EFFECT OF DISPLAY CONDITIONS ON COLOR FADING OF WAFER SLICED CURED AND COOKED BEEF

by

MITZI ANNETTE PONTIOUS SCHWAB

B.S., University of Illinois, Urbana-Champaign, 1976

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

Approved by:

D.H. Kropf

Major Professor

TABLE OF CONTENTS

Page

LIST OF TABLES v

LIST OF FIGURES ix

LIST OF APPENDICES x

ACKNOWLEDGMENTS xiv

ORGANIZATION OF THE THESIS xv

CHAPTER

I INTRODUCTION 1

II LITERATURE REVIEW 2

Light and Color 2

Light's spectral energy distribution and color rendition 3

Conditions which influence perceived color. 5

Spectral characteristics of meat 5

Eye sensitivity 5

Photochemical Reactions 6

Photochemical principles 6

Einstein's equivalence law 6

Grotthus-Draper law 8

Reciprocity law (Bunsen-Roscoe) 8

Lambert's law 8

Beer's law 8

Quantum theory-Planck's law 8

Factors influencing photochemical reactions 8

Temperature 8

Light wavelength 9

CHAPTER Page

Light intensity 9
Length of exposure 9
Impurities 10
Cured Meat Pigments 10
Myoglobin 10
Nitrosomyoglobin (nitrosylmyoglobin) 10
Nitrosohemochrome (nitrosylhemochrome) . . . 12
Objective Color Measurements for Cured Meat . . 14
Reflectance spectrophotometry 14
Factors Influenceing Cured Meat Fading 17
Lighting effect on cured and cooked meat . . 17
Lighting intensity 17
Type of lighting 18
Cured color regeneration 20
Cured meat packaging and processing 21
Temperature 24
Cured and cooked meat microbiology 26
pH and cured color fading 29
REFERENCES 33
III EFFECT OF LIGHTING INTENSITY, TYPE OF LIGHTING, AND TEMPERATURE ON WAFER SLICED CURED AND COOKED BEEF PROCESSED UNDER NONVACUUM 39
Abstract 39
Introduction 40
Experimental 41
Results and Discussion 44
Summary 58
REFERENCES 60

CHAPTER Page

IV EFFECT OF LIGHTING INTENSITY, TYPE OF LIGHTING, AND TEMPERATURE ON WAFER SLICED CURED AND COOKED BEEF PROCESSED UNDER VACUUM . . . 61

Abstract 61

Introduction 62

Experimental 63

Results and Discussion 66

Summary 76

REFERENCES 81

V EFFECT OF LIGHTING INTENSITY, TYPE OF LIGHTING, AND TEMPERATURE ON WAFER SLICED CURED AND COOKED BEEF 82

Abstract 82

Introduction 83

Experimental 84

Results and Discussion 88

Summary 106

REFERENCES 110

VI REGRESSION PREDICTED DISPLAY TEMPERATURE TO COMPENSATE FOR LIGHTING INTENSITY IN CONTROLLING CURED COLOR FADING OF WAFER SLICED CURED AND COOKED BEEF 112

Abstract 112

Introduction 113

Experimental 114

Results and Discussion 117

Summary 130

REFERENCES 132

VII SUMMARY 133

APPENDICES 137

LIST OF TABLES

CHAPTER	Table		Page
II	1.	Standard relative visibility curve of the visible spectrum defined by the International Commission on Illumination (Duggar, 1936)	7
III	1.	Mean visual color scores, 570 nm/650 nm reflectance ratios, and lm/m^2-hr values for the effect of lighting intensity and its interaction with display hours on wafer sliced cured and cooked beef processed under nonvacuum	46
	2.	Mean pH values for the effect of lighting intensity and its interaction with temperature on wafer sliced cured and cooked beef processed under nonvacuum .	48
	3.	Mean visual color scores for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef processed under nonvacuum	50
	4.	Mean visual color scores and 570 nm/650 nm reflectance ratio values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef processed under nonvacuum	52
	5.	Mean standard plate count values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef processed under nonvacuum	54
	6.	Mean package O_2 values for the effect of display hours and its interaction with type of lighting on wafer sliced cured and cooked beef processed under nonvacuum	56
	7.	Mean pH values for the interaction of temperature and display hours on wafer sliced cured and cooked beef processed under nonvacuum	57
IV	1.	Mean visual color scores, 570 nm/650 nm reflectance ratios, and lm/m^2-hr values	

CHAPTER	Table		Page
		for the effects of lighting intensity and display hours and their interaction on wafer sliced cured and cooked beef processed under vacuum	68
	2.	Mean visual color scores for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef processed under vacuum .	71
	3.	Measured spectral energy distribution of three light sources (Kropf, 1980) . .	72
	4.	Mean 570 nm/650 nm reflectance ratios for the effect of temperature and its interaction with display hours on wafer sliced cured and cooked beef processed under vacuum	74
	5.	Mean standard plate count values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef processed under vacuum	75
	6.	Mean pH values for the effect of lighting intensity and the interaction of temperature and display hours on wafer sliced cured and cooked beef processed under vacuum	77
	7.	Mean package O_2 values for the effects of type of lighting and display hours on wafer sliced cured and cooked beef processed under vacuum	78
V	1.	Mean visual color scores, 570 nm/650 nm reflectance ratios, and lm/m^2-hr values for the effect of lighting intensity and its interaction with display hours on wafer sliced cured and cooked beef .	89
	2.	Mean 570 nm/650 nm reflectance ratios for the effect of temperature and its interaction with lighting intensity on wafer sliced cured and cooked beef . . .	92
	3.	Mean pH values for the effect of lighting intensity on wafer sliced cured and cooked beef	93

CHAPTER Table Page

4. Mean visual color scores for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef 96

5. Mean visual color scores for the effect of type of lighting and its interaction with type of processing on wafer sliced cured and cooked beef 97

6. Mean package O_2 values for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef 99

7. Mean visual color scores and 570 nm/650 nm reflectance ratios for the effect of temperature and its interaction with display hours on wafer sliced cured and cooked beef 101

8. Mean standard plate values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef 103

9. Mean pH values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef 104

10. Mean pH values for the effect of type of processing and its interaction with temperature on wafer sliced cured and cooked beef 105

11. Visual color scores for the interaction of type of processing and display hours on wafer sliced cured and cooked beef . 107

VI 1. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Deluxe Cool White lighting, nonvacuum processed 119

2. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Incandescent Fluorescent lighting, nonvacuum processed 120

CHAPTER Table Page

3. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Natural lighting, nonvacuum processed 121

4. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Supermarket White lighting, nonvacuum processed 122

5. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Deluxe Cool White lighting, vacuum processed . 126

6. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Incandescent Fluorescent lighting, vacuum processed 127

7. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Natural lighting, vacuum processed 128

8. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, score, Supermarket White lighting, vacuum processed 129

LIST OF FIGURES

CHAPTER	Figure		Page
II	1.	Heme pigment reactions of meat and meat products (Clydesdale and Francis, 1971)	11

LIST OF APPENDICES

Table			Page
A		Distance in cm between light sources and wafer sliced cured and cooked beef product surfaces to achieve desired lighting intensities	138
B	1.	Effect of display treatments on characteristics of wafer sliced cured and cooked beef processed under nonvacuum. Analysis of variance probability levels for variance ratios of main treatment and interaction effects . .	139
	2.	Mean visual color scores for the interaction of lighting intensity by display hours on wafer sliced cured and cooked beef processed under nonvacuum	140
	3.	Mean pH values for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef processed under nonvacuum	141
C	1.	Effect of display treatments on characteristics of wafer sliced cured and cooked beef processed under vacuum. Analysis of variance probability levels for variance ratios of main treatment and interaction effects	142
	2.	Mean visual color scores for the interaction of type of lighting by temperature by display hours on wafer sliced cured and cooked beef processed under vacuum	143
	3.	Mean visual color scores for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef processed under vacuum	144
	4.	Mean package oxygen values for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef processed under vacuum	145
D	1.	Effect of display treatments on characteristics of wafer sliced cured and cooked beef. Analysis of variance probability levels for variance ratios fo main treatment and interaction effects	146

Table Page

2. Visual color scores for the interaction of type of lighting by lighting intensity by display hours on wafer sliced cured and cooked beef 148

3. Visual color scores for the interaction of temperature by lighting intensity by display hours on wafer sliced cured and cooked beef . 149

4. Visual color scores for the interaction of type of lighting by temperature by display hours on wafer sliced cured and cooked beef . 150

5. Mean pH values for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef . 151

E 1. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Deluxe Cool White lighting, nonvacuum processed 152

2. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Incandescent Fluorescent lighting, nonvacuum processed 153

3. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Natural lighting, nonvacuum processed 154

4. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Supermarket White lighting, nonvacuum processed 155

5. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Deluxe Cool White lighting, vacuum processed 156

6. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Incandescent Fluorescent lighting, vacuum processed 157

Table Page

7. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Natural lighting, vacuum processed 158

8. Simple linear regression predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef, ratio, Supermarket White lighting, vacuum processed 159

9. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Deluxe Cool White lighting, nonvacuum processed 160

10. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Incandescent Fluorescent lighting, nonvacuum processed . . 161

11. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Natural lighting, nonvacuum processes 162

12. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Supermarket White lighting, nonvacuum processed 163

13. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Deluxe Cool White lighting, vacuum processed 164

14. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Incandescent Fluorescent lighting, vacuum processed 165

15. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Natural lighting, vacuum processed 166

Table Page

16. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, score, Supermarket White lighting, vacuum processed 167

17. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Deluxe Cool White lighting, nonvacuum processed 168

18. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Incandescent Fluorescent lighting, nonvacuum processed . . 169

19. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Natural lighting, nonvacuum processed 170

20. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Supermarket White lighting, nonvacuum processed 171

21. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Deluxe Cool White lighting, vacuum processed 172

22. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Incandescent Fluorescent lighting, vacuum processes 173

23. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Natural lighting, vacuum processed 174

24. Simple linear regression predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef, ratio, Supermarket White lighting, vacuum processed 175

ACKNOWLEDGMENTS

The author wishes to express her deep gratitude to Dr. Donald H. Kropf, major professor, for his guidance, encouragement, patience, and professional example throughout the author's masters program.

Acknowledgment is made to Land O' Frost Corp., Lansing, Il. for supplying product, equipment, and financial support used in this research. A special thanks is made to Dr. John Butz for his input and interest.

Thanks is given to Larry Hayward, M.S. and to James Kuo, M.S. for their interest and assistance in collecting the data.

Sincere appreciation is expressed to Dr. Melvin C. Hunt, Dr. Curtis L. Kastner, and Dr. Carole S. Setser for serving on the advisory committee and their contributions in preparation of this thesis. Thanks are extended to Dr. Arthur D. Dayton and Dr. Michael R. Rubison for their assistance with the data's statistical analysis and to Ms. Janet Bosomworth for progreamming the data's statistical analysis.

To my husband, Kelvin "Kelly" R. Schwab, the author expresses her deepest gratitude to his patience and encouragement throughout the preparation of this thesis and for his love and complete support during the author's graduate program.

ORGANIZATION OF THE THESIS

This thesis is presented in a series of chapters.

Chapter I is a general introduction of the thesis. Chapter II contains a review of the literature pertaining to the topics and subjects included in the following chapters.

Chapters III through VI are individual sub-units of the total study representing technical papers written, with a few exceptions, in the style of the Journal of Food Science to which these will be submitted for publication.

Chapter VII is a summary of the entire thesis.

CHAPTER I

INTRODUCTION

Meat color becomes the consumer's primary means of determining product freshness and wholesomeness when packaging prevents use of the other physical senses. Nitrosohemochrome, the cured cooked meat pigment, appears bright pink. As cured color deviates from the "normal" bright pink, product acceptability decreases, although the product may still be unaffected nutritionally.

Cured meat fading became a problem when retailers employed highly illuminated self-service merchandizing cases. Nitrosohemochrome oxidation to a brown/gray color on illuminated product surfaces occurred within several hours, prematurely decreasing product shelf-life.

Despite approximately 30 years of research, cured meat fading continues to be a retailing problem even though minimized by vacuum and gas flush packaging. A wide variation can be found among retail meat display environments in lighting intensity at the product surface, light source, and holding temperatures. Display conditions can be controlled and offer a way to prolong product shelf-life other than packaging and production control. Stabilization of cured color can be enhanced by using specific display conditions in conjunction with product processing and packaging methods known to deter color fading.

CHAPTER II

LITERATURE REVIEW

Light and Color

Electromagnetic and radiant energy are synonomous terms for repeating wave patterns traveling in straight paths, as rays, in all directions from a source (General Electric, 1974) at the speed of 3×10^8 m/sec (186,000 miles / sec). Visible light is the radiant energy from a light source which becomes chemical energy when it sensitizes the human eye receptors in sufficient quantity. It can be described by its wavelength measured as nanometers (nm) where 1 nm is 1/1,000,000 millimeter. Visible light is but a small portion of the electromagnetic energy spectrum which ranges from cosmic rays (.00001 nm) at one end of the spectrum to electric power waves (3100 miles) at the other end. Eye sensitivity limits the visible spectrum to a band of wavelengths between 380 to 750 nm (Billmeyer and Saltzman, 1966) with the hue recognized as violet up to about 410 nm, blue up to 480 nm, green between 480 and 560 nm, yellow between 560 and 590 nm, orange between 590 and 630 nm, and red at wavelengths longer than 630 nm.

"White light is made up of all the colors of the spectrum," Francis and Clydesdale, 1975. Newton's classic experiment in optics showed a narrow beam of light being converted into a beam of diverging colors by a prism (Duggar, 1936).

"Color is the evaluation of radiant energy (physics) in terms that correlate with visual perception (psychology),"

THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH THE ORIGINAL
PRINTING BEING
SKEWED
DIFFERENTLY FROM
THE TOP OF THE
PAGE TO THE
BOTTOM.

THIS IS AS RECEIVED
FROM THE
CUSTOMER.

Judd and Wyszecki, 1975. Several factors which influence radiation and the color an individual perceives (Francis and Clydesdale, 1975) are: 1) light's spectral energy distribution, 2) the conditions under which the color is being viewed, 3) the object's spectral characteristics, ie. absorption, reflection, and transmission, and 4) the eye's sensitivity.

