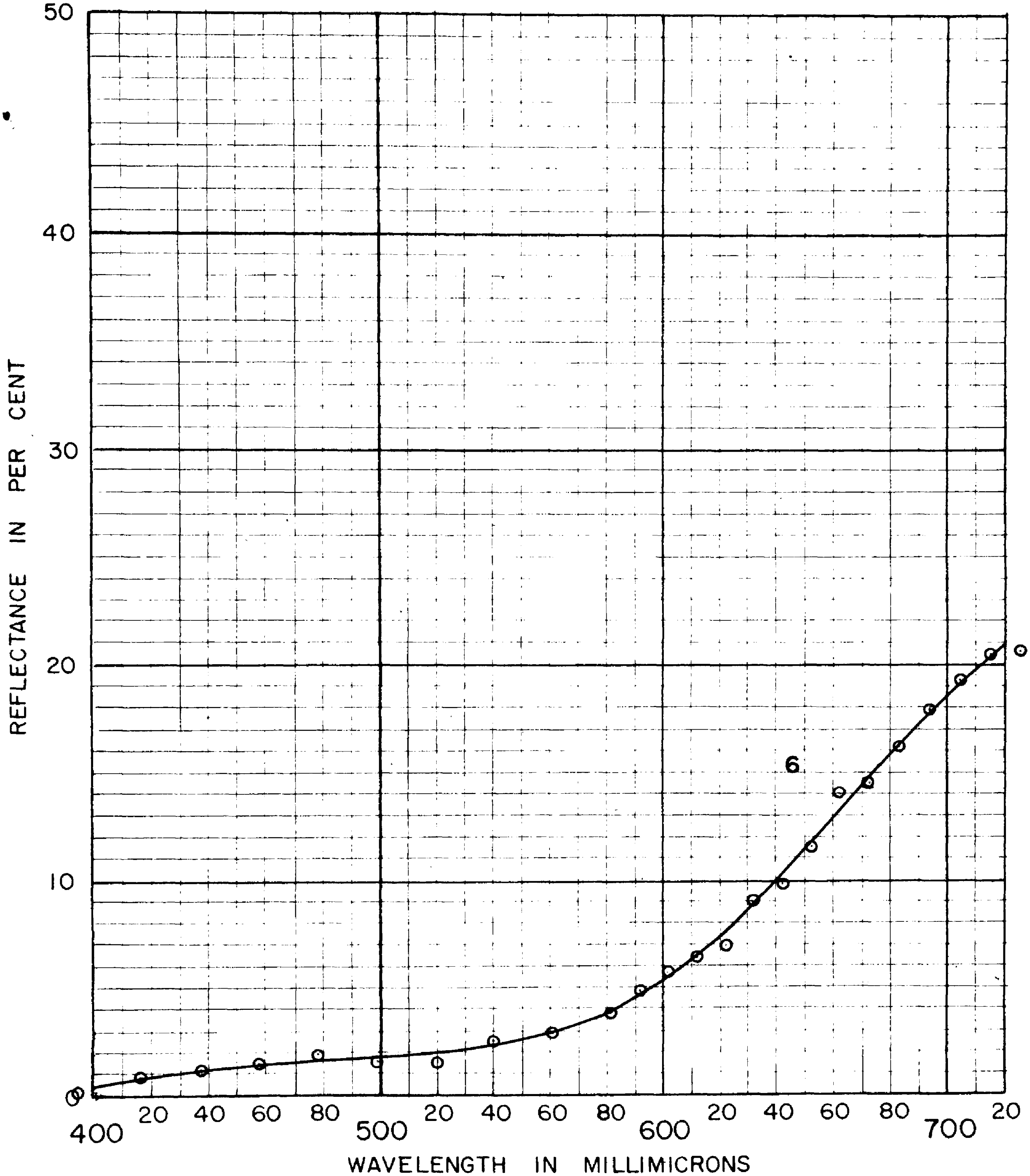


FIGURE 34. 45°-0° SPECTRAL REFLECTANCE CURVE FOR BROWN DEFECTIVE MONTMORENCY CHERRIES

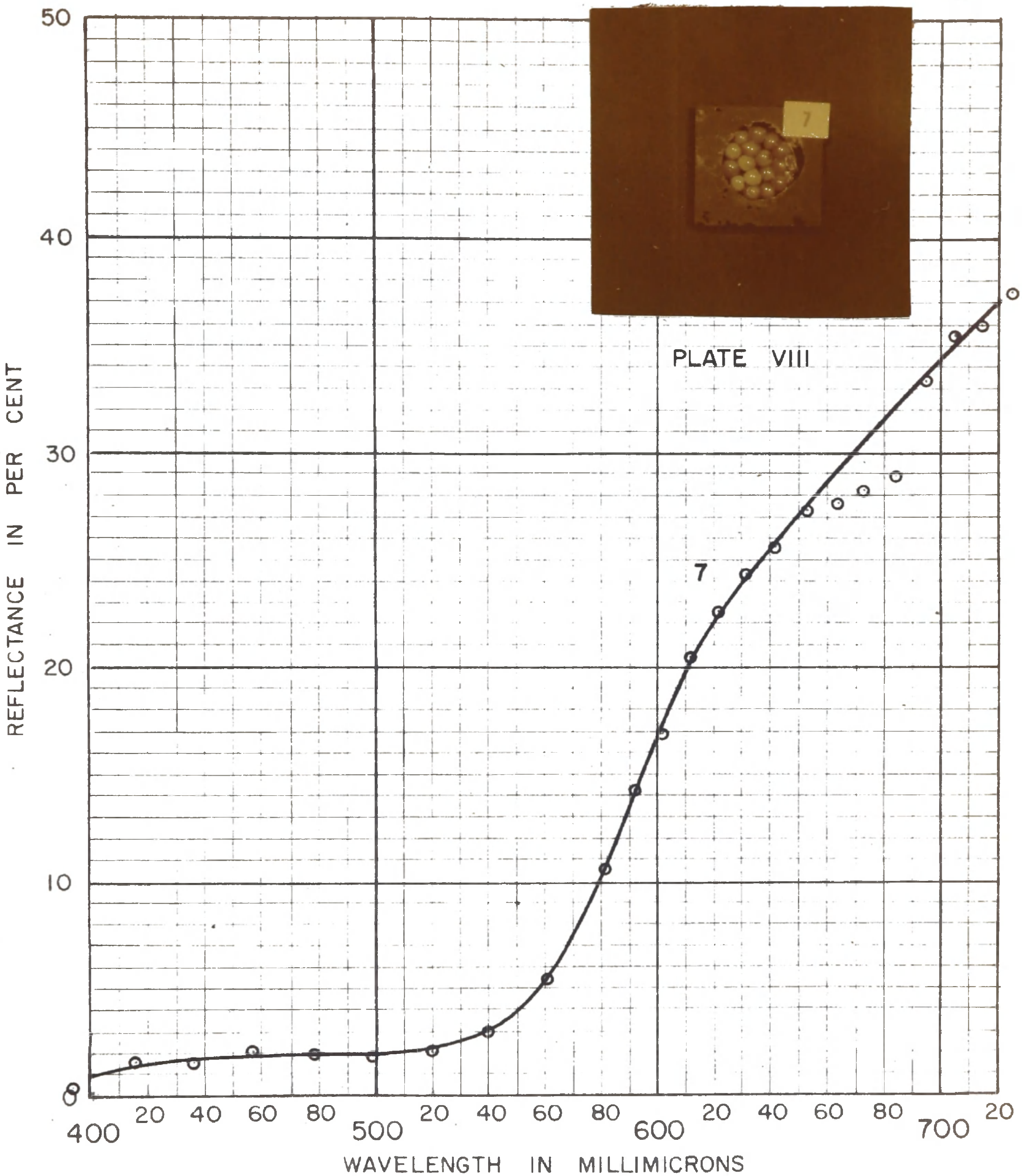


PLATE VIII

FIGURE 35. 45°-0° SPECTRAL REFLECTANCE CURVE FOR UNDER-COLOR MONTMORENCY CHERRIES

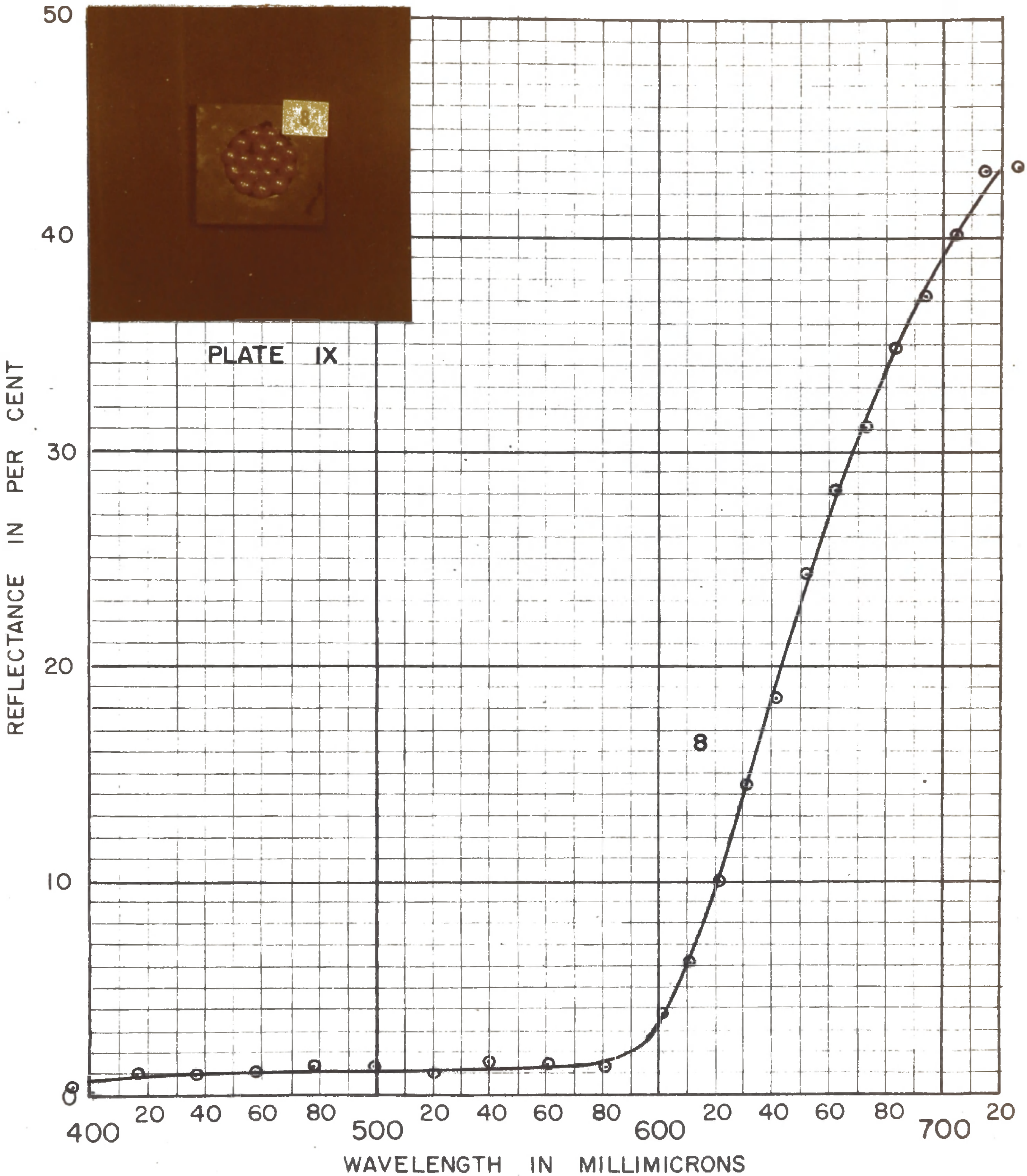


FIGURE 36. 45°-0° SPECTRAL REFLECTANCE CURVE FOR RED RIPE MONTMORENCY CHERRIES

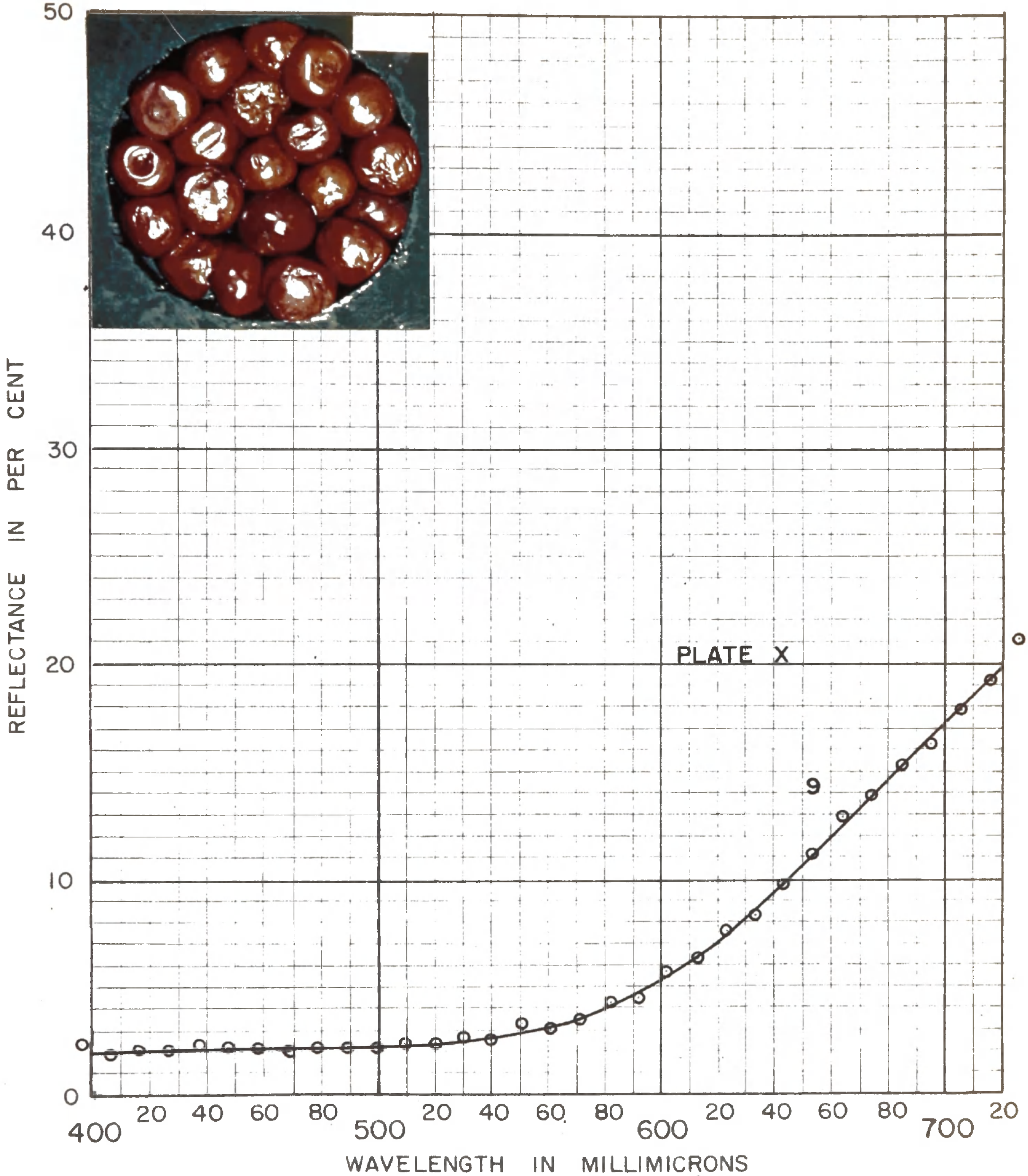


FIGURE 37. 45°-0° SPECTRAL REFLECTANCE CURVE FOR BROWN DEFECTIVE MONTMORENCY CHERRIES

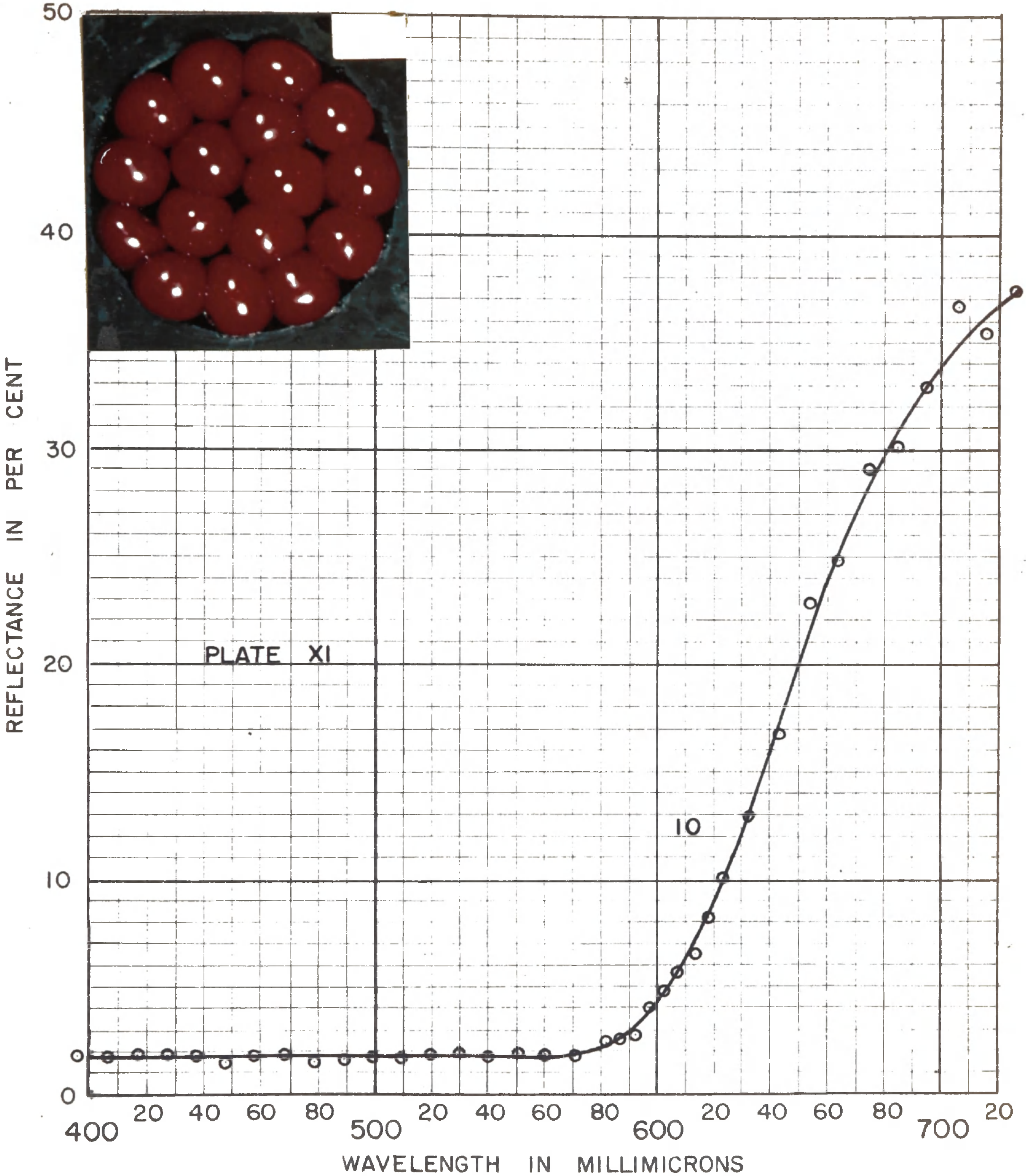


FIGURE 38. 45°-0° SPECTRAL REFLECTANCE CURVE FOR RED RIPE MONTMORENCY CHERRIES

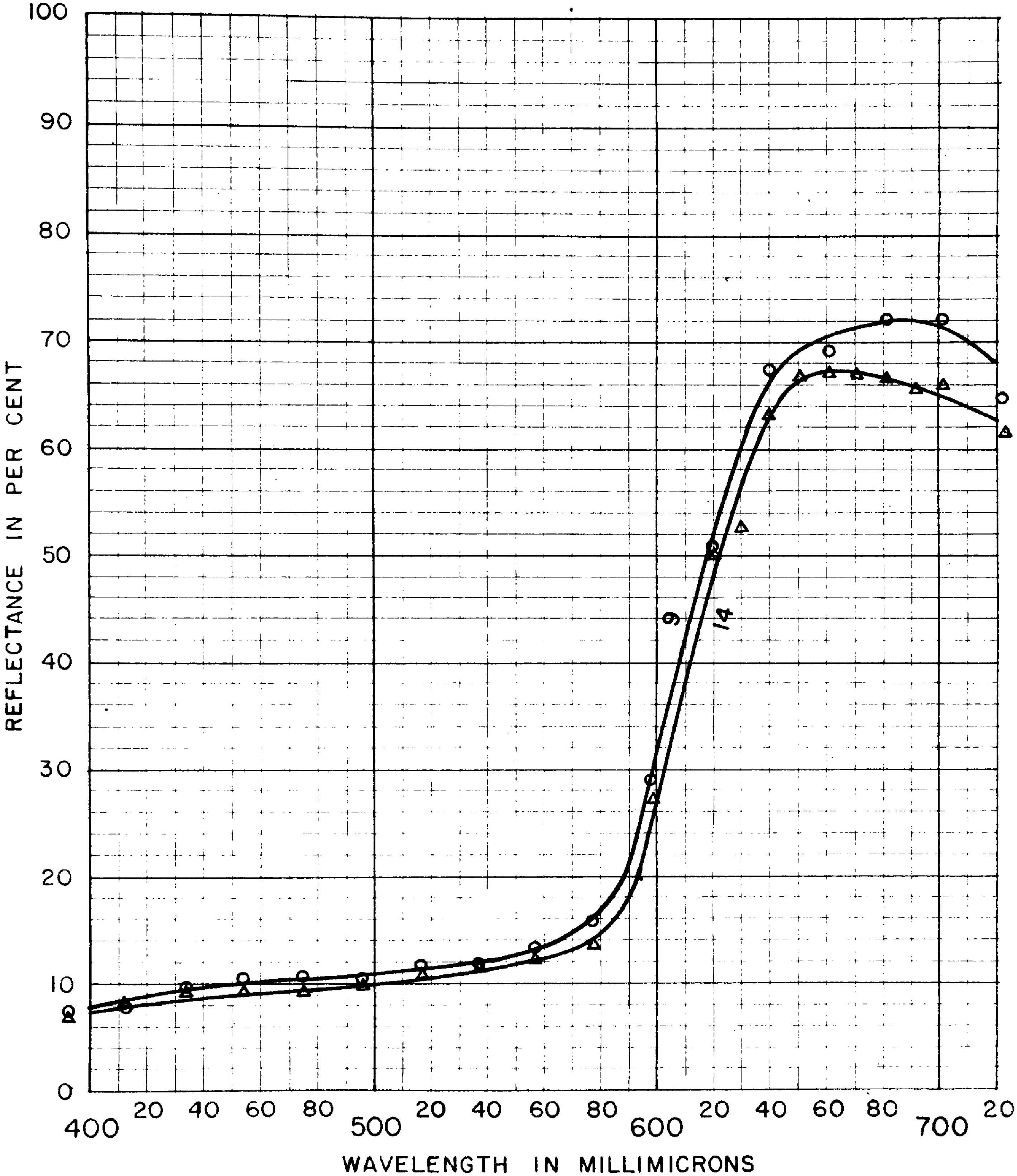


FIGURE 39. 45°-0° SPECTRAL REFLECTANCE CURVES FOR RED RIPE FLORIDA GROWN TOMATOES

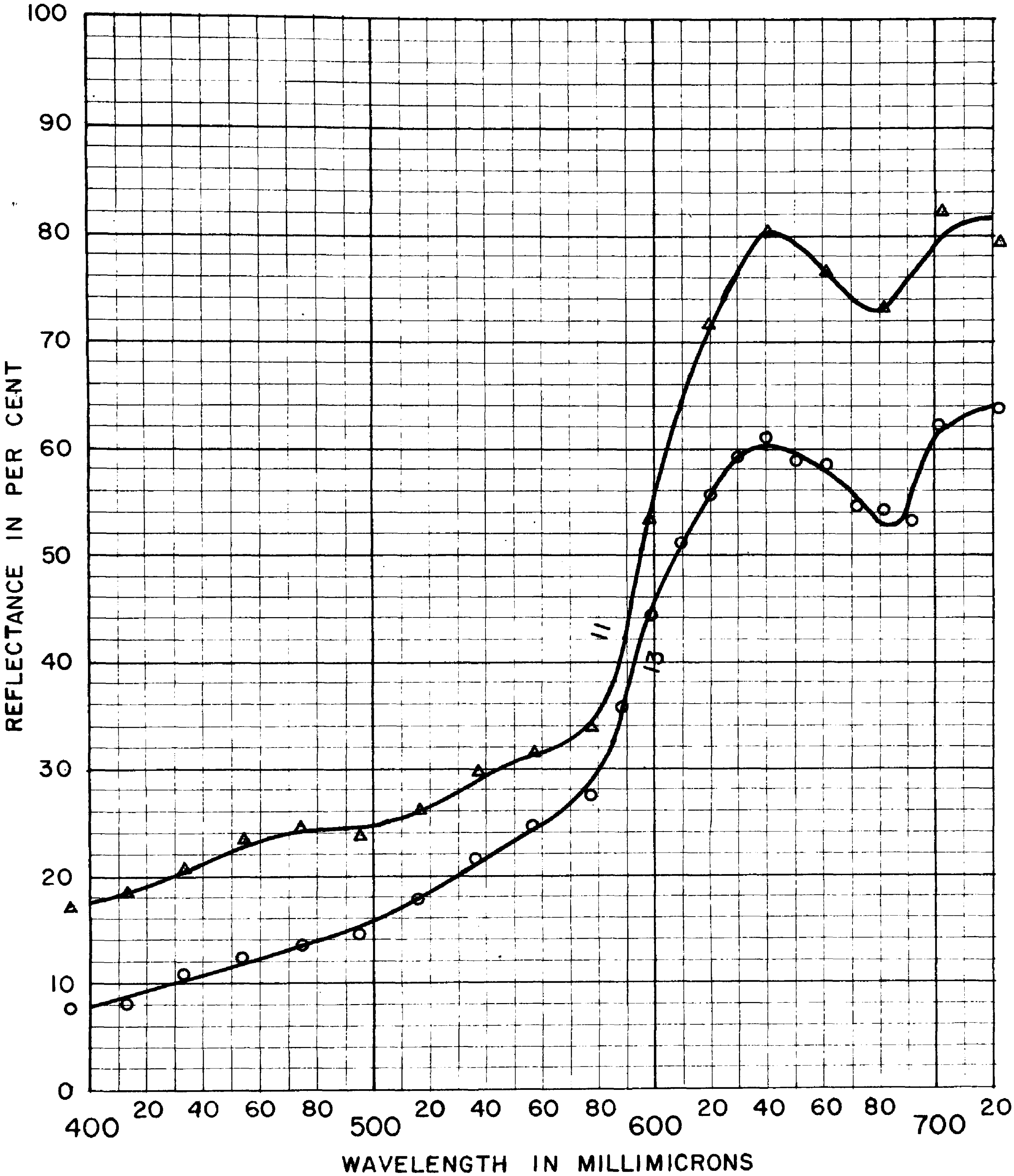


FIGURE 40. 45°-0° SPECTRAL REFLECTANCE CURVES FOR PINK * FLORIDA GROWN TOMATOES