Light's spectral energy distribution and color rendition

"A graphic presentation of the energy emitted by a light source at each wavelength in the spectrum is called a spectral energy distribution curve," General Electric, 1974.

According to Clark (1956), fluorescent lamps have replaced filament lamps in closed refrigerated display case lighting because of their higher efficiency, lower heat output, and their long tubular shape. In a fluorescent lamp, the inner glass tube is lined with a selected mixture of phosphors which absorb and re-radiate energy, especially that of 253.7 nm wavelength, which forms part of the mercury discharge spectrum (General Electric, 1974 and Wright, 1969). Major mercury resonance radiation lines occur at 253, 296, and 365 nm in the ultraviolet region and at 405, 436, 546, and 578 nm in the visible spectrum which are determined by specific shifts in electron orbits within mercury's atomic structure. Some fluorescent light originates from the mercury discharge; however, most of the light results from the fluorescence of the phosphors. Fluorescent lighting's spectral energy distribution can be altered by the choice of phosphors used.

When selecting lighting for meat displays, a lamp's color

rendition becomes very important (Clark, 1956). A balance must be met between emitting sufficient red light to give meats a red appearance and emitting large amounts of all hues to differentiate between subtle color differences of the meats.

Deluxe Cool White lamps commonly are used for general lighting of a retail store and for supplementary lighting of meat displays (Clark, 1956). They give a red appearance to lean meat and a white appearance to fat and bones (Clark, 1956 and Ramsbottom et al., 1951). However, according to Kropf (1980), Deluxe Cool White lighting does not have enough red emission to bring out the natural red color of frozen beef muscles. Wide variations between ultraviolet emissions of 4 commercially produced Deluxe Cool White lamps were reported by Thorington and Parascandola (1967) with differences attributed to the use of calcium silicate phosphors by some manufacturers for improved color rendition. Near ultraviolet emissions between 320 and 380 nm ranged from 26 to 146 microwatts/lumen.

Incandescent Fluorescent lighting has been reported to provide excellent red appearance of frozen beef (Kropf, 1980) but caused fat color to be slightly yellow. Over 50 % of the measured spectral energy distribution of 1 commercial Incandescent Fluorescent source was emitted in the orange-red wavelengths. Similarly a larger portion of Natural lighting's spectral energy was emitted in the orange-red wavelengths than in the green-yellow wavelengths.

When selecting fluorescent lamps, it is more important

to maintain the appearance of familiar colors than to maintain the appearance of unusual colors at the expense of familiar colors (Barr et al., 1952).

Conditions which influence perceived color

Briefly, the color response of an observer can be influenced by a wide variety of conditions (Francis and Clydesdale, 1975, General Electric, 1974, and Wright, 1969) including: 1) the type of lighting under which an object is viewed, 2) changes in viewing distance to an object, 3) the position of an object in relation to its surroundings, 4) daylight variations from dawn to dusk when viewing an object, 5) adaptation of the eye to light of a given intensity, 6) viewer memory color, 7) viewer frame-of-reference, 8) figure-ground relationships, and 9) viewer age.

Spectral characteristics of meat

Meat color depends upon the relative proportions of the visible spectrum which are reflected or absorbed. Although meat is generally considered to be a non-metallic opaque object, wafer sliced meats may transmit some light (Hunt, 1980). Particulate meat surfaces scatter light at a 45° angle from incident light and give rise to diffuse reflectance which is responsible for meat color. Spectral reflectance occurs at an angle 90° from the incident light and is responsible for meat gloss or shine (Francis and Clydesdale, 1975).

Eye sensitivity

The greatest sensitivity of the cones is to visible light at 555 nm in the green-yellow portion of the spectrum (Duggar, 1936, Francis and Clydesdale, 1975, Judd and Wyszecki, 1975,

and Sylvania, No Date). The relative luminous efficiency of the different spectral regions has been determined by a large number of observers and the standard relative visibility curve approximated by the International Committee on Illumination is given in Table 1 (Duggar, 1936).

Photochemical Reactions

"Photochemical reactions are chemical reactions which are produced directly or indirectly by the absorption of radiation," Duggar, 1936. The first step in the photobiological processs is an activation step, the absorption of a quantum of radiant energy supplied by the visible or ultraviolet region by a molecule. The act of absorption may be represented as $A + h\nu \rightarrow A'$ where A is the normal, A' the excited atom or molecule, and hv the light frequency (Blum, 1941).

This energy of electron or molecular excitement from radiation absorption can be dispersed by several ways. Fluorescence is the emission of a quantum of energy by an excited atom or molecule. The excited atom or molecule may directly take part in a chemical reaction. Energy may be transferred by collision of the excited particle with a nonexcited atom or molecule. If the energy of atomic displacement becomes sufficiently large, the molecule may be driven apart with ionization occurring.

Photochemical principles

Einstein's equivalence law. The first act in any photochemical reaction is the absorption of a quantum of energy by an atom or molecule in the reacting system (Blum, 1941 and

Table 1. Standard relative visibility curve of the visible spectrum defined by the International Commission on Illumination (Duggar, 1936).

Wavelength (nm)	Relative Visibility
410	.0012
470	.091
520	.710
555	.995
580	.870
600	.631
650	.107

Duggar, 1936).

Grotthus-Draper law. Photochemical reactions in a system are produced by only those wavelengths of light which are absorbed (Blum, 1941 and Duggar, 1936).

Reciprocity law (Bunsen-Roscoe). The product of the duration, t, and the intensity, I, of light flux which will produce a given quantity of a given chemical reaction is a constant: $I \times t = k$ (Blum, 1941 and Taylor and Pracejus, 1950).

Lambert's law. Connects the transmission of light with the thickness of the absorbing material when E=extinction coefficient, I_o=incident light, I=transmitted light, l=thickness of absorbing medium, and K=constant: $E = \frac{1}{l} \log \frac{I_o}{I}$ (Duggar, 1936).

Beer's law. Measures the influence of the concentration of an absorbing material on the intensity of transmitted light where $K' = \frac{2.303}{c} \log \frac{I_o}{I}$ (Duggar, 1936).

Quantum theory-Planck's law. The energy of one photon (1 quantum, ε) is directly proportional to the frequency of the light (hv) where $\varepsilon = hv$. As the frequency of radiation increases, its energy increases (Blum, 1941 and Duggar, 1936).

Factors influencing photochemical reactions

Temperature. As the activation of atoms or molecules by absorption of quanta is independent of temperature (Q_{10}, temperature coefficient=1), many photochemical reactions are unaffected by temperature. When a photochemical reaction has a high temperature coefficient, the reaction rate is dominated by a thermal reaction which occurs after the primary reaction.

The photochemical reaction can serve as a stimulus to the second reaction. The majority of photochemical reactions have small temperature coefficients. Sometimes a change in temperature changes the absorption of light by a reaction (Blum, 1941 and Duggar, 1936).

Light Wavelength. Photochemically induced reactions decrease as the wavelength of the energy absorbed increases from ultraviolet to blue to green to red, as the intensity of photon energy is more important than the total amount of energy contained in a light beam (Blum, 1941 and Duggar, 1936).

Light Intensity. The amount of photochemical reaction should be directly proportional to the quanta of light absorbed in a simple photochemical process. If there is deviation from proportionality, then the mechanism of photochemical response could: 1) be energizing the absorbing molecules into atoms, all which participate in the reaction, 2) involve a secondary thermal response which cannot keep pace with the primary process, especially when light intensity becomes very great, and 3) slow or accelerate the reaction as a result of a high congestion of reaction products from high light intensity (Duggar, 1936).

Length of Exposure. The amount of chemical change should be directly proportional to exposure time in a primary photochemical process when quanity of light absorbed is held constant. Proportionality changes could be caused by: 1) autocatalytic effects, 2) inhibitor destruction, 3) changing light absorption, and 4) secondary reactions (Duggar, 1936).

Impurities. Photochemical reactions are sensitive to impurities, such as oxygen, which may act to carry or break reactions, especially chain reactions (Blum, 1941 and Duggar, 1936).

Cured Meat Pigments

Meat pigment forms which occur in the change of myoglobin (fresh meat) to nitrosylhemochrome (cured meat) are shown in Figure 1.

Myoglobin

Myoglobin is the major muscle pigment, comprising part of the sarcoplasmic protein (Solberg, 1970). In the live animal, myoglobin stores oxygen deposited from blood hemoglobin for cell oxidative reactions (Schweigert, 1956). It has a molecular weight of 17,000 and it's basic structure is a conjugated protein with a protein, globin, complexed to a heme moiety (an iron containing planar porphyrin ring made up of 4 pyrrole sub-units linked together by methene bridges) (Clydesdale and Francis, 1971). Myoglobin is chemically characterized as $Mb \cdot H_2O$ (Fe^{+2}), appears purplish red in color, and has an absorption peak at 555 nm (Schweigert, 1956).

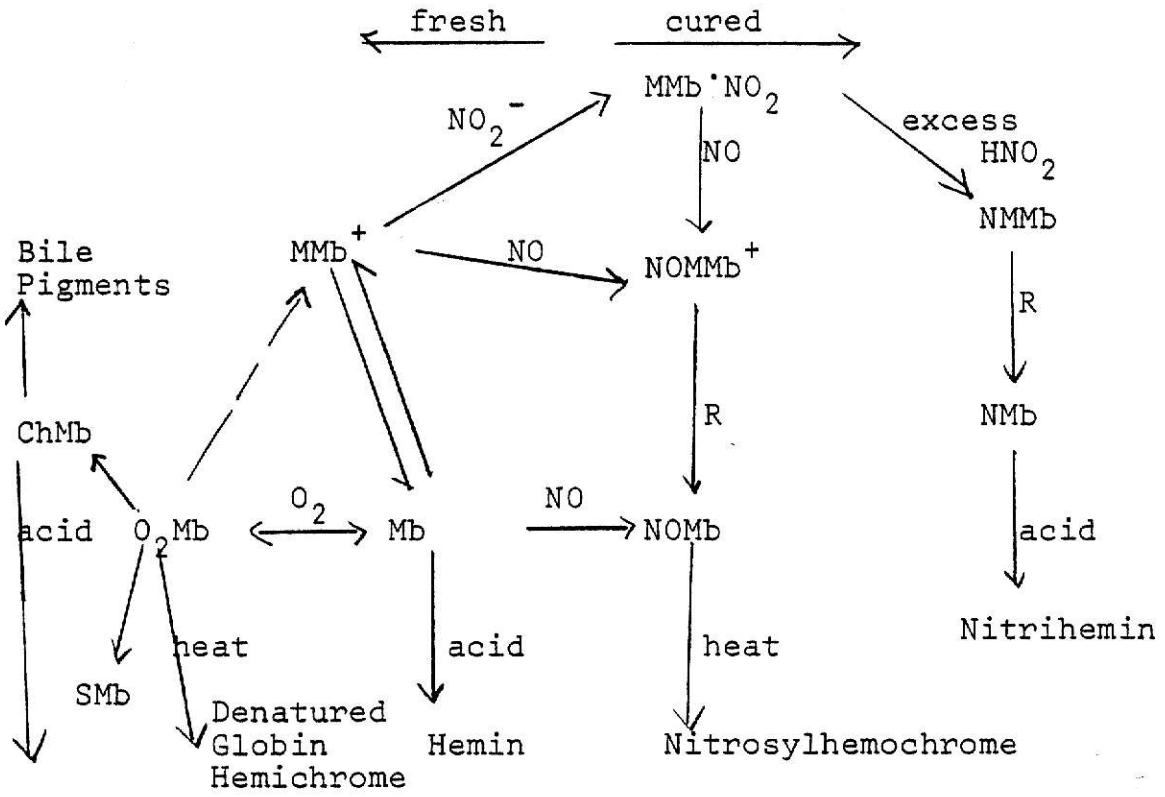
Nitrosomyoglobin (nitrosylmyoglobin)

Watts and Lehman (1952) proposed a 3 step mechanism for formation of nitrosomyoglobin. First, metmyoglobin is reduced to myoglobin, nitrite is reduced to nitric oxide, and then the 2 compounds complex to form nitrosomyoglobin.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

Figure 1. Heme pigment reactions of meat and meat products (Clydesdale and Francis, 1971).



KEY: ChMb, cholemyoglobin (oxidized porphyrin ring); O_2Mb, oxymyoglobin (Fe^{+2}); MMb, metmyoglobin (Fe^{+3}); Mb, myoglobin (Fe^{+2}); $MMb \cdot NO_2$, metmyoglobin·nitric; NOMMb, nitrosylmetmyoglobin; NOMb, nitrosylmyoglobin (nitrosomyoglobin, nitric oxide myoglobin); NMMb, nitrimetmyoglobin; NMb, nitrimyoglobin, the latter 2 being reaction products of nitrous acid and the heme of the molecule; R, reductants, O, strong oxidizing conditions; SMb, sulfmyoglobin; nitrosylhemochrome (nitrosohemochrome, myochromogen, hemochromogen).

Nitrosomyoglobin Formation

1. MMb + Reducing conditions $\rightarrow$ Mb
2. NO_2^- + Reducing conditions $\rightarrow$ NO
3. Mb + NO $\rightarrow$ NOMb

Objections to this scheme were raised by Fox (1962), who stated that in excess nitrite, reduced heme pigments were immediately oxidized back to the met-form and that nitric oxide in the presence of oxygen is oxidized to nitrogen dioxide.

Ginger and Schweigert (1954) suggested that an increase of absorbance at 545 and 575 nm and a decrease at 555 nm would be indicative of nitric oxide myoglobin formation and the disappearance of myoglobin.

Fox and Thompson (1963) proposed a reaction mechanism in which nitrous and ascorbic acids formed an intermediate complex which decomposed slowly to yield nitric oxide. The nitric oxide complexed immediately with metmyoglobin to form nitrosometmyoglobin which was reduced to nitrosomyoglobin. As pH decreased, the over-all reaction rate decreased. Nitrosomyoglobin is in the Fe^{+2} state and has a red appearance.

Nitrosohemochrome (nitrosylhemochrome)

Nitrosohemochrome is the result of 2 reactions (Fox, 1959): 1) the formation of nitric oxide from nitrite with subsequent heme and nitric oxide combination and 2) the physical or chemical denaturation of the globin or protein portion. Tarladgis (1962) proposed the compound responsible for the color of cured meats was a low-spin ferrous-porphyrin co-ordination complex, with both the co-ordination positions of the

iron ion occupied by nitric oxide. This theory was also suggested by Hornsey (1956) when nitrosohemochrome was extracted from ham with an 80:20 acetone: water mixture without the globin attached. In the presence of a reducing agent and excess nitrite, oxidized nitrosohemochrome can regenerate its original pink color (Fox, 1959).

Cooked cured meat's spectral reflectance, as measured by Tappel (1957) shows: 1) an α band in the 570 nm region, 2) a β band in the 550 nm region, 3) a γ band in the 400 nm region, and 4) an unusual band for hemochromes in the 480 nm region. Nitrosohemochrome is characterized as appearing bright pink in the Fe^{+2} state (Forrest et al., 1975) and can be oxidized further to form metmyochromogen or metmyoglobin and green pigments (Watts, 1954).

"Ferrohaem" compound sensitivity to light was suggested as a general property by Gibson and Ainsworth (1957). When fatty acids were shaken with cured meat pigment in light, Draudt and Deatherage (1956) noted a separation of the heme and protein with a subsequent brown darkening which they related to meat fading. Walsh and Rose (1956) found the nitric oxide myoglobin oxidation to be a first-order reaction, affected by light, pH changes, temperature variations, nitrite concentration and certain inhibitors. Fading rates of cooked cured pork obtained by Hornsey (1957) were interpreted as light catalyzed reactions with air where the primary fading rate was limited by light intensity and penetration until oxygen became the limiting factor. Siedler and Schweigert (1959) have shown that nitrosohemochrome is more stable in the presence of air and light

than nitrosomyoglobin.

Objective Color Measurements for Cured Meat

Reflectance Spectrophotometry

Reflectance spectroscopy measures the amount of radiant energy reflected from a sample surface (Surles et al, 1975) with data reported as percent reflectance where I=reflected radiant energy intensity from the sample and I_o=reflected radiant energy intensity from a "standard" reflecting surface: $\%R=(I/I_o) \times 100$.

According to Surles et al. (1975) and Snyder (1968), the most generally accepted theory concerning diffuse reflectance and the transparency of light scattering and light absorbing layers has been developed by Kubelka and Munk, based upon surface scattering and absorption of light, where R_∞=reflectance of layer thickness beyond which a further thickness increase does not change reflectance, absorption coefficient (K), and scattering coefficient (S): $(1-R_\infty)^2/2\ R = K/S$. This theory is valid only for weakly absorbing substances in diffuse reflecting systems.

Generally, diffuse reflectance measurements are made against an accepted standard. When K=0 for a standard, R =1 (usually R =.98 for good standards) and a linear relationship between $(1-R_\infty)^2/2\ R$ and K should still be true. Blocks of $MgCO_3$ are often used as standards because of their easy handling characteristics and relatively low cost (Surles et al., 1975), although diffuse reflectance falls off below 300 nm

and above 1800 nm and absolute measurements have a built in error of ± 1%.

Ramsbottom et al. (1951) used the reflectance ratio of 650 nm to 570 nm to objectively measure fading of sliced bologna illuminated under 20 and 60 fc of Soft White fluorescent light at 32 to 36°F. A close correlation between the reflectance ratio and visual fading scores was found.

Reproducible standards for subjective color evaluation of sliced bologna were based upon the reflectance ratio, 650 nm/570 nm (Kraft and Ayres, 1954), standardized against $MgCO_3$. Fading of color increased as the reflectance ratio decreased. When samples became dehydrated and faded, reflectance ratio increased and didn't correlate well with visual scoring.

Using a spectrophotometer with reflectance attachment and $MgCO_3$ as a standard, freshly exposed surfaces of 8 kinds of cured and sliced meat showed a broad absorption peak centered at 570 nm and very low absorption above 650 nm (Erdman and Watts, 1957 b). Samples treated with 0.1% potassium ferricyanide to approximate the faded brownish color of denatured ferric hemochromogen had a lower maximum absorption than freshly cut cured meat at 540 nm. Light faded samples illuminated under 15 or 200 fc of incandescent light showed intermediate absorption spectra between freshly cut and ferricyanide treated samples. As fading increased, the absorption peak at 570 nm shifted to 540 nm, Erdman and Watts (1957 b) concluded that "extinction ratios" of 570 nm/650 nm were more meaningful in characterizing cured pigment changes than the reflection ratios

of 650 nm/570 nm because the "extinction ratio" would be expected to remain the same for a pigment form regardless of the amount present at the reflected surface, whereas reflectance ratios for the same pigment would vary with the percent of reflected or absorbed light. Therefore, comparison of "extinction ratios" between types of cured meat could be made but not comparisons between reflectance ratios as surface phenomenon vary in pigmentation and fat. A correlation coefficient of .90 for all tested samples was found between the extinction ratios and visual scores of the faded meats.

Barton (1967) compared the reflectance ratios of 650 nm/570 nm and 540 nm/560 nm for measuring the color stability of cooked cured longissimus dorsi and ham muscles (mainly semimembranosus and biceps femoris), each muscle group including treatments cured with and without added phosphates. Reflectance ratio 650 nm/570 nm varied with both nitroso-pigment content and % conversion to metmyochrome for the 3 muscle and curing groups, with a different relationship in each case whereas the relationship between R 540 nm/560 nm and % conversion was found to be the same between all 3 groups. Both reflectance ratios showed good fading patterns.

A reflectance ratio of K/S for 570 nm/650 nm was used to determine pigment nitrososation of sliced bologna (Lin and Sebranek, 1979). The higher the ratio, the greater the color development, with a ratio of 3.5 or more indicating acceptable color.

Factors Influencing Cured Meat Fading

Lighting effect on cured and cooked meat

Lighting intensity. Light fading of packaged luncheon meats became a serious retailing problem when meat markets began utilizing high intensity display case lighting designed for maximum sales appeal (Hockman, 1946). Cured meat and meat products were wrapped in transparent, air permeable films. Lighting intensity was noted as having a greater effect on fading than light color. Display lighting intensities on meats varied from 10 to 200 foot-candles (fc) in retail stores in a survey conducted by Ramsbottom et al. (1951).

Taylor and Pracejus (1950) found that processed meats such as bologna, meat loaf, and boiled ham were affected by light during normal display. Perceptible color change of bologna was observed within 150 to 200 fc-hr when illuminated under Soft White fluorescent or tungsten-filament lamps, which would occur in 2 to 3 hours in a well lighted display case. Within experimental errors, fading under the 2 sources was identical under equal fc-hr exposure. Visual appraisal of sliced bologna by Allen (1949) showed bologna acceptability declined as lighting intensity increased from 13 to 48 fc when exposed under fluorescent light for 3 hours at 35 to 45°F.

Archer and Bandfield (1950) stated discoloration of veal loaf was a function of time, temperature, light level, and spectral quality of illumination. Their data suggested fc-hr to least perceptible difference increased as lighting intensity decreased from 150 to 50 fc. Comparing lighting inten-

sities of 20 versus 60 fc under Soft White fluorescent light at 32 to 36°F on bacon, ham, and bologna, Ramsbottom et at. (1951) found discoloration determined objectively and subjectively occurred most rapidly under the higher lighting intensity for all samples. Lighting intensity to noticeable fading of sliced cured, smoked, and table ready meats packaged in transparent air permeable films was 60 fc for 1 hour. Discoloration upon exposure to light was limited to the top layer of sliced meats and the exposed surfaces of large pieces. Kraft and Ayres (1954) confirmed the conclusion of Ramsbottom et al. (1951) that noticeable fading of packaged bologna occurred within 1 hr exposure under Soft White fluorescent light at 60 fc and 2.5°C by objective and subjective color determinations. Less fading occurred under 30 to 35 fc than under 50 to 60 fc of Soft White fluorescent light throughout a 7 day storage period for cellophane packaged bologna. Color fading was most rapid during the first day of display.

Cured meat fading is a function of fc-hr exposure (Clark, 1956, Ramsbottom, 1950, and Ramsbottom et al., 1951) and generally follows the reciprocity law, ie. more fc-hr results in more fading, also equal fading would be produced by 20 fc for 100 hr as would be produced by 200 fc for 10 hr.

Type of Lighting. According to Hockman (1946), all portions of the visible light spectrum cause cured meat fading to some extent including ultraviolet light. Using an acceptability scale of 10=High and 0=Low, at a temperature of 45 to 52°F after 3 hr exposure, bologna acceptability was evaluated as

THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH THE ORIGINAL
PRINTING BEING
SKEWED
DIFFERENTLY FROM
THE TOP OF THE
PAGE TO THE
BOTTOM.

THIS IS AS RECEIVED
FROM THE
CUSTOMER.

5.4 under "near ultraviolet light", 7.2 under white fluorescent light, and 8 under yellow light (7=limit of sales acceptability).

The absorption curve of nitric oxide hemoglobin increases between 500 and 600 nm and then decreases sharply at wavelengths above 600 nm (Urbain and Ramsbottom, 1948), indicating that if all absorbed light is photochemically active, all wavelengths of the visible spectrum but red contribute substantially to fading. Sliced boiled ham wrapped in red cellophane exhibited less fading than ham wrapped in uncolored semi-moisture proof cellophane or amber cellophane after 20 hours of exposure under 40 to 50 fc of fluorescent light at 1.7°C.

Using dark blue, dark yellow, light blue, light yellow, and light green filters over sliced bologna wrapped in cellophane under 33 fc of fluorescent light at 35 to 45°F, Allen (1949) didn't find any visual fading differences between filter treatments. Ultraviolet light caused greater fading than visible light but was not considered important in retailing packaged meats due to small ultraviolet emittance by fluorescent lamps.

Archer and Bandfield (1950) found the predominantly yellow and red wavelength emittance from 100 watt tungsten lamps to be visually advantageous over 20 watt fluorescent lamp emittance as determined by fc-hr to least perceptible discoloration of veal loaf. Using a "Noviol C" 2.05 mm filter which cut off all wavelengths shorter than 450 nm (blue) under 20 watt fluorescent lamps, fc-hr to least perceptible discoloration in-

creased for all lighting intensity and temperature treatments, suggesting that wavelengths shorter than 450 nm were more potent than longer visible wavelengths in producing discoloration.

As only absorbed energy could be effective in the dissociation of nitrosomyoglobin, Kampschmidt (1955 a,b) theorized the effective distribution curve for nitrosomyoglobin dissociation would closely fit its absorption curve. Using a reflectance ratio of 650 to 570 nm to determine fading of purified nitrosomyoglobin in solution, greatest amount of fading was caused by wavelengths between 350 and 580 nm. The absorption curve of nitrosohemochrome in cured ham was similar to the absorption curve of nitrosomyoglobin.

Danielson (1969) hypothesized lighting in refrigerated display counters should be dominant in red wavelengths to provide the best color for vacuum packaged boiled ham and sausages under 900 lux at 2 to 4°C. Blue light was found to catalyze deteriorative color changes in the meat.

Cured color regeneration

Watts et al. (1955) suggested meat rich in free sulfhydral groups, freed by protein denaturation, would recover from light fading when stored in the dark if free sulfhydral groups were capable of reducing ferric hemochromogens and nitrite. Nitroprusside reaction tested meats were illuminated under 125 and 20 fc to complete oxidation as compared to a ferricyanide-treated control. Meats, such as boiled ham which showed a strong nitroprusside reaction, after exposure to

light and stored in the dark at 7°C, when dipped in nitrite showed almost full recovery of their original bright pink color within 1 day. Fading rate was not correlated with nitroprusside reaction intensity. For meats giving a strong nitroprusside test, the limiting factor in preventing light dissociation and subsequent oxidation was nitrite concentration.

Canned comminuted pork with free sulfhydral groups was sliced, packaged in polyethylene, wrapped in aluminum foil to prevent light access, dipped in 2% or .2% nitrite solutions versus no dip, and stored at -25, 4, and 26°C (Erdman and Watts, 1957 a). Sample color and sulfhydral loss was evaluated over a 180 day period. For all nitrite treatments as storage temperature increased, free sulfhydral loss was accelerated, especially at room temperature, and it was accompanied by loss of typical pink cured color.

Cured meat packaging and processing

Urbain and Jensen (1940) found the rate of oxidation of nitric oxide hemoglobin was influenced by oxygen pressure. Although they didn't establish any specific relationship between the quantity of oxygen present and the degree of pigment oxidation, their data showed nitric oxide hemoglobin was easily oxidized by small quantities of oxygen with larger oxygen quantities causing complete oxidation. They concluded the oxidation mechanism involved the dissociation of nitric oxide hemoglobin before oxidation as hemoglobin complexed with oxygen. Carbon monoxide myoglobin appeared incapable of oxidation.

Referring to oxygen being a principal reactant in the fading process, Urbain and Ramsbottom (1948) suggested excluding oxygen from cured meat by vacuum packaging as a solution to fading. They illuminated sliced boiled ham in a transparent vacuumized wrapper under Soft White fluorescent lights at 2.2 to 5.6°C, and found visual fading within 24 hours (scored 6 on a 10 point scale where 10=perfection and 1=extremely poor). After 3 days, the ham was visually scored at 8 and within 5 days was rated at 9. They explained the regeneration of the ham's cured color as a result of pigment reduction and combination with excess curing agents when package conditions became increasingly anaerobic. Anaerobic package conditions were created by consumption of the small residuum of oxygen by the pigment oxidation reaction and normal "biological oxygen demand" of the ham. They concluded that cured meat fading was controlled best by the exclusion of oxygen or light from the product.

Bressler (1954) found ham sealed under 29 in of vacuum discolored at a lower rate than samples sealed under atmospheric pressure during storage in a refrigerated (32 to 42°F) cabinet under 115 fc of Cool White fluorescent light. Comparing the effects of vacuum packaging and lighting intensity, Bressler (1954) stated light had a greater effect on the rate of discoloration than vacuum packaging. Samples sealed under 29 in of vacuum and stored under the light maintained and attractive color for only 2 days whereas control samples sealed under 29 in of vacuum and stored in the dark maintained an attractive

color for 12 days.

From spectral reflectance measurements and visual evaluation, Kraft and Ayres (1954) found vacuumized bologna (28.5 in of Hg) in a saran-cellophane laminate illuminated under 45 to 60 fc of Soft White fluorescent light at 2.5°C did not show as pronounced discoloration as samples wrapped under atmospheric pressure when stored for 1 and 2 days. Fading upon exposure to light was attributed to the action of the small amount of residual package oxygen after the evacuation process.