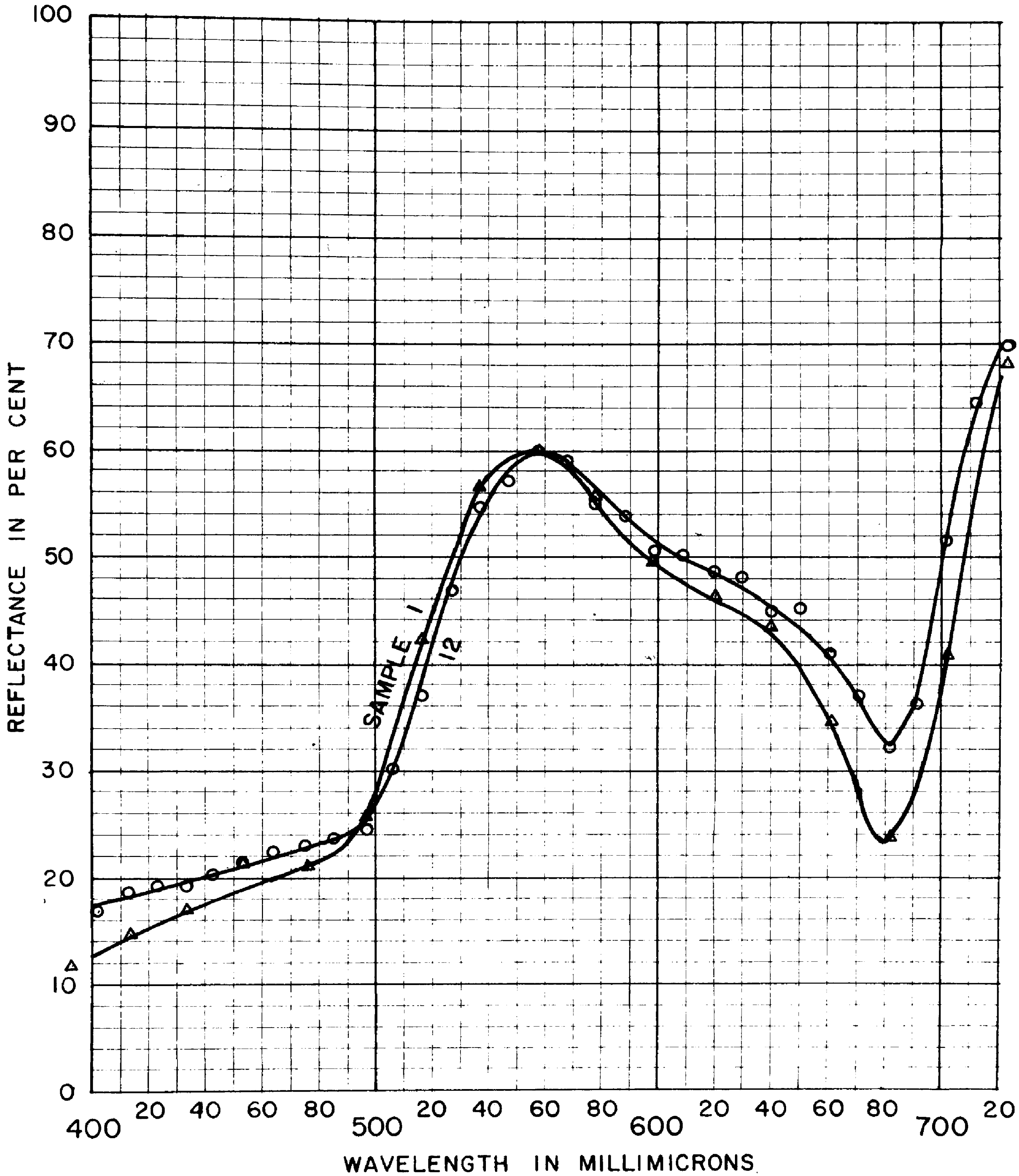


FIGURE 41. 45°-0° SPECTRAL REFLECTANCE CURVES FOR GREEN FLORIDA GROWN TOMATOES

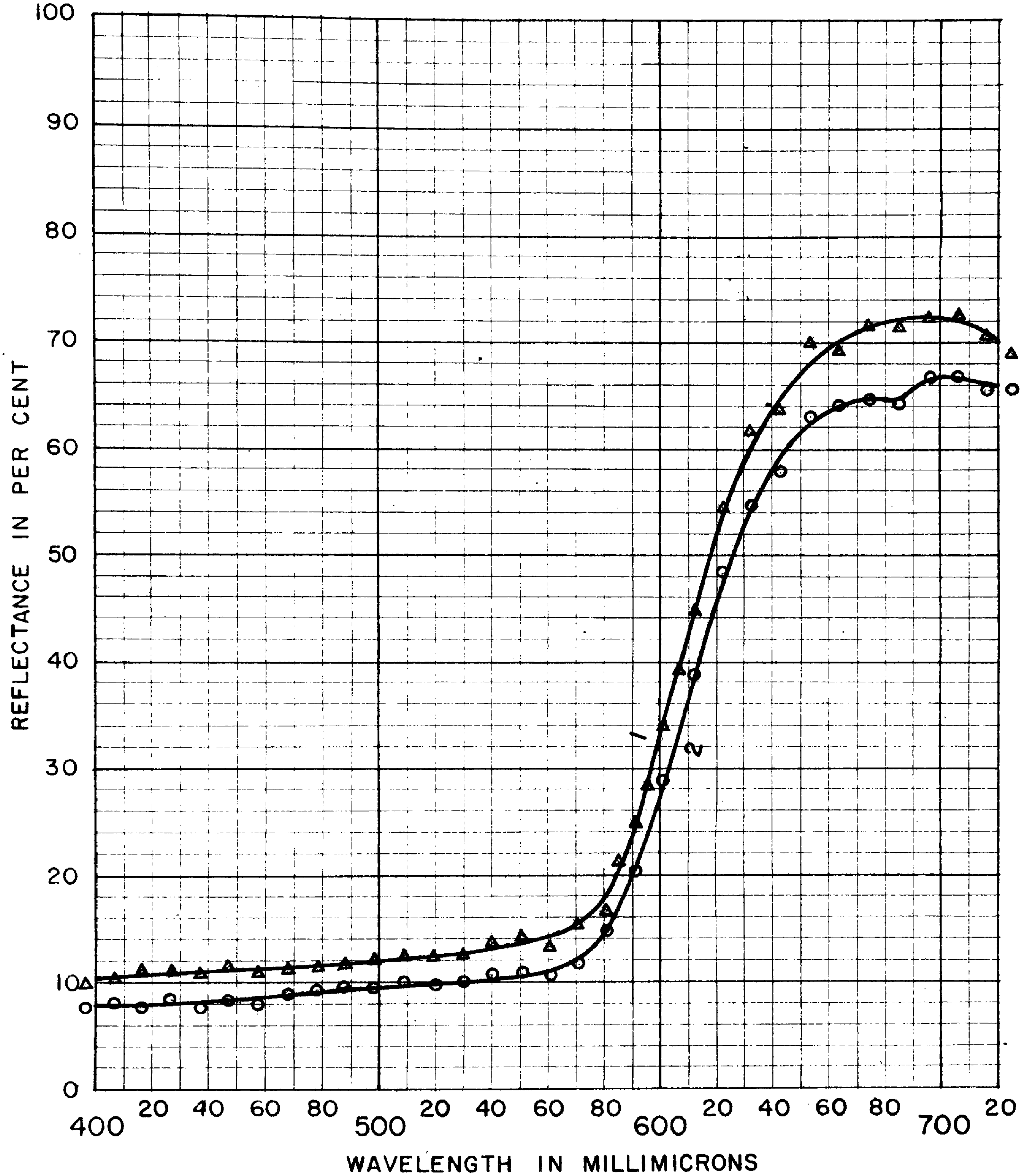


FIGURE 42. 45°-0° SPECTRAL REFLECTANCE CURVES FOR LIGHT RED MICHIGAN GROWN TOMATOES

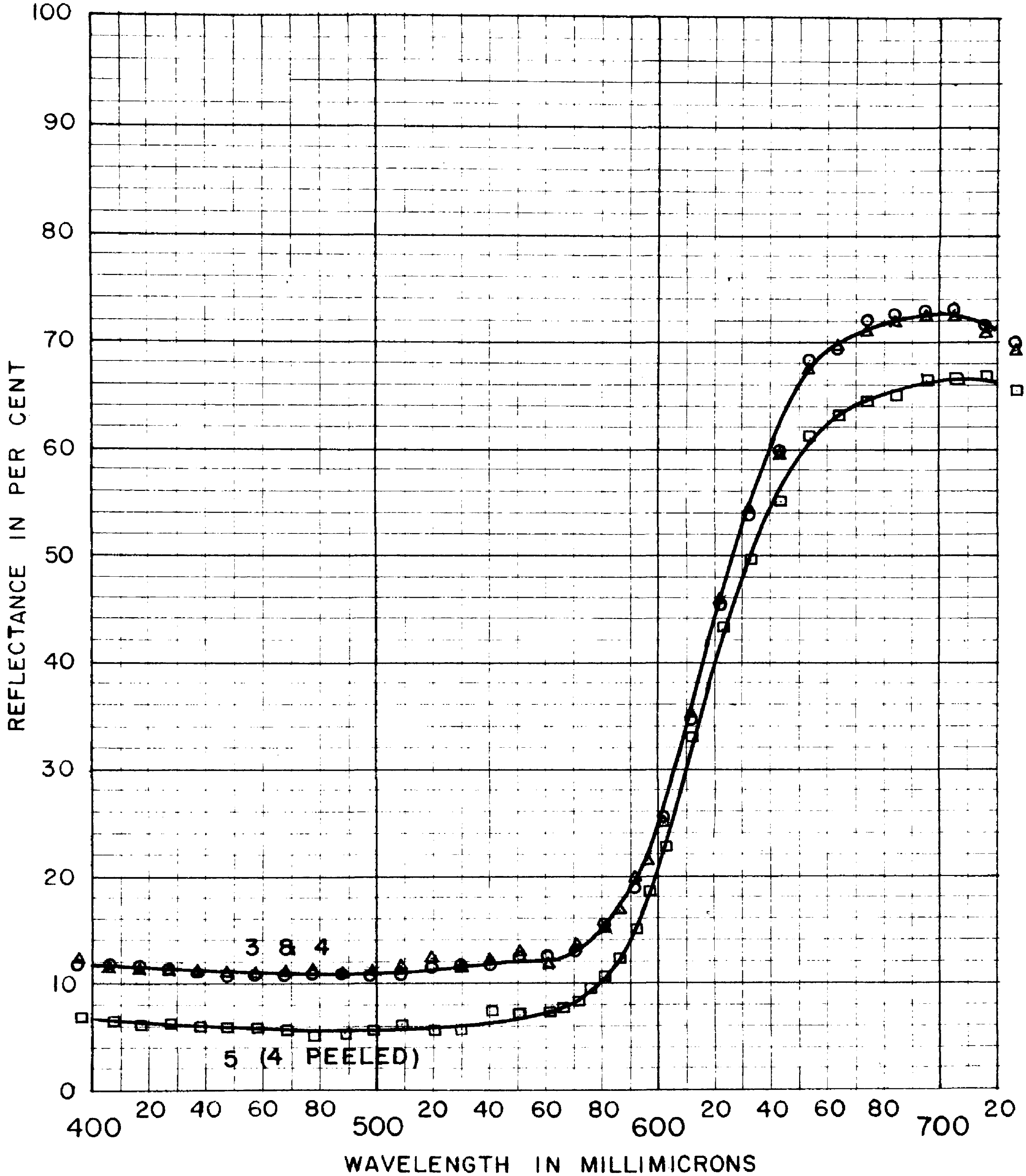


FIGURE 43. 45°-0° SPECTRAL REFLECTANCE CURVES FOR RED RIPE MICHIGAN GROWN TOMATOES

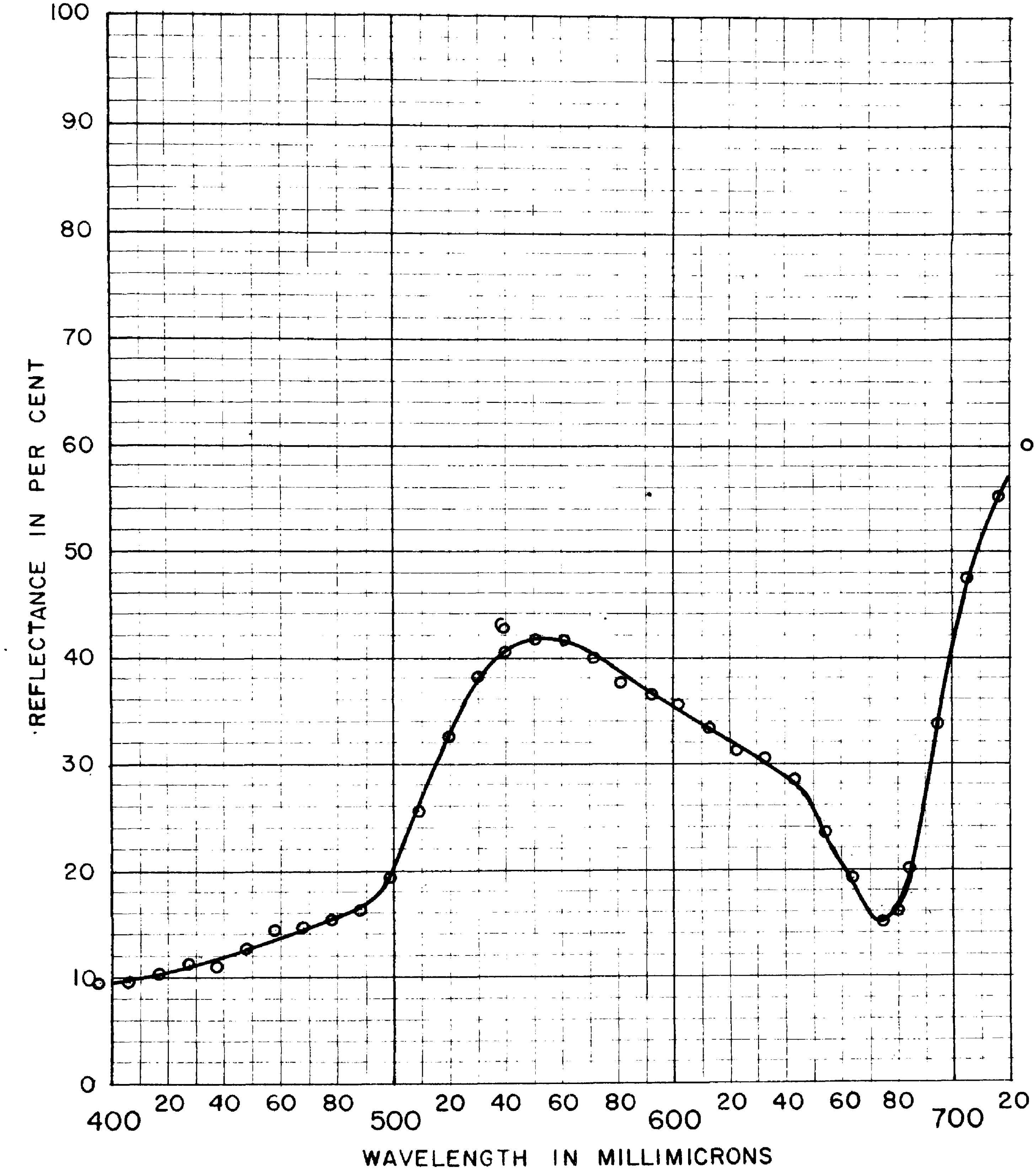


FIGURE 44. 45°-0° SPECTRAL REFLECTANCE CURVE FOR GREEN MICHIGAN GROWN TOMATO

APPENDIX II

FIELD TEST DATA

This section gives a list of samples and the number of defects counted for each sample in the chromatic illumination tests at three cherry processing plants. The samples given on one continous line were taken from the same batch of cherries as described in the field test procedure.

TABLE XIII

List of Samples and Defects Counted for Chromatic Illumination Tests at Plant A*

Before Sorting			Filter B-7			No Filter		
Total	Brown	Black	Total	Brown	Black	Total	Brown	Black
373	11	15	377	4	6	400	14	5
402	21	7	371	10	9	416	6	5
422	21	2	389	6	4	403	5	0
404	17	24	365	14	10	395	14	8
416	23	9	368	8	9	391	6	9
388	13	13	370	13	7	391	8	10
393	14	8	382	9	7	400	4	7
382	16	16	355	3	11	387	12	7
Total 3180	136	94	2977	67	63	3183	69	51
% defects	4.28	2.95		2.25	2.12		2.16	1.60

Before Sorting			Filter B-11			No Filter		
Total	Brown	Black	Total	Brown	Black	Total	Brown	Black
368	10	7	385	2	6	358	7	6
383	16	16	374	1	7	341	5	4
397	20	11	381	7	10	383	20	12
405	10	13	393	4	2	376	12	0
351	24	12	377	13	1	390	14	9
409	18	31	400	11	12	388	20	9
345	21	9	348	13	3	340	16	10
Total 2658	119	99	2658	51	41	2576	94	50
% defects	4.48	3.72		1.92	1.54		3.65	1.94

(Continued)

TABLE XIII (cont'd)

List of Samples and Defects Counted for
Chromatic Illumination Tests at Plant A*