Rikert et al. (1957) found color retention at the surface of gound cured ham packaged in a cellophane-pliofilm laminate to slightly improve as partial pressure of oxygen increased from 20 to 80 cm. Samples stored in the light indicated a return in redness after an initial decrease in redness over a 3 day period. Samples stored in the dark decreased slowly in redness.

A combination of high initial vacuum (686 to 737 mm Hg) and package films with low oxygen permeability (7.0 ml/m^2/ 24 hr or less) gave maximum color stability and shelf-life for sliced bologna (Lin and Sebranek, 1979).

According to Winans (1950), vacuum packaging's success in detering cured color fading depends upon pulling a minimum of 29 in of vacuum initially and retaining at least 24 in. Films should have a maximum oxygen permeability of .0015 cm^3/ in^2/24 hr at 40°F and 85% RH.

A cellophane/adhesive/saran/adhesive/polyethylene laminate is commonly used in the food industry (Henrickson,

1978) for light sensitive products. The cellophane imparts rigidity to the package and a printable surface. Polyethylene acts as an effect heat sealer (Sacharow, 1969). Emulsions or solutions of saran form oxygen barrier coatings on clear plastic food packages (Gifford and Seiferth, 1969).

Gas packaging is a relatively new method of preventing oxidation compared with vacuum packaging (Douglas, 1970 and Sacharow, 1975). As a continuous motion unit, the meat is fed into the machine, over-wrapped with film, and prior to sealing a manifold flushes gas into the package when product "snugging" (close adherance) is objectionable. It isn't absorbed by the food, allowing expression of each food product's natural "free flowing" properties.

Another means of reducing cured processed product oxidation is by the use of vacuum in conjunction with bowl chopping to prevent the whipping in of excess air (Schmidt, 1979). Wirth (1978) stated chopping under vacuum enhanced keeping qualities of the meat product, retarding oxidative rancidity and color deterioration. Vacuum chopped sausage has a more intense, more stable cured color (Starr, 1979). Vacuumized blenders, emulsion mills, and stuffers used with vacuum packaging can minimize air incorporation into the meat product and its detrimental effects.

Temperature

Meat temperature in an open top display case is affected by the following factors (Zahorsky, 1968): 1) the temperature differential introduced into the meat from its

surface to its coldest spot when lighting is on versus off, 2) air temperature above the meat compared to air temperature under the meat, 3) ambient radiation effects from such surfaces as the room walls and ceiling, 4) entrapment of warm air which causes a temperature rise between discharge air and the air over the meat which is affected by ambient air conditions, and 5) the direct effect of defrosting. Display case design can control these variables to maintain specific meat holding temperatures.

Temperature influences luncheon meat fading according to Hockman (1946), with temperatures in the range of 36 to 40°F giving the best color retention. Using a range of 35 to 45°F, Allen (1949) noted higher temperatures under a given lighting intensity, visual fading of bologna was accelerated. Under 100 watt incandescent or 20 watt fluorescent lighting between 50 and 150 fc of intensity, Archer and Bandfield (1950) found fc-hr to least perceptible discoloration of veal loaf to decrease as display temperatures increased from 40 to 60°F.

Temperature studies on purified nitrosomyoglobin in solution by Kampschmidt (1955 a, b) found sample stored at 40°F in the dark had a ratio of 1.52 and sample stored at 70°F in the dark had a ratio of 0.68, indicating greater pigment dissociation and oxidation at the higher temperature. Walsh and Rose (1956) found nitrosomyoglobin oxidation rate constants at pH 6.3 to increase with increasing temperature, measuring 0.025, 0.113, 0.437, and 1.13 at temperatures of 0.5, 11.05

20.15, and 26.32°C respectively.

When the reflection ratio of 650 nm/570 nm of cured ham was measured after 24 hours of dark storage at 40 and 70°F by Kampschmidt (1955 a) ratio only slightly increased from 2.16 to 2.32 respectively. It was concluded that nitrosohemochrome's rate of dissociation was not increased by an increase in storage temperature for dark storage.

From a microbiological viewpoint, the optimum temperature range for most microorganism growth is from 15 to 40°C (Forrest et al., 1975). At refrigerated display conditions, psychrotrophic microorganism growth is favored (optimum growth temperature below 20°C). Temperatures below 5°C greatly retard spoilage microorganism growth and prevent nearly all pathogenic bacterial growth. Peacock and Fitzgerald (1971) suggested that food contamination with pathogens and their ability to multiply to a health risk level must be considered along with maintaining the food temperature below or above the range of 10 to 62.7°C when determining holding temperature safety zones for any food that provided a good medium for microorganism growth.

Cured and cooked meat microbiology

According to Jensen (1954), the major types of nonpathogenic bacteria present in sausages include Pseudomonas, Achromobacter, Proteus, Micrococcus, Chromobacterium, Bacillus, Serratia, Flavobacterium, Lactobacillus, plus in lesser incidence, Xanthomonas, Sarcina, Neisseria, Alcaligenes, coliforms, Bacterium, Microbacterium, and yeasts. Microbial sta-

bility in cured meats depends upon a number of factors (Dempster, 1976) including: 1) type and quantity of the contaminating microflora, 2) water activity, 3) meat composition and pH, 4) degree of organism heat induced injury, 5) packaging, ie. gas permeability, 6) storage conditions, and 7) the amount and type of curing salt and nitrite the product contains.

Microorganisms, alive and dead, and their end-products may oxidize nitric oxide myochromogen to the met-form, a dark brown in color (Jensen, 1954) with discoloration found only on the product surface, not in the meat. Robach and Costilow (1961) found the primary role of bacteria in the color changes of fresh meat is be reduction of oxygen tension at the meat surface. Reduced oxygen tension increased reduced myoglobin which became oxidized by H_2O_2 produced either by the meat or the bacteria. Oxygen availability and pH, which can be altered by bacterial growth, can improve the color chroma and hue with an elevated pH in fresh bovine tissue (Ockerman and Cahill, 1977). However, it is probable that microorganisms only indirectly cause color fading of sausage (Jensen, 1954).

Monitoring total microorganism numbers is often used as a means of evaluating meat and meat product quality. Ayres (1960) obtained growth curves of organisms surviving on beef stored at 0, 5, 10, 15, 20, and 25^{o}C. The critical value for slime production was found to be 6×10^7 organisms (log 7.8). Initial bacterial loads of 50 to 200 organisms/cm^2 took 21 days to reach the slime point at 0^{o}C, whereas an initial bacterial load of 50,000 organisms/cm^2 became slimy by 11 days.

After vacuum packaging, sliced cured processed meats initial mean viable log count/g varied between 2.5 and 3.0 (Mol et al., 1970). Shay et al. (1978) found total microbial counts for 41 retail purchased samples of sliced vacuum packaged meats averaged 2.5×10^7/g with 44% of the samples exceeding 10^8/g.

Quist (1976) tested sliced vacuum packaged meat products and found total counts of more than 10^8/g without detectable organoleptic changes. After 5 weeks, total counts generally decreased, although lactic acid producing bacteria increased into the 6th week, and could be misleading because of the great number of bacterial deaths occurring. Emphasis was placed on initial total counts, with the total counts latter in product shelf-life useful only as a part of an analysis of the quantitative and qualitative composition of the bacterial flora.

Microorganism genera and growth in sliced vacuum packaged luncheon meats have been documented by a number of researchers and will be briefly discussed.

Allen and Foster (1960) found lactic acid bacteria were the only organisms capable of rapid proliferation in sliced vacuum packed processed meats in an environment of air exclusion, 7.2°C or less, and with curing agents present. Extended storage life of vacuum packaged products appeared to be the result of a gradual development of a lactic population compared to a surface overgrowth of yeasts and molds (Shank and Lundquist, 1963) where principal metabolic end-products were lactic acid and carbonyls. At a salt concentration of 5%, Micrococcus initially are predominant, but are succeeded by Lactobacillus

which are able to multiply under low temperature, low salt conentration, and low oxygen tension conditions (Richardson, 1973). At salt concentrations of 8 to 12%, the Micrococcus remained dominant (Ingram and Dainty, 1971).

Both Mol et al. (1970) and Kempton and Bobier (1970) found that cooking eliminated all lactic acid bacteria present in raw meats, but that product recontamination occurred during slicing and packaging operations. Stringent plant sanitation was recommended as the most effective means of reducing initial product bacterial loads.

pH and cured color fading

Beef muscle pH declines rapidly during chilling, from 7.2 to 6 within 48 hours, and after 48 hours, to 5.7 (Jensen, 1954) due to postmortem lactic acid accumulation in the muscle as a metabolic by-product of anaerobic glycolysis. Normal pH ranges given by Watts (1954) varied from 5.2 to 6.6. In meat biochemistry, pH differences can cause quality variation including pigment oxidation and subsequent color change.

Urbain and Jensen (1940) prepared solutions of nitric oxide hemoglobin by the action of nitric oxide on hemoglobin prepared from hog's blood in the absence of air. The solution was buffered to pH's of 5.75 and 6.75 with phosphate and 8.25 with borate. At a temperature of 10°C, pigment oxidation upon exposure to air proceeded more rapidly at lower pH's and was appreciably retarded at a pH of 8.25. Rate of nitric oxide hemoglobin oxidation was slowed by high pH and low temperature, as pigment at pH 5.75 and 37°C was 100% oxidized in 1

day while the pigment at pH 8.25 and 0°C was 44% oxidized in 29 days. Oxidation % was determined by spectrophotometric analysis as % methemoglobin in solution.

By adding lactic acid to frozen ground pork (Watts and Peng, 1947) raw meat pH was lowered from 6.5 to 4.8 which was correlated with increasing rancidity after 4.5 months storage at -15 to -18°C as determined by peroxide values. Meat color faded as rancidity progressed.

Lower meat pH is preferred for use with conventional curing treatments (Watts, 1954). Color fixation between pH of 5 and 6 was normal (Duisberg and Miller, 1943) in curing pork loins. Between a pH of 4.4 and 4.9, color fixation was inadequate and below pH of 4 a brownish-gray color developed, indicating no nitrite color fixation. Nitrite destruction below pH of 4.4 was attributed to the instability of nitrous acid in acid solution.

Bailey et al. (1964) studied the photooxidation of nitrosomyoglobin using hams and picnics, cured with brine with pH adjusted to 6.2 or 6.8 by sodium orthophosphate buffer, displayed under 50 fc of fluorescent light at 38°F. The phosphates at pH 6.8 or 6.2 buffered the meat tissue pH to approximately 6.2 to 6.4 and 5.7 to 6.0 respectively. Samples treated with orthophosphate buffer at pH 6.8 were more stable to light irradiation than samples treated with orthophosphate buffer at pH 6.2, indicating pH optimum for nitrosomyoglobin formation and stability in ham in the range pH 6.2 to 6.4. At low pH, nitrite is easily reduced to nitric oxide and can be dissi-

pated as a gas if formed too rapidly, decreasing nitrosomyoglobin formation. Nitric oxide, especially at pH 5.5 and below, can be depleted because of its association with water and nitric acid to produce nitrous acid.

When Bailey et al. (1964) purified light irradiated extract from beef at 77°F, nitrosomyoglobin formation was greatest and more stable when buffered at 6.8 than 6.2. Although pH effects on nitrosomyoglobin cannot be directly applied to nitrosohemochrome, similiarities are possible. Sacharow (1969) briefly concurs that raising pH inhibits the tendency of nitrosomyoglobin to undergo oxidation.

Microbiological growth is frequently associated with meat pH alteration, although difficulties are encountered in determining if alteration in muscle quality characteristics is due to microorganism growth or due to the alteration of pH caused by these microorganisms (Ockerman and Cahill, 1977). Microorganism optimim growth pH range is generally near neutrality (pH 7.0). Forrest et al. (1975) reported meat pH ranges of 5.4 to 5.6 to favor the growth of molds, yeasts, and the acidophilic (acid loving) bacteria.

Ockerman and Cahill (1977) inoculated sterile bovine tissue with Pseudomonas putrefaciens (known to raise meat pH), Leuconostoc mesenteroides (known to lower tissue pH), and Bacillus subtilis (known to maintain neutral to slightly basic pH). After 21 days storage, correlation coefficients were -0.77 between log of bacteria number and % reflectance at 685 nm and -0.83 between pH and % reflectance at 685 nm, suggesting that

both pH and bacterial growth play a role in muscle color deterioration.

pH of sliced processed meats without added phosphate usually drops during storage (Luke, 1978 cited by Zeuthen, 1980). Zeuthen (1980) found ham (0.4% tripolyphosphate added) pH to remain stable over 7 weeks. However, by 7 weeks, log bacteria/g of hams at pH range 5.5 to 5.7 was approximately 5.0 while log bacteria/g of hams at pH range 6.3 to 6.5 was greater than 7.0.

REFERENCES

Allen, J.R. and Foster, E.H. 1960. Spoilage of vacuum-packed sliced processed meats during refrigerated storage. Food Res. 25:19.

Allen, N. 1949. Meat-film considerations. Reactions of fresh and prepared meats to packaging differ; film must be carefully chosen to control color shrinkage, and bacterial growth. Modern Packaging 22:134.

Archer, H. and Bandfield, R.E. 1950. The discoloration of veal loaf when exposed to high illumination. Illum. Engr. 45:429.

Ayres, J.C. 1960. Temperature relationships and some other characteristics of the microbial flora developing on refrigerated beef. Food Res. 25:1.

Bailey, M.E., Frame, R.W., and Naumann, H.D. 1964. Studies of the photooxidation of nitrosomyoglobin. Agric. and Food Chem. 12(1):89.

Barr, A.C., Clark, C.N., and Hessler, J. 1952. Evaluation of color rendition by fluorescent lamps. An explanatory study. Illum. Engr. 47:649.

Barton, P. 1967. Measurement of color stability of cooked cured meats to light and air. I. Development of method. J. Sci. Food Agric. 18:298.

Billmeyer, F.W. and Saltzman, M. 1966. "Principles of Color Technology." Interstate Publishers, New York, N.Y.

Blum, H.F. 1941. "Photodynamic Action and Diseases Caused by Light." Reinhold Publishing Corp., New York, N.Y.

Bressler, L. 1954. Color changes during storage of prepackaged cured ham sealed in cellophane-pliofilm laminate containers while surrounded by air at various pressures. M.S. thesis, Rutgers Univ., New Brunswick, N.J.

Clark, C.N. 1956. The basis for appropriate lighting for meat displays. Proc. 8th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.83.

Clydesdale, F.M. and Francis, F.J. 1971. Color measurement of foods. 28. The chemistry of meat color. Food Prod. Dev. 5(4):81.

Danielson, C.E., Hagland, G., and Günther, G. 1969. Exposure of meat slices to light from fluorescent tubes of special light energy. Livsmedelsteknik 11(2):70.

Dempster, J.F. 1976. Pathogenic microorganisms in cured meats. Food Man. 51(1): 41.

Douglas, J.A.L. 1970. Laminates for vacuum and gas packaging. Food Man. 45(4):46.

Draudt, H.N. and Deatherage, F.E. 1956. Studies on the chemistry of cured meat pigment fading. Food Res. 21:122.

Duggar, B.M. 1936. "Biological Effects of Radiation," Vol. 1. McGraw-Hill Book Co., Inc., N.Y.

Duisberg, P.C. and Miller, R.C. 1943. Relation of hydrogen ion concentration to color developed in cured pork. Food Res. 8:78.

Erdman, A.M. and Watts, B.M. 1957 a. Effect of storage conditions on loss of color and free sulfhydral groups in cured meats. Food Technol. 11:183.

Erdman, A.M. and Watts, B.M. 1957 b. Spectrophotometric determination of color change in cured meat. J. Agr. Food Chem. 5:453.

Forrest, J.C. Aberle, E.D., Hedrick, H.B., Judge, M.D., and Merkel, R.A. 1975. "Principles of Meat Science." W.H. Freeman and Co., San Francisco, Calif.

Fox, J.B.Jr. 1959. The pigment of cured meats. Am. Meat Inst. Found. Bull. No. 41.

Fox, J.B.Jr. 1962. New concepts in meat curing. Proc. 14th Res. Conf., Am. Meat Inst. Found., Chicago, p.93.

Fox, J.B.Jr. and Thompson, J.S. 1963. Formation of bovine nitrosylmyoglobin. I. pH 4.5-6.5. Biochem. 2:465.

Francis, F.J. and Clydesdale, F.M. 1975. "Food Colorimetry: Theory and Applications." AVI Publishing, Co., Inc., Westport, Conn.

General Electric. 1974. Light and color. Bull. TP-119. General Electric Co., Large Lamp Dept., Nela Park, Cleveland, Ohio.

Gibson, Q.H. and Ainsworth, S. 1957. Photosensitivity of haem compounds. Nature 180:1416.

Gifford, M.J. and Seiferth, O.E. 1969. Saran oxygen barrier. U.S. Patent 3,438,788.

Ginger, I.D. and Schweigert, B.S. 1954. Biochemistry of myoglobin. Chemical studies with purified metmyolobin. J. Agr. Food Chem. 2:1037.

Henrickson, R. 1978. "Meat, Poultry, and Seafood Technology." Prentice-Hall, Inc., Englewood Cliffs, N.J.

Hockman, R.O. 1946. Problems in packaging meat products. Natl. Provisioner 114:76A.

Hornsey, H.C. 1956. The colour of cooked cured pork. I. Estimation of the nitric oxide-haem pigments. J. Sci. Food Agric. 7:534.

Hornsey, H.C. 1957. The colour of cooked cured pork. II. Estimation of the stability to light. J. Sci. Food Agric. 8:547.

Hunt, M.C. 1980. Meat color measurement. Proc. 33rd Recip. Meat Conf., Natl. Livestock and Meat Board, Chicago, (In Press).

Ingram, M. and Dainty, R.H. 1971. Changes caused by microbes in spoilage of meats. J. Appl. Bact. 34(1):21.

Jensen, L.B. 1954. "Microbiology of Meats," 3rd ed. Garrard Press, Champaign, Il.

Judd, D.B. and Wyszecki, G. 1975. "Color in Business, Science, and Industry," 3rd ed. John Wiley and sons, N.Y.

Kampschmidt, R.F. 1955 a. Effect of wavelength of light on discoloration of cured meats. J. Agr. Food Chem. 3:510.

Kampschmidt, R.F. 1955 b. Meat color and influence of light. Proc. 7th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.42.

Kempton, A.G. and Bobier, S.R. 1970. Bacterial growth in refrigerated, vacuum-packed luncheon meats. Can. J. Microbiol. 16:287.

Kraft, A.A. and Ayres, J.C. 1954. Color changes in packaged bologna. Food Technol. 8:22.

Kropf, D.H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recip. Meat Conf., Natl. Livestock and Meat Board, Chicago, (In Press).

Lin, H. and Sebranek, J.G. 1979. Effect of sodium nitrite concentration and packaging conditions on color stability and rancidity development in sliced bologna. J. Food Sci. 44:1451.

Luke, K. 1978. Dissertation "Zur Charakterisierung des mikrobiellen Verderbs bei vakuumverpakten Brühwurstwaren," Journal nr. 939. Diefreie Universität, Berlin. Quoted

in Zeuthen, P. 1980. Some observations on the bacterial growth in sliced, vacuum packed ham in relation to pH of the product. p.266. 26th European Meeting of Meat Research Workers, Am. Meat Sci. Assoc., p.265.

Mol, J.H.H., Hietbrink, J.E.A., Mollen, H.W.M., and vanTinteren, J. 1971. Observations on the microflora of vacuum packed sliced cooked meat products. J. Appl. Bact. 34 (2):377.

Ockerman, H.W. and Cahill, V.R. 1977. Microbiological growth and pH effects on bovine tissue inoculated with Pseudomonas putrefaciens, Bacillus subtilis, or Leuconostoc mesenteroides. J. Food Sci. 42:141.

Peacock, J.W. and Fitzgerald, E.E. 1971. Technical note: temperature control of food. J. Food Technol. 6:107.

Quist, S. 1976. Microbiology of sliced vacuum packed meat products. Proc. 22nd European Meeting of Meat Research Workers 22:1411.

Ramsbottom, J. 1950. Discoloration. Natl. Provisioner 123:166.

Ramsbottom, J.M., Goeser, P.A., and Shulta, H.W. 1951. How light discolors the meat and what to do about it. Food Ind. 23:120.

Richardson, K.C. 1973. Some aspects of the microbiology of packaged foods. CSIRO Food Research Quarterly 33(3):59.

Rikert, J.S., Bressler, L., Ball, C.O., and Stier, E.F. 1957. Factors affecting quality of prepackaged meat. 2. Color studies. C. Effects of air and oxygen under different pressures upon color of product. Food Technol. 11:277.

Robach, D.L. and Costilow, R.N. 1961. Role of bacteria in the oxidation of myoglobin. Appl. Microbiol. 9:529.

Sacharow, S. 1969. Cured meat packaging. Food Prod. Dev. 3(8):60.

Sacharow, S. 1975. What's new in packaging for cured meat. Food Engr. 47(3):67.

Schmidt, G.R. 1979. New methods in meat processing. Proc. Meat Ind. Res. Conf., Am. Meat Found., Washington D.C., p.31.

Schweigert, B.S. 1956. Chemistry of meat pigments. Proc. 8th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.61.

Siedler, A.J. and Schweigert, B.S. 1959. Effects of heat, nitrite level, iron salts, and reducing agents on formation of denatured nitrosomyoglobin. J. Agr. Food Chem. 7(4):271.

Shank, J.L. and Lundquist, B.R. 1963. The effect of packaging conditions on the bacteriology, color, and flavor of table-ready meats. Food Technol. 17:1163.

Shay, B.J., Grau, F.H., Ford, A.L., Egan, A.F., and Ratcliff, D. 1978. Microbiological quality and storage life of sliced vacuum-packed small goods. Food Technol. in Austl. 30(2):48.

Snyder, H.E. 1968. The study of myoglobin derivatives in meat samples by reflectance spectrophotometry. Proc. Res. Conf., Am. Meat Inst. Found., p.21.

Solberg, M. 1970. The chemistry of color stability in meat. A review. Canad. Inst. Food Technol. J. 3(1):55.

Starr, L.D. 1979. What's new in the old technologies: cooking, chopping, and converting. Proc. Meat Ind. Res. Conf., Am. Meat Inst. Found., Washington D.C., p.41.

Surles, T., Erickson, J.O., and Priesner, D. 1975. Practical aspects of diffuse reflectance spectrophotometry. Am. Lab. 7(3):55.

Sylvania. No Date. Spectral energy distribution curves of Sylvania F40T12 fluorescent lamps. Engr. Bull. 0-283. Commercial Engr. Dept., Lighting Div., Salem, Mass.

Tappel, A.L. 1957. Spectral studies of the pigments of cooked cured meats. Food Res. 22:479.

Tarladgis, B.G. 1962. Interpretation of the spectra of meat pigments. II. Cured meats. The mechanism of color fading. J. Sci. Food Agr. 13:485.

Taylor, A.H. and Pracejus, W.G. 1950. Fading of colored materials by light and radiant energy. Illum. Engr. 45:149.

Thorington, L. and Parascandola, L.J. 1967. Ultraviolet emissions from light sources used as general illuminants. Illum. Engr. 62:674.

Urbain, W.M. and Jensen, L.B. 1940. Heme pigments of cured meats. I. Preparation of nitric oxide hemoglobin and stability of the compound. Food Res. 5:593.

Urbain, W.M. and Ramsbottom, J.M. 1948. Controlling quality changes in cured meats by packaging. Food Res. 13:432.

Walsh, K.A. and Rose, D. 1956. Factors affecting the oxidation of nitric oxide myoglobin. J. Agr. Food Chem. 4:352.

Watts, B.M. 1955. Oxidative rancidity and discoloration in meat. Advances in Food Res. 5:1.

Watts, B.M. and Peng, D. 1947. Rancidity development in raw versus precooked frozen pork sausage. J. Home Econ. 39:88.

Watts, B.M. and Lehmann, B.T. 1952. The effect of ascorbic acid on the oxidation of hemoglobin and the formation of nitric oxide hemoglobin. Food Res. 17:100.

Watts, B.M., Erdman, A.M., and Wentworth, J. 1955. Relation of free sulfhydral groups to cured meat color. J. Agr. Food Chem. 3:147.

Winans, W.E. 1950. Prepackaging. Natl. Provisioner 123:163.

Wirth, F. 1978. Advantages of vacuum chopping in sausage manufacturing. Meat Industry Magazine, October, p.65.

Wright, W.D. 1969. "The Measurement of Color," 4th ed. Adam Hilger LTD, London.

Zahorsky, L.A. 1968. Meat surface temperature. Affect of radiant heat, air velocity, and air temperature. Hussman Adv. Engr. Rep. No. 725-5-6-68.

Zeuthen, P. 1980. Some observations on the bacterial growth in sliced vacuum packed ham in relation to pH of the product. 26th European Meeting of Meat Research Workers, Am. Meat Sci. Assoc., p.265.

CHAPTER III

EFFECT OF LIGHTING INTENSITY, TYPE OF LIGHTING, AND TEMPERATURE ON WAFER SLICED CURED AND COOKED BEEF PROCESSED UNDER NONVACUUM

ABSTRACT

Display conditions' influence on cured color fading of nonvacuum processed wafer sliced cured and cooked beef was visually estimated and measured by 570 nm/650 nm reflectance ratios. Microbial standard plate counts, pH, and package oxygen were also determined. Product fading increased with increasing lighting intensities from 1076 to 3228 lm/m^2 and display time up to 72 hours. Incandescent Fluorescent and Natural lighting caused less visual fading than Deluxe Cool White or Supermarket White. Subjectively and objectively measured fading was similar at 1.1 and 4.4°C but accelerated at 7.8°C. Between 24 and 72 hours, microbial standard plate counts increased up to log 5.1/g whereas pH and package oxygen decreased.

Introduction

Supermarkets utilize refrigerated display cases for the presentation of individually wrapped packages of meat and meat products. The cases utilize bright lighting to attract customers' attention and elicit favorable purchase responses. Meat color is a primary factor in determining consumer preferences.

The pigment responsible for the typical bright pink color in cured and cooked meats is nitrosohemochrome. Upon oxidation this pigment is denatured with the pink color fading to brown/gray. Sensitivity of nitrosohemochrome to photooxidation and subsequent color fading in a short period of time is an economic problem in highly illuminated self-service display cases. Consumers, relying upon the bright pink cured meat color as a means of determining product freshness and wholesomeness, reject cured meats and meat products with faded appearance.

Packaged cured meats and meat products, fully cooked and ready to serve, are convenient and popular menu items for today's mobile society. Many new items have been developed for sale, including cured and fully cooked wafer sliced beef.

Despite approximately 30 years of research concerning the photooxidation of nitrosohemochrome, the color fading of cured meats continues to be a problem in retail stores. Wide variation can be found in sources of display illumination, light intensity at the product surface, and product holding temperatures.

Our study had the following objectives: 1) to determine the effects of various display conditions (type of lighting, lighting intensity, and temperature) upon color stability of wafer sliced, cured and cooked beef in an 84 g gas flush package, 2) to determine any contributing role of package microbial numbers, pH, and oxygen level to cured color fade during and after display conditions, and 3) to form the basis for recommendations to retailers concerning controllable display conditions.

Experimental

Commercially prepared wafer sliced (.711 mm thick) cured and cooked beef in an 84 g nitrogen flushed package was furnished to Kansas State University by Land O' Frost Corp., Lansing, Il. Product composition was approximately 20% protein, 70% water, 3.7 to 3.8% salt, 5 to 6% fat, plus sodium erythorbate, sodium nitrite, and seasonings. The wafer sliced cured and cooked beef was packaged with a laminated film of saran-cellophane-saran-polyethylene with oxygen permeability of .55 cc/24 hours/m^2 at 22.2^{o}C and moisture permeability < 1 cc. The pouches were opaque except for a transparent product viewing area on the principal display panel, and a hole was punched outside the package seal for pegboard type display. This product was produced with nonvacuumizing equipment.

All samples were transported to the Kansas State University Meat Science Laboratory by commercial refrigerated truck

from Land O' Frost. Packages were checked for seal integrity and color, then randomly assigned to predetermined display treatments. Using a random sampling method, packages were removed at the initiation of the display study for the purpose of determining product microbial standard plate count, pH of product surface, and package oxygen level.