Before Sorting			Filter B-23			No Filter		
Total	Brown	Black	Total	Brown	Black	Total	Brown	Black
368	34	9	411	35	3	399	19	10
375	39	4	396	30	0	390	19	4
389	10	10	369	8	11	425	7	9
348	11	18	374	17	4	397	8	13
372	13	10	380	12	11	399	8	16
392	19	15	382	14	6	414	13	7
379	12	13	368	6	5	397	3	6
Total								
2623	138	79	2680	122	40	2821	77	65
% defects	5.25	3.01		4.55	1.49		2.72	2.30

Before Sorting			Filter B-67			No Filter		
Total	Brown	Black	Total	Brown	Black	Total	Brown	Black
405	15	15	395	6	7	402	17	9
444	21	15	425	5	1	382	5	3
432	23	12	417	6	7	413	18	4
372	13	9	378	10	3	381	12	8
413	28	5	395	19	7	365	18	12
330	12	8	358	6	5	314	5	5
335	12	18	356	7	4	321	10	6
327	14	9	345	5	5	354	4	4
Total								
3058	138	91	3069	64	39	2932	89	51
%defects	4.52	2.98		2.08	1.27		3.04	1.74

* The source for chromatic illumination consisted of G. E. deluxe warm white fluorescent tubes and the filter as indicated. Three tubes were used side by side (12 tubes total in fixture). For the comparison source a single tube fixture, (4 tubes total in fixture) containing G. E. deluxe warm white fluorescent tubes, was used. Four standard cool white fluorescent tubes were used regularly on belts.

TABLE XIV

List of Samples and Defects Counted for
Chromatic Illumination Tests at Plant B*

FILTER B-11						NO FILTER					
Total		Brown		Black		Total		Brown		Black	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
306	295	16	18	12	11	349	330	14	8	9	6
320	319	16	14	10	5	380	378	15	12	9	4
338	331	25	28	2	5	357	371	11	15	7	5
327	324	8	5	3	0	345	335	15	5	3	0
373	338	15	2	5	3	325	319	9	7	11	4
395	356	20	7	9	0	330	381	15	18	4	10
361	296	19	10	9	0	289	301	12	11	6	6
351	331	12	5	7	7	282	324	14	3	1	0
2771	2590	131	89	57	31	2657	2739	105	79	50	35
Total	percent	4.74	3.44	2.06	1.20			3.96	2.88	1.88	1.28

(Continued)

TABLE XIV (cont'd)

List of Samples and Defects Counted for
Chromatic Illumination Tests at Plant B*

FILTER B-23						NO FILTER					
Total		Brown		Black		Total		Brown		Black	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
320	330	10	12	15	5	390	345	18	8	18	10
349	355	15	11	12	12	345	349	19	6	15	6
361	379	25	10	12	4	352	383	15	9	11	5
335	365	14	4	4	2	355	345	12	12	4	3
338	325	17	7	3	6	333	328	17	8	10	5
337	353	14	8	14	4	359	343	15	9	14	10
368	352	9	6	6	8	343	361	13	13	5	3
387	366	24	9	3	0	358	364	15	9	5	7
2795	2825	128	67	69	41	2835	2818	124	74	82	49
Total	percent	4.58	2.37	2.47	1.45			4.38	2.62	2.89	1.74

*The source for chromatic illumination consisted of 100 Watt filament type incandescent lamps; twelve lamps covered with filter indicated were used for the entire belt. The comparison illuminant consisted of six 100 Watt lamps for the entire belt. This was the regular lighting used on belts.