Display treatments studied included all possible combinations of the following variables: 4 types of lighting (each 40 watt tubes), namely General Electric Deluxe Cool White, Sylvania Incandescent Fluorescent, General Electric Natural and Westinghouse Supermarket White; 4 lighting intensities at product surface level, 1076 lm (lumens)/m^2 (100 fc, foot-candles), 1614 lm/m^2 (150 fc). 2152 lm/m^2 (200 fc), and 3228 lm/m^2 (300 fc); and 3 display temperatures, 1.1°C (34°F), 4.4°C (40°F), and 7.8°C (46°F).

Due to the large number of samples studied and limited display case space, retail display conditions were simulated on a large scale in refrigerated chill rooms meeting prescribed treatment requirements. Surfaces and background under each source of illumination were covered with white meat wrapping paper. Light intensity levels at the package surface level were determined by a General Electric Light Meter, Model No. 201. Distances in cm between the light sources and the surface of the cured and cooked wafer sliced beef to achieve the desired intensities of light are given in the appendix. Lighting under the display conditions was a 12 hour on/12 hour off cycle, beginning with the lights on.

Subjective (visual) and objective (reflectance) color determinations were taken over a period of 3 days at the folowing times: 0 hr (before light exposure), 6, 12, 24, 48, and 72 hr.

Subjective cured color scores were assigned to each package under every display condition treatment for all designated time periods by 2 trained visual panelists. The following visual color scale was used to the nearest 0.5 point: 1=Bright Pink cured color (all pink, no brown/gray), 2=Slight Fade (more pink, less brown/gray), 3=Moderate Fade (less pink, more brown/gray), and 4=Complete Fade (no pink, all brown/gray). Color scales were assigned to the product exposed to the light sources and visible through the transparent window on the principal display panel.

Reflectance was scanned from 560 nm to 660 nm through the clear film of the unopened packages on a Bausch and Lomb 600 Spectrophotometer (scan speed 250 nm/min) with reflectance attachment. Pure magnesium carbonate blocks were used to standardize 100% reflectance. Reflectance values were read to the nearest 0.1% at wavelengths of 570 and 650 nm and a ratio of the % reflectance was calculated as an objective measure of color fade using wavelengths suggested by Erdman and Watts (1957).

Microbial standard plate counts were determined on randomly delected preassigned packages: 2 packages from each treatment after display for 24 and 72 hr (arbitrarily considered as "Complete Fade"). Dilute phosphate buffer was prepared

from 1.25 ml of stock solution diluted to 1000 ml (phosphate buffer stock solution of 3.4 g of KH_2PO_4 in 50 ml distilled water, pH adjusted to 7.2 with .01 N NaOH, then diluted to 100 ml). Packages were aseptically injected with 100 ml of sterile dilute phosphate buffer, and product slices thoroughly rinsed. Appropriate dilutions were made and plated onto standard methods tryptone glucose extract agar. Counts were made after incubation for 96 hr at 25°C.

In determining the pH of the product surface exposed to the light sources, the top layer of the wafer sliced beef was removed from the package, placed in a beaker, and minced with a knife. Distilled water (50 ml) was added to the mince and thoroughly mixed. pH readings were taken with a surface electrode of a Corning Digital 110 pH Meter. Sampling was limited to randomly preassigned product with 2 packages from each display treatment after 24 hr and again after 72 hr.

Again a preassigned package sampling method was used as described for microbial standard plate counts and pH determinations for identical time intervals for measuring package oxygen level. Readings were made to the nearest 0.1% with a Beckman C-2 Oxygen Analyzer which evacuated package gas by using a probe and vacuum pump.

Data were analysis of variance and main effects were determined by the method of least significant differences as specified by Snedecor and Cochran (1967).

Results and Discussion

Visual color scores indicated increased cured color fading

with increases in lighting intensity (Table 1). This was confirmed by increasing 570 nm/650 nm reflectance ratios and suggests a shift of the pink colored nitrosohemochrome to an oxidized brown/gray color. Upon opening of packages at the end of the 72 hr display, fading was found only on product exposed to light and not on internal non-exposed product. The effect of greater lighting intensity in producing more fading in cured meat products has been reported by several workers. Ramsbottom et al. (1951) found sliced bacon, ham, and bologna exhibited more discoloration under fluorescent lighting at 60 fc (645.6 lm/m^2) than when held under 20 fc (215.2 lm/m^2) for equal periods of exposure. Less fading was produced by light intensities in the range of 30 to 35 fc (322.8 to 376.6 lm/m^2) for bologna than at 50 to 60 fc (538 to 645.6 lm/m^2) when exposed to Soft White fluorescent light (Kraft and Ayres, 1954).

Table 1 also shows the lighting intensity by display hr interaction ($P<.05$) for visual color scores. At display initiation (0 hr) all samples were visually estimated to exhibit typically bright pink cured color. Beginning at 6 hr and continuing through 72 hr, 2 general trends were noted: 1) within each level of lighting intensity visual color scores indicated progressive fading for each time interval and 2) for each time interval visual color fade increases with the level of lighting intensity. However, these increases in visual fading were not equal. Visual fading increased more for the 1614 lm/m^2 intensity over that of the 1076 lm/m^2 inten-

Table 1. Mean visual color scores[y], 570nm/650nm reflectance ratios, and lumens/meter^2-hours values for the effect of lighting intensity and its interaction with display hours on wafer sliced cured and cooked beef processed under nonvacuum.

Lighting Intensity[z] lm/m^2		Display Hours 0	6	12	24	48	72	All Times Score	All Times Ratio
1076	Score	1.000^{a}	1.250^{b}	1.646^{cd}	1.781^{d}	2.350^{f}	2.702^{gh}	1.788^{m}	.4928^{q}
	lm/m^2-hrs		6,456	12,912	12,912	25,824	38,736		
1614	Score	1.000^{a}	1.327^{b}	2.000^{e}	2.073^{e}	2.954^{i}	3.317^{j}	2.112^{n}	.5221^{r}
	lm/m^2-hrs		9,684	19,368	19,368	38,736	58,104		
2152	Score	1.000^{a}	1.583^{c}	2.250^{f}	2.350^{f}	3.198^{j}	3.500^{k}	2.314^{o}	.5172^{r}
	lm/m^2-hrs		12,912	25,824	25,824	51,648	77,472		
3228	Score	1.021^{a}	1.763^{d}	2.590^{g}	2.798^{h}	3.510^{k}	3.771^{l}	2.575^{p}	.5533^{s}
	lm/m^2-hrs		19,368	38,736	38,736	77,472	116,208		

[y]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z]Lighting Intensity: 1076 lm/m^2=100 foot-candles (fc), 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

a-l or m-p or q-s Means with the same superscript letter are not different (P>.05).

sity at 48 and 72 hr than for any other increase in lighting intensity at any other display time. In addition, less fading was noted at 6, 12, and 24 hr display for lower light intensities and less was noted between 48 and 72 hr for the highest light intensity, perhaps because product was already badly faded at 48 hr. Visual fading did not increase ($P<.05$) between the 12 and 24 hr evaluations for the 3 lower light intensities and increased only a small amount for the 3228 lm/m^2 intensity level. Lights were on 12 hr, off 12 hr and this period was a light off period.

Clark (1956) stated the degree of discoloration for a particular processed meat was a function of exposure in fc-hr, with the law of reciprocity applicable over a range of 20 to 200 fc. Earlier work by Taylor and Pracejus (1950), Ramsbottom et al. (1951), and Kraft and Ayres (1954) suggested this idea. Table 1 compares lm/m^2-hr of illumination which largely accounts for the fading trends.

The pH of wafer sliced cured and cooked beef rose slightly when the level of surface illumination was increased from 1076 lm/m^2 to higher intensities for product displayed at 7.8°C (Table 2). Raising product pH, according to Sacharow (1969) and Urbain and Jensen (1940), tends to stabilize nitrosohemochrome fading as measured by either visual or objective color measurements.

Visual color scores showed different degrees of fading by the cured and cooked product when displayed and evaluated under the different lighting systems (Table 3). Product as

Table 2. Mean pH values for the effect of lighting intensity and its interaction with temperature on wafer sliced cured and cook beef processed under nonvacuum.

	Temperature (T)			
	1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)	All T
Lighting Intensity lm/m^2 [z]				
1076	6.280[e]	6.222[c]	6.189[a]	6.230[g]
1614	6.293[f]	6.226[c]	6.203[b]	6.240[h]
2152	6.277[e]	6.228[cd]	6.203[b]	6.236[h]
3228	6.275[e]	6.236[d]	6.198[b]	6.236[h]

[z]Lighting Intensity: 1076 lm/m^2=100 foot-candles (fc), 1614 lm/m^2=150 fc, 2152 lm/m^2=200fc, 3228 lm/m^2=300 fc.

[a-f or g-h]Means with the same superscript letter are not different (P>.05).

rated by 2 trained panelists under Incandescent Fluorescent (IF) and Natural (N) lighting systems displayed less visual color fade. Product exposed to Supermarket White (SW) showed the most fading. Deluxe Cool White (DCW) illuminated product was intermediate in color fading.

Objective color measurements (570 nm/650 nm reflectance ratio) did not confirm visual observations. This suggests that visual differences were largely due to color rendition under the varios light sources and not to actual photochemical effects.

Archer and Bandfield (1950) suggested that wavelengths shorter than 450 nm (blue) were responsible for increasing discoloration in veal loaf. Kampschmidt (1955) found pure nitric oxide myoglobin in solution absorbed energy from wavelengths between 300 and 580 nm resulting in more pigment dissociation and oxidation than the longer wavelengths of the visible spectrum. He inferred nitrosohemochrome reacted to wavelength energy in the same manner as the pure nitric oxide myoglobin in solution.

Eye sensitivity is greatest to wavelengths in the green and yellow portion of the visible spectrum and decreases in sensitivity to orange and red wavelengths (Francis and Clydesdale, 1975). Lamp systems with greater emissions in the orange and red wavelengths were perceived as causing the least visual fade. IF and N lamps emit a larger percentage of their energy in the orange-red wavelengths than in the yellow-green wavelengths (Kropf, 1980), bringing out the redness of the cured

Table 3. Mean visual color scores[y] for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef processed under nonvacuum.

	Display Hours						
	0	6	12	24	48	72	All Times
Type of Lighting[z]							
DCW	1.010^{a}	1.452^{c}	2.177^{g}	2.329^{h}	3.038^{k}	3.342^{m}	2.225^{p}
IF	1.000^{a}	1.392^{bc}	1.906^{e}	2.063^{fg}	2.879^{j}	3.188^{l}	2.071^{o}
N	1.000^{a}	1.317^{b}	1.990^{ef}	2.021^{ef}	2.704^{i}	3.083^{kl}	2.019^{o}
SW	1.010^{a}	1.763^{d}	2.413^{h}	2.590^{i}	3.392^{m}	3.677^{n}	2.474^{q}

[y]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z]Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[a-n or o-q]Means with the same superscript letter are not different (P>.05).

and cooked meat while losing some sharpness of white and a degree of color distinction exhibited by DCW and SW.

Visual color scores increased progressively, but not consistently, from display initiation (0 hr) to completion (72 hr). The 570 nm/650 nm reflectance ratio also increased with display time. Lighting systems were turned off between the 12 and 24 hr observations and 12 of each 24 hr thereafter. Continued cured color fading demonstrated by both visual and reflectance measurements between 12 and 24 hr show that once oxidation of the nitrosohemochrome pigments has been initiated, oxidation may proceed in the dark on wafer sliced cured and cooked beef processed under nonvacuum procedures, but not as rapidly as under light. Watts et al. (1955) have shown that light faded cured meats in the presence of free sulfhydral groups and free nitrite could regenerate cured color when held at 7°C within 24 hr under dark storage conditions, but we did not encounter such regeneration. The type of lighting by display hr interaction (Table 3) is largely explained by the large increase in visually perceived fading of product between 0 and 6 hr displayed under SW lighting compared with other lighting systems. Thereafter, increases in fading were similar for all lighting types with increases in display time.

Significant interactions of temperature by display hr were found for both subjective and objective color measurements (Table 4). Mean visual color scores for product at the 3 temperatures were estimated as bright pink at 0 hr. A 6 hr illuminated product held at 1.1°C (34°F) faded less than

Table 4. Mean visual color scores[z'] and 570nm/650nm reflectance ratio values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef processed under nonvacuum.

		Display Hours					
		0	6	12	24	48	72
Temperature (T)							
1.1°C (34°F)	Ratio	.4105^{ab}	.4833^{cde}	.5118^{ef}	.5128^{ef}	.5670^{h}	.6061^{i}
	Score	1.008^{j}	1.352^{k}	2.055^{m}	2.231^{n}	2.953^{p}	3.258^{q}
4.4°C (40°F)	Ratio	.4293^{b}	.4728^{cd}	.5004^{def}	.5147^{f}	.5615^{gh}	.6203^{i}
	Score	1.008^{j}	1.541^{l}	2.083^{m}	2.161^{mn}	2.883^{p}	3.217^{r}
7.8°C (46°F)	Ratio	.3941^{a}	.4670^{c}	.5310^{fg}	.5510^{gh}	.6143^{i}	.6363^{i}
	Score	1.000^{j}	1.550^{l}	2.227^{n}	2.359^{o}	3.173^{q}	3.492^{s}
All T	Ratio	.4113^{t}	.4744^{u}	.5144^{v}	.5262^{v}	.5809^{w}	.6209^{x}
	Score	1.005^{y}	1.481^{z}	2.121$^{a'}$	2.251$^{b'}$	3.003$^{c'}$	3.492$^{d'}$

[z'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

a-i or j-s or t-x or y-d' Means with the same superscript letter are not different (P>.05).

product held at 4.4 and 7.8°C. At 12 hr and each time period thereafter, visual cured color fade progressed for each temperature with fading similar for 1.1 and 4.4°C. Product held at 7.8°C for 48 and 72 hr faded more than at the 2 lower temperatures.

570 nm/650 nm reflectance ratios confirmed differences in visual cured color fade values as changes occurring because of oxidation of the bright pink nitrosohemochrome to a brown/gray metmyoglobin. Results show little difference in visual and objective color measurements for nonvacuum processed wafer sliced cured and cooked beef held under 1.1 and 4.4°C, with greater product fade occurring when held at 7.8°C for 12 through 72 hr. Archer and Bandfield (1950) showed a time/temperature relationship for discoloration of veal loaf. Time expressed as fc-hr to least perceptable discoloration decreased as temperature treatments increased from 40 to 60°F (4.4 to 15.6°C).