TABLE XV

List of Samples and Defects Counted for Chromatic Illumination Tests at Plant C*

	Before Sorting				Filter B-23				No Filter			
	Total	Minor	Brown	Black	Total	Minor	Brown	Black	Total	Minor	Brown	Black
I	431	***	27	3	398	***	15	7	381	***	20	5
	412		24	16	393		13	3	402		33	8
	401	31	21	6	393	30	12	1	419	30	20	6
	436	47	22	6	476	20	13	5	442	32	23	4
	449	43	23	13	378	27	7	5	444	36	14	6
	444	26	20	4	395	35	9	3	410	32	17	2
	409	31	15	5	412	22	13	0	417	19	13	8
	393	27	14	15	401	35	26	12	432	31	15	10
II	434	24	16	10	430	17	13	5	437	26	16	8
	431	15	27	4	425	16	17	2	442	9	8	3
	395	16	11	6	422	11	11	2	417	20	8	3
	405	31	7	7	417	13	11	4	399	10	15	4
	413	20	19	6	400	7	16	4	424	9	8	7
	434	31	24	8	448	31	19	4	451	28	24	4
III	385	25	24	13	396	23	22	7	397	18	28	6
	367	21	32	7	394	17	22	4	377	12	23	5
	404	19	29	19	404	21	25	15	387	17	28	16
	425	16	29	16	418	20	37	8	385	16	31	17
	435	11	17	12	408	7	17	8	417	14	20	4
	464	18	32	12	425	2	13	9	460	15	15	8
IV	428	33	62	11	414	25	52	5	412	25	53	5
	333	13	49	17	354	8	36	5	358	11	33	6
	474	8	25	12	417	6	17	6	468	5	10	6
	423	16	15	7	409	8	25	7	432	9	27	11
	427	16	40	18	423	10	42	6	421	10	50	19
	444	12	79	30	441	20	68	27	438	6	46	29
	314	12	44	26	279	6	40	18	284	10	38	15
V	474	12	35	8	428	9	25	5	460	7	27	9
	459	20	42	12	455	9	20	5	479	6	26	2
	474	3	31	13	461	10	14	3	509	10	29	6
	454	9	39	16	443	7	29	5	435	4	29	11
	474	10	44	14	500	10	38	6	452	6	28	4
	420	7	38	17	437	7	33	12	422	4	26	9

(Continued)

TABLE XV (cont'd)

List of Samples and Defects Counted for Chromatic Illumination Tests at Plant C*

	Before Sorting				Filter B-23				No Filter			
	Total	Minor	Brown	Black	Total	Minor	Brown	Black	Total	Minor	Brown	Black
VI	470	11	55	12	448	15	29	9	438	13	36	12
	430	10	37	11	430	12	27	5	417	8	37	12
	419	6	29	12	411	4	26	8	409	10	33	9
	412	6	47	9	395	10	48	5	413	12	30	7
	439	8	42	18	437	10	46	6	453	4	48	9
	428	5	40	10	427	7	36	4	451	3	54	8
	Totals and Percent Defective											
	16563	669 4.25	1226 7.41	461 2.78	16299	547 3.52	982 6.02	255 1.57	16491	537 3.41	1039 6.32	323 1.96
	Totals and Percent Defective (excluding Test IV)**											
	13720	559 4.34	912 6.65	340 2.48	13508	464 3.64	702 5.20	181 1.34	13678	461 3.58	782 5.72	232 1.70

* The source for chromatic illumination consisted of 150 Watt filament type incandescent lamps; twelve lamps, covered with filter B-23, were used for the entire belt. The comparison illuminant consisted of six 150 Watt lamps for the entire belt.

**Test IV was eliminated from the test data because the number of defects was excessive. All workers could locate more defects under either illuminant than they could remove.

***Minor defects were not counted for the first two samples.

APPENDIX III

SPECTRAL DISTRIBUTION OF G. E. FLUORESCENT
AND
TUNGSTEN FILAMENT LAMPS

This section gives in tabular form the spectral distribution of the G. E. daylight fluorescent, G. E. deluxe warm white fluorescent, and the 2910° K tungsten filament lamps. The same designation for illuminants of other manufacturers may not have the same spectral distribution. Also the spectral distribution of lamps manufactured in the future may be altered. The values presented here were obtained from the Nela Park laboratory of the General Electric Company in 1953.

TABLE XVI

Spectral Distribution of G. E. Fluorescent and Tungsten Filament Lamps.*

Wavelength Mu	Microwatts per 10 Mu per Lumen: Daylight Fluorescent	Deluxe Warm White Fluorescent	2910° K Tungsten Filament Lamp**
400	129.0	94.3	22.5
10	67.7	9.5	27.5
20	86.7	12.3	32.5
30	102.9	14.0	37.5
40	315.4	255.8	43.5
50	130.0	19.0	50.0
60	138.8	20.6	57.0
70	140.8	22.3	63.5
80	140.3	23.4	70.5
90	135.4	27.3	78.5
500	127.9	39.6	86.0
10	119.2	64.2	94.5
20	112.1	92.2	102.0
30	107.2	100.0	111.0
40	108.2	100.5	119.5
50	222.2	217.0	129.0
60	144.1	114.0	137.5
70	156.0	130.7	146.0
80	189.0	187.0	154.5
90	153.9	183.0	163.0
600	137.7	204.0	172.0
10	107.1	208.0	180.5
20	95.4	199.0	189.0
30	74.8	181.0	197.5
40	58.5	155.7	205.0
50	45.5	128.0	212.5
60	35.2	100.5	220.0
70	26.6	78.7	227.5
80	19.5	59.2	233.5
90	14.6	44.7	240.0
700	11.9	31.2	247.0
10	9.6	22.4	252.5
20	8.0	16.0	258.5

* Tolerance of manufacture may be as high as plus or minus five percent.

** Values in this column were read from spectral distribution curve for tungsten filament lamps.

APPENDED REFERENCES

1. U.S.D.A. Standards for Grades of Canned Red Sour (Tart) Pitted Cherries. Production and Marketing Administration. 5th issue. June 23, 1949.

2. Nickerson, D. "Color Measurement and Its Application to the Grading of Agricultural Products." A Handbook on the Method of Disk Colorimetry. Misc. Pub. 580. U.S.D. A. March 1946.

3. Michigan Agricultural Statistics. Michigan Department of Agriculture May 1953.

4. The Science of Color. Committee on Colorimetry, Optical Society of America. T. Y. Crowell Co. New York. pp. 67,69-173,220-253,376. 1953.

5. Peterson, G. M. The Effects of Color Environment on Grading Efficiency in Food Processing Plants. Unpublished M. S. Thesis. Michigan State College. 1951. 78 numb. leaves.

6. Farnham, R. E. and E. A. Linsday. "Colored Lighting for Color Printing". Nela Park, Cleveland, Ohio. General Electric Bulletin LS-122 1949.

7. White, D. C. "Maximizing Color Differences." Ph. D. Thesis in Electrical Engineering, Stanford University. 1950. 122 numb. leaves.

8. Nickerson, D. "The Illuminant in Color Matching and Discrimination." Illuminating Engineering. v. 36, pp. 373-399. 1941.

9. Taylor, A. H. "The Nature and Causes of Small Color Differences in Industry; Lighting for Their Detection." J. of Opt. Soc. of America. v. 32, no. 11, pp. 651-658. November 1942.

10. Judd, D. B. Oral Communication. June 25, 1953.

11. Malcolm, D. G. and E. P. DeGarmo. Visual Inspection of Products for Surface Characteristics in Grading Operations. U.S.D.A., Production and Marketing Administration. Marketing Research Report No. 45. Washington, D. C. June 1953.

12. Rossi, A. "Some Effects of Direction, Speed, and Size in the Visual Inspection of Cylindrical Surfaces." Unpublished Masters Thesis, University of California. September 1951. (After Ref. 11).

13. DeHart, A. L. "Inspection of Cylindrical Surfaces in Combined Translation and Rotation." Unpublished Masters Thesis, University of California. July 1950. (After Ref. 11).

14. Evans, R. M. "Psychological Aspects of Color and Illumination." *Illuminating Engineering*. v. 46, pp. 176-181. April 1951.

15. Evans, R. M. *An Introduction to Color*. John Wiley and Sons. New York. pp. 95-137, 164. 1948.

16. Bartley, S. H. *Vision*. D. Van Nostrand Company. 1941.

17. Judd, D. B. *Color in Business, Science, and Industry*. Wiley and Sons, Inc. New York. pp. 1-30, 80-131, 249. 1952.

18. Ruch, F. L. *Psychology and Life*. 3rd Edition. Scott, Foresman and Company. 1948.

19. Wald, George. "Molecular Basis of Visual Excitation." *American Scientist*. v. 42, pp. 73-95. January 1954.

20. Helson, Harry. "Fundamental Problems in Color Vision. I. The Principle Governing Changes in Hue, Saturation, Lightness of Non-Selective Samples in Chromatic Illumination." *Journal of Experimental Psychology*. v. 23, pp. 439-476. 1938.

21. Helson, H. and V. B. Jeffers. "Fundamental Problems in Color Vision. II. Hue, Lightness, and Saturation of Selective Samples in Chromatic Illumination." *Journal of Experimental Psychology*. v. 26, pp. 1-27. 1940.

22. *Illuminating Engineering Society Lighting Handbook*. 2nd Edition. Illuminating Engineering Society. New York. 1952.

23. Bartley, S. H. "The Comparative Distribution of Light in the Stimulus and on the Retina." *Journal of Comparative Psychology*. v. 19, pp. 149-154. 1935.

24. Adams, E. Q. and P. W. Cobb. "The Effect on Foveal Vision of Bright (and Dark) Surrounds." *Journal of Experimental Psychology*. v. 5, 39ff. 1922.

25. *Fundamentals of Light and Lighting*. Lamp Department, General Electric Company. Bulletin LD-2, Third printing. February 1950.

26. Phillips, L. Oral Communication. July 24, 1953.

27. Rice, R. A. Written Communication. January 5, 1954.

28. Judd, D. B. *Colorimetry*. National Bureau of Standards Circular 478. March 1950.

29. *Preparation and Colorimetric Properties of a Magnesium-Oxide Reflectance Standard*. U. S. Department of Commerce National Bureau of Standards. Letter Cir; LC-547. Superseding LC-395. March 17, 1939.

OTHER REFERENCES

1. Becker, C. and W. [illegible]. Appel. "Evaluation of Manila-Rope Fiber for Color". U. S. Department of Commerce, Bureau of Standards, Research Paper RP627. Part of Bureau of Standards Journal of Research. v. 11. December 1933.

2. Bentley, G. P. "Industrial Tristimulus Color Matcher." Electronics. v. 24, no. 8, pp. 102-3. August 1951.

3. Brant, A. W., K. H. Norris, and G. Chin. "A Spectrophotometric Method for Detecting Blood in White-Shell Eggs". Poultry Science. v. 32, no. 2. March 1953.

4. Davidson, H. R. "Visual Sensitivity to Surface Color Differences". Opt. Soc. Am. J. v. 41, pp. 104-11. February 1951.

5. de Vries, H. "Basic Sensation Curves of the Three-Color Theory." Opt. Soc. Am. J. v. 36, pp. 121-7. March 1946.

6. Evans, R. M. "Light Sources and Colored Objects." Illuminating Engineering. v. 44, pp. 47-54. January 1949.

7. Finn, J. F. "Inspection Lighting for the Dry Cleaning Industry." Illuminating Engineering. April 1949.

8. Guth, S. K. "Comfortable Brightness Relationships for Critical and Casual Seeing." Illuminating Engineering. v. 46, pp. [illegible]. February 1951.

9. Hardy, L. H. "The Bases of Color Vision." Illuminating Engineering. v. 36, pp. 295-312. 1941.

10. Hecht, S. "The Development of Thomas Young's Theory or Color Vision." Jour. Opt. Soc. Am. v. 20, 231ff. 1930.

11. Helmholtz, H. Von. "A Treatise on Physiological Optics." Opt. [illegible]. of America. Translated from Third Ed. Edited by J. P. C. Southall. v. II. 1924.

12. Helson, Harry. "Color Tolerances as Affected by Changes in Composition and Intensity of Illumination and Reflectance of Background." The American Journal of Psychology. v. 52, pp. 406-412. 1939.

13. Helson, H. and D. B. Judd. "An Experimental and Theoretical Study of Changes in Surface Colors Under Changing Illuminations." Psychological Bulletin. v. 33, p. 740. 1936.

14. Helson, H. and W. C. Michels. "The Effects of Chromatic Adaptation on Achromaticity." J. Opt. Soc. Am. v. 38, pp. 1025-1032. 1948.

15. Hunter, R. S. "Photoelectric Tristimulus Colorimetry with Three Filters." Circular of the National Bureau of Standards 429. July 30, 1942.

16. Hunter, R. S. "The Basis of Color Measurement." A paper presented at the First Annual Meeting of the Technical Association of the Lithographic Industry. Chicago, Ill. April 15, 1949.

17. Hunter, R. S. "Gloss Evaluation of Materials." ASTM Bulletin No. 186. December 1952.

18. Judd, D. B. "The 1931 I. C. I. Standard Observer and Coordinate System for Colorimetry." Jour. Opt. Soc. Am. v. 23, pp. 359-374. 1933.

19. Judd, D. B. "Specification of Color Tolerances at the National Bureau of Standards." Am. Jour. of Psychology. v. 52, pp. 418-428. 1939.

20. Judd, D. B. "Hue, Saturation and Lightness of Surface Colors with Chromatic Illumination." J. Opt. Soc. Am. v. 30, pp. 2-32. 1940.

21. Judd, D. B. "Surface Color." J. Opt. Soc. Am. v. 25, p. 44. 1935.

22. Kramer, Amihud. "This Meter Gives Better Color Evaluation." Food Industries. v. 22, pp. 1897-1900. 1951. (copyrighted 1951 by McGraw-Hill Publishing Co., Inc. New York 18, N. Y.)

23. Larson, L. C. "Illumination of a Laboratory Table for Inspection of Blood Samples from Bovine Animals." Illuminating Engineering. v. 46, pp. 338-339. July 1951.

24. "Lighting for Canneries; Report of the Sub-Committee on Lighting." Illuminating Engineering. v. 45, p. 45. January 1950.

25. Linsday, E. A. and T. Payne. "Cotton Classing." The Magazine of Light. v. 21, no. 1. 1952.

26. MacAdam, D. L. "Maximum Visual Efficiency of Colored Materials." J. Opt. Soc. Am. v. 25, pp. 361-367. 1935.

27. MacBeth, N. and D. Nickerson. "Spectral Characteristics of Light Sources." Journal of the Society of Motion Picture Engineers. v. 52, pp. 157-183. February 1949.

28. Moon, P. The Scientific Basic of Illumination Engineering. McGraw-Hill Book Co. New York. 1936.

29. Moon, [illegible] and [illegible] E. Spencer. "Visual Effect of Non-Uniform Surrounds." Opt. Soc. [illegible]

30. Nickerson, Dorothy. "Artificial Daylighting Studies." Illuminating Engineering Society Transactions. v. 34, pp. 1233-[illegible]. August 19[illegible].

31. Nickerson, D. et. al. "New Automatic Colorimeter for Cotton." J. Opt. Soc. Am. v. 40, no. 7, pp. 446-4[illegible]. July 19[illegible].

32. Nickerson, D. "Artificial Daylighting for Color Grading of Agricultural Products." J. Opt. Soc. Am. v. 29, no. [illegible], pp. 1-9. 1939.

33. Nickerson, D. "Cotton Classing by Artificial Light." Illuminating Engineering. v. 47, no. [illegible]. March 1952.

34. Nickerson, D. "The Illuminant in Textile Color Matching." Illuminating Engineering. v. 43, no. 4, pp. 416-467. April 1948.

35. Nickerson, D. "The Illuminant in Textile Color Matching." J. Opt. Soc. Am. v. 38, no. 5, pp. 458-466. May 1948.

36. Osborn, [illegible] H. and W. [illegible] Kenyon. "A General Method of Color Grading." Ind. & Eng. Chem. Anal. ed. v. 1[illegible], pp. 523-30. September 19[illegible].

37. The Reflectance of Paints and Pigments. National Bureau of Standards. Letter Circular LC-470. May 1936.

38. Scofield, [illegible], D. B. Judd, and R. S. Hunter. "A Proposed Method of Designating Color." ASTM Bulletin. May 1941.

39. Simonson, [illegible] and J. Brozek. "Effects of Illumination Level on Visual Performance and Fatigue." J. Opt. Soc. Am. v. 38, [illegible]. April 1948.

40. Smith, T. J. and [illegible] Huggins. "Tomato Classification." Electronics. January 1952.

41. Sterns, Nickerson, [illegible] et al. "Discussion Session on Small Color Differences." American Dyestuff Reporter. v. 33. 1944.

42. Taylor, A. H. and W. G. Pracejus. "Fading of Colored Materials by Light and Radiant Energy." Illuminating Engineering. v. 45, no. 3. March 1950.

43. Vogel, E. E. "Special Inspection Lights Increase Production." Elec. World. v. 136, p. 122. September 24, 1951.

44. Wald, G. "Spectral Sensitivity of the Human Eye." Opt. Soc. Am. J. v. 35, pp. 187-96. March 1945.