Standard plate counts ($\log_{10}$ bacteria/g, Table 5) increased between 24 and 72 hr of display. No observations of spot discoloration or slime production due to microbial presence were noted, therefore, exerting no influence on visual and objective color measurements of the product surface.

The temperature by display hr interaction for mean microbial standard plate count values, expressed as $\log_{10}$ bacteria/g, showed no difference between temperature groups in log standard plate counts at 24 hr (Table 5). The higher temperature of 7.8°C favored increased microorganism growth

Table 5. Mean standard plate count values[z] for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef processed under nonvacuum.

	Display Hours	
	24	72
Temperature (T)		
1.1°C (34°F)	1.567[a]	2.596[b]
4.4°C (40°F)	1.402[a]	3.185[b]
7.8°C (46°F)	1.449[a]	5.098[c]
All T	1.478[d]	4.627[e]

[z]Log_{10} bacteria/g.

[a-c or d-e]Means with the same superscript letter are not different (P>.05).

by about 2 logs at 72 hr.

Mean package oxygen (Table 6), expressed as % O_2 of gas volume, decreased between 24 and 72 hr of display. Initial package osygen levels varied considerably. In view of the increasing numbers of microorganisms in the nonvacuum processed product during this same time period, it is probable that package oxygen levels were depleted in part by microbial oxygen demand.

Mean pH values also expressed an interaction between temperature and display hr (Table 7). However, no consistent trend of pH change with time was observed. pH increased from 24 to 72 hr at 1.1°C, decreased from 24 to 72 hr at 4.4°C, and did not change from 24 to 72 hr at 7.8°C, but changes were very small and likely without practical meaning.

An interaction of lighting intensity by temperature was determined for mean pH value (Table 2). pH values decreased with increasing temperatures for each level of lighting intensity. Within each temperature treatment no consistent trend of pH decrease or increase for change in lighting intensity was determined. Although the microbial population of the nitrogen flushed nonvacuum processed product was not identified, the temperature by display hr interaction for microbial standard plate counts indicated substantial growth of microorganisms in the packages with increasing temperature and time. Ingram and Dainty (1971) stated with time, lactic acid producing bacteria became a predominant bacterial species on Wiltshire bacon placed in an oxygen impermeable package.

Table 6. Mean package O_2 values[z] for the effect of display hours and its interaction with type of lighting on wafer sliced cured and cooked beef processed under nonvacuum.

	Display Hours	
	24	72
Type of Lighting (TL)		
GE Deluxe Cool White (DCW)	2.275[d]	0.519[a]
Sylvania Incandescent Fluorescent (IF)	1.488[bc]	1.340[bc]
GE Natural (N)	1.848[cd]	1.038[ab]
Westinghouse Supermarket White (SW)	1.869[cd]	0.904[ab]
All TL	1.870[f]	0.950[e]

[z]% O_2 of gas volume.

a-d or e-f Means with the same superscript letter are not different (P>.05).

Table 7. Mean pH values for the interaction of temperature and display hours on wafer sliced cured and cooked beef processed under nonvacuum.

	Display Hours	
	24	72
Temperature		
1.1°C (34°F)	6.219[ab]	6.343[c]
4.4°C (40°F)	6.260[b]	6.195[a]
7.8°C (46°F)	6.197[a]	6.199[a]

[a-c]Means with the same superscript letter are not different (P>.05).

As bacterial numbers increased in the nonvacuum processed product, the oxygen impermeable package may have resulted in an increase in the lactic acid producing bacteria, accounting for the decreasing pH for lighting intensity levels as display temperature increased.

Summary

Light induced photooxidation of wafer sliced cured and cooked beef processed under nonvacuum production increased as lighting intensity levels at the product surface are increased from 1076 lm/m^2 to 3228 lm/m^2. The visual cured color faded as a function of both time and light intensity, with perceptible discoloration within 6 hr of display. At 3228 lm/m^2 the product visually approached "Complete Fade" in 72 hr.

Color stability of the wafer sliced cured and cooked beef processed under nonvacuum procedures was affected by the display light source. Product appearance was a brighter pink when viewed under Incandescent Fluorescent and Natural lamps for all display times after treatment initiation. Since reflectance did not confirm visual observations, the lighting systems had a greater effect on product appearance due to differences in their spectral energy distribution through the visible light range rather than a stimulation of a photooxidative effect on nitrosohemochrome by the absorption of light energy.

Temperature, as a function of time, induced the oxida-

tion and subsequent changes of nitrosohemochrome from pink to brown/gray. Display temperatures of 1.1°C and 4.4°C faded the wafer sliced beef to a similar degree from 12 through 72 hr of display. Beginning at 6 hr and continuing through 72 hr or "Complete Fade", product at 7.8°C treatments exhibited greater cured color fading both by subjective and objective color measurements.

Time exerted an influence upon all criteria studied except pH, where by upon initiation of product oxidation from a specific display treatment, product oxidation continued throughout all display hr.

Standard plate counts increased between 24 and 72 hr and possibly exerted an influence upon product pH and package oxygen levels. No other noticeable product deterioration occurred during the 72 hr display. pH dropped slightly in product as display temperatures increased. Package oxygen levels as a % of package gas volume were low and variable in the nonvacuum processed product, dropping from 24 to 72 hr display time. Change in package oxygen levels may have been a function of an increasing product microbial oxygen demand.

In selection of optimum display conditions of wafer sliced cured and cooked beef processed under nonvacuum production all the criteria, subjective and objective, must be considered. The problem of cured color fading was not eliminated; however, product fading was reduced by display adjustments.

REFERENCES

Archer, H. and Bandfield, R.E. 1950. The discoloration of veal loaf when exposed to high illumination. Illum. Engr. 45:429.

Clark, C.N. 1956. The basis for appropriate lighting for meat displays. Proc. 8th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.83.

Erdman, A.M. and Watts, B.M. 1957. Spectrophotometric determination of color change in cured meats. J. Agr. Food Chem. 5:453.

Francis, F.J. and Clydesdale, F.M. 1975. "Food Colorimetry: Theory and Applications." AVI Publishing, Co., Inc., Westport, Conn.

Ingram, M. and Dainty, R.H. 1971. Changes caused by microbes in spoilage of meats. J. Appl. Bact. 34(1):21.

Kampschmidt, R.F. 1955. Effect of wavelength of light and discoloration on cured meats. J. Agr. Food Chem. 3:510.

Kraft, A.A. and Ayres, J.C. 1954. Color changes in packaged bologna. Food Technol. 8:22.

Kropf, D.H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recip. Meat Conf., Natl. Livestock and Meat Board, Chicago, (In Press).

Ramsbottom, J.M., Goeser, P.A., and Shultz, H.W. 1951. How light discolors the meat and what to do about it. Food Ind. 23:120.

Sacharow, S. 1969. Cured meat packaging. Food Prod. Dev. 3(8):60.

Snedecor, G.W. and Cochran, W.G. 1967. "Statistical Methods," 6th ed. Iowa State Univ. Press, Ames, Iowa.

Taylor, A.H. and Pracejus, W.G. 1950. Fading of colored materials by light and radiant energy. Illum. Engr. 45:149.

Urbain, W.M. and Jensen, L.B. 1940. Heme pigments of cured meats. I. Preparation of nitric oxide hemoglobin and stability of the compound. Food Res. 5:593.

Watts, B.M., Erdman, A.M., and Wentworth, J. 1955. Relation of free sulfhydral groups to cured meat color. J. Agr. Food Chem. 3:147.

CHAPTER IV

EFFECT OF LIGHTING INTENSITY, TYPE OF LIGHTING, AND TEMPERATURE ON WAFER SLICED CURED AND COOKED BEEF PROCESSED UNDER VACUUM

ABSTRACT

Display conditions' influence on cured color fading of vacuum processed wafer sliced cured and cooked beef was visually estimated and measured by 570 nm/650 nm reflectance ratios. Standard plate counts and package oxygen were also determined. Product fading increased with increasing lighting intensities from 1076 to 3228 lm/m^2 and display time up to 72 hours. Incandescent Fluorescent and Natural lighting caused less visual fading than Deluxe Cool White or Supermarket White, probably resulting from different color rendition. Fading, measured by reflectance, was similar at 1.1 and 4.4°C but accelerated at 7.8°C. Between 24 and 72 hours, standard plate counts increases up to log 4.2/g, whereas package oxygen decreased.

Introduction

Supermarkets utilize refrigerated display cases for the presentation of individually wrapped packages of meat and meat products. The cases utilize bright lighting to attract customers' attention and elicit favorable purchase responses. Meat color is a primary factor in determining consumer preferences.

The pigment responsible for the typical bright pink color in cured and cooked meats is nitrosohemochrome. Upon oxidation this pigment is denatured with the pink color fading to brown/gray. Sensitivity of nitrosohemochrome to photooxidation and subsequent color fading in a short period of time is an economic problem in highly illuminated self-service display cases. Consumers, relying upon the bright pink cured meat color as a means of determining product freshness and wholesomeness, reject cured meats and meat products with faded appearance.

Packaged cured meats and meat products, fully cooked and ready to serve, are convenient and popular menu items for today's mobile society. Many new items have been developed for sale, including cured and fully cooked wafer sliced beef.

Despite approximately 30 years of research concerning the photooxidation of nitrosohemochrome, the color fading of cured meats continues to be a problem in retail stores. Wide variation can be found in sources of display illumination, light intensity at the product surface, and product holding temperatures.

Our study had the following objectives: 1) to determine the effects of various display conditions (type of lighting, lighting intensity, and temperature), upon color stability of wafer sliced, cured and cooked beef in an 84 g gas flush package, 2) to determine any contributing role of package microbial numbers, pH, and oxygen level to cured color fade during and after display conditions, and 3) to form the basis for recommendations to retailers concerning controllable display conditions.

Experimental

Commercially prepared wafer sliced (.711 mm thick) cured and cooked beef in an 84 g nitrogen flushed package was furnished to Kansas State University by Land O' Frost Corp., Lansing, Il. Product composition was approximately 20% protein, 70% water, 3.7 to 3.8% salt, 5 to 6% fat, plus sodium erythorbate, sodium nitrite, and seasonings. The wafer sliced cured and cooked beef was packaged with a laminated film of saran-cellophane-saran-polyethylene with oxygen permeability of .55 cc/24 hr/m^2 at 22.2°C and moisture permeability < 1 cc. The pouches were opaque except for a transparent product viewing area of the principal display panel, and a hole was punched outside the package seal for pegboard type display. This product was produced with vacuumizing equipment.

All samples were transported to the Kansas State University Meat Science Laboratory by commercial refrigerated truck from Land O' Frost. Packages were checked for seal integrity

and color, then randomly assigned to predetermined display treatments. Using a random sampling method, packages were removed at the initiation of the display study for the purpose of determining product microbial standard plate count, pH of product surface, and package oxygen level.

Display treatments studied included all possible combinations of the following variables: 4 types of lighting (each 40 watt tubes), namely General Electric Deluxe Cool White, Sylvania Incandescent Fluorescent, General Electric Natural and Westinghouse Supermarket White; 4 lighting intensities at product surface level, 1076 lm (lumens)/m^2 (100 fc, foot-candles), 1614 lm/m^2 (150 fc), 2152 lm/m^2 (200 fc), and 3228 lm/m^2 (300 fc); and 3 display temperatures, 1.1°C (34°F), 4.4°C (40°F), and 7.8°C (46°F).

Due to the large number of samples studied and limited display case space, retail display conditions were simulated on a large scale in refrigerated chill rooms meeting prescribed treatment requirements. Surfaces and background under each source of illumination were covered with white meat wrapping paper. Light intensity levels at the package surface level were determined by a General Electric Light Meter, Model No. 201. Distances in cm between the light sources and the surface of the cured and cooked wafer sliced beef to achieve the desired intensities of light are given in the appendix. Lighting under the display conditions was a 12 hr on/12 hr off cycle, beginning with the lights on.

Subjective (visual) and objective (reflectance) color determinations were taken over a period of 3 days at the following times: 0 hr (before light exposure), 6, 12, 24, 48, and 72 hr.

Subjective cured color scores were assigned to each package under every display condition treatment for all designated time periods by 2 trained visual panelists. The following visual color scale was used to the nearest 0.5 point: 1= Bright Pink cured color (all pink, no brown/gray), 2=Slight Fade (more pink, less brown/gray), 3=Moderate Fade (less pink, more brown/gray), and 4=Complete Fade (no pink, all brown/gray). Color scales were assigned to the product exposed to the light sources and visible through the transparent window on the principal display panel.

Reflectance was scanned from 560 nm to 660 nm through the clear film of the unopened packages on a Bausch and Lomb 600 Spectrophotometer (scan speed 250 nm/min) with reflectance attachment. Pure magnesium carbonate blocks were used to standardize 100% reflectance. Reflectance values were read to the nearest 0.1% at wavelengths of 570 and 650 nm and a ratio of the % reflectance was calculated as an objective measure of color fade using wavelengths suggested by Erdman and Watts (1957).

Microbial standard plate counts were determined on randomly selected preassigned packages: 2 packages from each treatment after display for 24 and 72 hr (arbitrarily considered as "Complete Fade"). Dilute phosphate buffer was pre-

pared from 1.25 ml of stock solution diluted to 1000 ml (phosphate buffer stock solution of 3.4 g of KH_2PO_4 in 50 ml distilled water, pH adjusted to 7.2 with .01 N NaOH, then diluted to 100 ml). Packages were aseptically injected with 100 ml of sterile dilute phosphate buffer, and product slices thoroughly rinsed. Appropriate dilutions were made and plated onto standard methods tryptone glucose extract agar. Counts were made after incubation for 96 hr at 25°C.

In determining the pH of the product surface exposed to the light sources, the top layer of the wafer sliced beef was removed from the package, placed in a beaker, and minced with a knife. Distilled water (50 ml) was added to the mince and thoroughly mixed. pH readings were taken with a surface electrode of a Corning Digital 110 pH Meter. Sampling was limited to randomly preassigned product with 2 packages from each display treatment after 24 hr and again after 72 hr.

Again a preassigned package sampling method was used as described for microbial standard plate counts and pH determinations for identical time intervals for measuring package oxygen level. Readings were made to the nearest 0.1% with a Beckman C-2 Oxygen Analyzer which evacuated package gas by using a probe and vacuum pump.

Data were analyzed by analysis of variance and main effects were determined by the method of least significant differences as specified by Snedecor and Cochran (1967).

Results and Discussion

Cured color fading estimates by visual color scores increased as product exposure and lighting intensity increased (Table 1). 570 nm/650 nm reflectance ratios using wavelengths suggested by Erdman and Watts (1957) also increased with increased lighting intensity. Visual differences in product cured color fading were likely caused by the photochemically induced oxidation of nitrosohemochrome to oxidized porphyrins. Studies by Kampschmidt (1955), Walsh and Rose (1956), and Watts et al. (1955) have proposed cured color fading to be an oxidative process stimulated light.

Processing the wafer sliced cured and cooked beef under vacuum reduced, but did not eliminate package oxygen; thus, oxidized porphyrin formation occurred at all treatment lighting intensities. Kraft and Ayres (1954) stated bologna vacuum packaged in a saran cellophane laminate faded less when exposed under lighting intensities of 30 to 35 fc (322.8 to 376.6 lm/m^2) than 50 to 60 fc (538 to 645.6 lm/m^2) of Soft White fluorescent light.

Cured color fading was limited to the top layer or wafer slice of beef exposed to the light source through the package principal display panel. This is in agreement with the findings of Ramsbottom et al. (1951).

Visual color fading increased as reflectance ratios increased with product display time (Table 1). Less fading occurred between 12 and 24 display hr when lights were off, although still significant ($P<.05$). Nitrosohemochrome oxidation once initiated continued through the 72 hr display of

Table 1. Mean visual color scores[y'], 570nm/650nm reflectance ratios, and lumens/meter^2-hours values for the effects of lighting intensity and display hours and their interaction on wafer sliced cured and cooked beef processed under vacuum.

Lighting Intensity (LI) lm/m^2 [z']		Display Hours 0	6	12	24	48	72	All Times Score	All Times Ratio
1076	Score	1.000^{a}	1.198^{b}	1.531^{de}	1.594^{e}	2.079^{gh}	2.400^{i}	1.634^{n}	.4883^{r}
	lm/m^2-hrs		6,456	12,912	12,912	25,824	38,736		
1614	Score	1.000^{a}	1.304^{bc}	1.865^{f}	1.979^{fg}	2.656^{j}	3.025^{k}	1.972^{o}	.5048^{rs}
	lm/m^2-hrs		9,684	19,368	19,368	38,736	58,104		
2152	Score	1.000^{a}	1.381^{cd}	2.063^{gh}	2.192^{h}	2.950^{k}	3.313^{l}	2.150^{p}	.5161^{s}
	lm/m^2-hrs		12,912	25,824	25,824	51,648	77,472		
3228	Score	1.010^{a}	1.565^{c}	2.367^{i}	2.594^{j}	3.383^{l}	3.729^{m}	2.441^{q}	.5449^{t}
All LI	Ratio	.4065^{u}	.4634^{v}	.5060^{w}	.5149^{x}	.5813^{y}	.6091^{z}		
	Score	1.003$^{a'}$	1.362$^{b'}$	1.956$^{c'}$	2.090$^{d'}$	2.767$^{e'}$	3.117$^{f'}$		

[y'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z'] Lighting Intensity: 1076 lm/m^2=100 foot-candles (fc), 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

a-m or n-q or u-z or a'-f' Means with the same superscript letter are not different (P>.05).

12 hr on and 12 hr off lighting. Lighting intensity interacted with time for visual color scores (Table 1). 2 trends were observed after display initiation: 1) visual color scores increased as display hr increased for each lighting intensity and 2) within each display time visual color scores increased with increasing light intensity. For scores at 6, 12, and 48 hr the effects of increasing intensity and time were additive. Converting lighting intensity and time into lm/m^2-hr, the reciprocity law of Taylor and Pracejus (1950), Clark (1956), and Ramsbottom et al. (1951) appeared to apply. Some examples of vacuum processed product fade that were statistically comparable for the following lighting intensity/hr combinations were: 2152 lm/m^2 at 6 hr and 1076 lm/m^2 at 12 hr; 2152 lm/m^2 at 12 and 24 hr and 1076 lm/m^2 at 48 hr; 3228 lm/m^2 at 12 hr and 1076 lm/m^2 at 72 hr; 3228 lm/m^2 at 24 hr and 1614 lm/m^2 at 48 hr; and 3228 lm/m^2 at 48 hr and 2152 lm/m^2 at 72 hr. The interaction of lighting intensity and time for reflectance ratio was not significant ($P<.05$).

At treatment initiation, product visual color scores under all fluorescent lighting types were estimated as "Bright Pink" (Table 2). After 6 hr of display, product fading was similar under all the lighting types. At 12 hr, product viewed under Incandescent Fluorescent (IF) was evaluated as less faded than product viewed under the other lighting systems. From 24 through 72 hr, product fading differed under different lighting treatments: product under IF faded less than product under Supermarket White (SW). Available information for spec-

tral energy distribution of the light sources used is given in Table 3. Eye sensitivity is greatest to green-yellow wavelengths, decreasing in sensitivity to orange-red wavelengths (Sylvania, No Date). Lamps emitting less energy in the orange-red wavelengths maximize apparent visual cured meat color fading. IF, N, and DCW lamps respectively decreased in orange-red and increased in green-yellow energy output. SW's spectral energy distribution was not available; however, from treatment results, it would be expected to emit a larger portion of its energy in the green-yellow wavelengths and less in the orange-red wavelengths than the other 3 light sources.

Early work by Archer and Bandfield (1950) with various filters on Soft White fluorescent lamps indicated wavelengths below 450 nm induced color fading in veal loaf. Kampschmidt (1955) found pure nitrosomyoglobin in solution to absorb more energy between 350 and 580 nm resulting in more dissociation than for energy absorbed from the upper range of the visible light spectrum. Product ratio for type of lighting and display hr interaction did not confirm differences in visual color score fading as oxidative changes in nitrosohemochrome structure. Therefore, visual differences in product fading were caused by differences in lamp spectral energy balance or color rendition.

Mean 570 nm/650 nm reflectance ratios indicate differences in nitrosohemochrome oxidation and resulting product cured color fade due to display temperature and its interaction with time (Table 4). Over-all display hr, mean 570 nm/650

Table 2. Mean visual color scores[z] for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef processed under vacuum.

	Display Hours						
	0	6	12	24	48	72	All Times
Type of Lighting							
General Electric Deluxe Cool White	1.000^{a}	1.392^{b}	2.073^{def}	2.150^{ef}	2.806^{hi}	3.113^{k}	2.089^{m}
Sylvania Incandescent Fluorescent	1.000^{a}	1.325^{b}	1.746^{c}	1.969^{d}	2.631^{g}	2.990^{jk}	1.944^{m}
General Electric Natural	1.000^{a}	1.319^{b}	1.958^{d}	2.010^{de}	2.710^{gh}	2.969^{jk}	1.994^{m}
Westinghouse Supermarket White	1.010^{a}	1.413^{b}	2.048^{de}	2.229^{f}	2.921^{ij}	3.396^{l}	2.170^{m}

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

a-l or m means with the same superscript letter are not different (P>.05).

Table 3. Measured spectral energy distribution of three light sources (Kropf, 1980).

		Deluxe Cool White		Natural		Incandescent Fluorescent	
	nm	Watts	%	Watts	%	Watts	%
uv	380	0.15	2.1	0.26	3.6	0.12	1.9
Violet	380-430	0.56	7.8	0.51	7.1	0.13	2.0
Blue	430-490	1.36	18.8	1.12	15.5	0.45	7.0
Green	490-560	1.73	24.0	1.54	21.3	1.04	16.2
Yellow	560-590	0.86	11.9	0.79	10.9	0.76	11.8
Orange	590-630	1.20	16.6	1.18	16.3	1.23	19.2
Red	630-700	1.36	18.8	1.83	25.3	2.21	34.4
Total		7.22		7.23		6.42	
Far Red						0.48	7.2

nm ratios indicate best cured color stability for vacuum processed wafer sliced cured and cooked beef displayed under low (1.1 or 4.4°C) refrigeration temperatures. Visually estimating veal loaf color fade, Archer and Bandfield (1950) found fc-hr to the point of least perceptible color fade to decrease as display temperature rose from 35 to 65°F (1.7°C to 18.3°C).

From 0 through 24 hr, little difference in nitrosohemochrome oxidation was measured between the 3 temperature treatments. During the light off period between 12 and 24 hr, a slight regeneration in cured color was detected in the 4.4°C treatment but not at 1.1 and 7.8°C. Watts et al. (1955) found cured meat with free sulfhydral groups and an excess of nitrite could regenerate cured color within 24 hr when stored at 7°C in the dark. Accelerated cured color fading was noted for 7.8°C product at 48 and 72 hr over the lower temperature treatments. Chill room temperature fluctuation could have been a possible explanation why cured color fade was greater at 48 and 72 hr for product displayed at 1.1 than 4.4°C.

Mean standard plate counts, $\log_{10}$ bacteria/g increased from 24 to 72 hr of display (Table 5). At 24 hr microbial growth was not different for product displayed under the 3 temperature treatments. By 72 display hr, the 7.8°C display resulted in higher standard plate counts, about 1 log higher than the 2 lower temperatures.

Vacuum processed product mean pH values exhibited small differences without any consistent trend for the 3 temperature treatments between 24 and 72 display hr (Table 6). Pro-

Table 4. Mean 570nm/650nm reflectance ratios for the effect of temperature and its interaction with display hours on wafer sliced cured and cooked beef processed under vacuum.

	Display Hours						All Times
	0	6	12	24	48	72	
Temperature							
1.1°C (34°F)	.4067[a]	.4736[cd]	.5113[e]	.5244[ef]	.5725[g]	.6060[hi]	.5157[k]
4.4°C (40°F)	.4159[ab]	.4442[bc]	.5071[e]	.4955[de]	.5550[f]	.5912[gh]	.5015[j]
7.8°C (46°F)	.3970[a]	.4725[cd]	.4994[de]	.5248[ef]	.6164[hi]	.6302[i]	.5234[l]

a-i or j-l Means with the same superscript letter are not different (P>.05).

Table 5. Mean standard plate count values[z] for rhw effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef processed under vacuum.

	Display Hours	
	24	72
Temperature (T)		
1.1°C (34°F)	1.400[a]	3.050[b]
4.4°C (40°F)	1.933[a]	3.104[b]
7.8°C (46°F)	1.719[a]	4.215[c]
All T	1.736[d]	3.797[e]

[z]Log_{10} bacteria/g.

a-c or d-e Means with the same superscript letter are not different ($P>.05$).

duct pH displayed at 1.1°C increased, 4.4°C decreased, and 7.8°C did not change. As package microbial populations were not identified, the small changes in product pH means couldn't be positively attributed to temperature selection of specific bacterial genera.

A slightly lower (P .05) pH was noted for product displayed under 1076 lm/m^2 than at the higher lighting intensities, but differences were very small and not useful in predicting changes in product cured color fading.

Mean package oxygen values, expressed as % O_2 of gas volume (Table 7), showed packages displayed under SW lighting to contain less oxygen (P<.05) than packages displayed under the other fluorescent lighting treatments. Due to experimental error and packaging material problems, type of lighting's effect on package oxygen means was not reliable.

For all treatment combinations, package oxygen means decreased from 24 to 72 display hr. As standard microbial plate count means rose from 24 to 72 hr, the decrease in package oxygen level may be the result of an increasing microbial oxygen demand by surviving aerobic of facultative organisms from the initial beef microflora.

Summary

Product cured color faded with increasing lighting intensity from 1076 to 3228 lm/m^2 as determined by both subjective and objective color measurements. The increasing reflectance ratios suggest that light induced nitrosohemochrome oxidation

Table 6. Mean pH values for the effect of lighting intensity and the interaction of temperature and display hours on wafer sliced cooked and cured beef processed under vacuum.

Lighting Intensity	
1076 lm/m^2 (100 fc)	6.210^{d}
1614 lm/m^2 (150 fc)	6.224^{e}
2152 lm/m^2 (200 fc)	6.220^{e}
3228 lm/m^2 (300 fc)	6.226^{e}

	Display Hours	
	24	72
Temperature		
1.1°C (34°F)	6.197^{a}	6.317^{c}
4.4°C (40°F)	6.247^{b}	6.186^{a}
7.8°C (46°F)	6.184^{a}	6.188^{a}

a-c or d-e Means with the same superscript letter are not different (P>.05).

Table 7. Mean package O_2 values[z] for the effects of type of lighting and display hours on wafer sliced cured and cooked beef processed under vacuum

Type of Lighting	
General Electric Deluxe Cool White (DCW)	1.408[b]
Sylvania Incandescent Fluorescent (IF)	1.249[b]
General Electric Natural (N)	1.479[b]
Westinghouse Supermarket White (SW)	0.916[a]
Display Hours	
24	1.547[d]
72	0.979[c]

[z]% O_2 of gas volume.

a-b or c-d Means with the same superscript letter are not different (P>.05).

was the major display effect on cured color fading of vacuum processed wafer sliced cured and cooked beef.

Oxidative changes in the cured meat pigment, once initiated, continued as a function of time. Cured color fading increased visually as a function of lighting intensity and display time under a lighting source, substantiating the reciprocity law of equal product fading when illuminated under equal lm/m^2-hr.

Different visual product fading under 4 fluorescent lighting systems, which was not confirmed by reflectance ratio, was largely caused by differences in lamp spectral energy distribution and respective color rendition rather than an effect of stimulation of cured pigment dissociation and resulting oxidation by absorbing energy from specific wavelengths emitted from the lamps. Lamps emitting a larger percent of their energy in the orange and red wavelengths than in the shorter visible wavelengths reduced visual product cured color fade.

Displaying vacuum processed product at 7.8°C accelerated cured pigment fading from pink to brownish gray in 72 hr. Lower display temperatures of 1.1 and 4.4°C both reduced nitrosohemochrome oxidation as determined by 570 nm/650 nm reflectance ratios.

Total package microorganism numbers increased from 24 to 72 display hr and also as display temperature increased from 1.1 to 7.8°C. Package oxygen levels decreased from 24 to 72 hr. This change could have been the result of an in-

creasing oxygen demand from surviving aerobic and facultative bacteria from the initial beef microflora in the vacuum processed nitrogen flushed package.

REFERENCES

Archer, H. and Bandfield, R.E. 1950. The discoloration of veal loaf when exposed to high illumination. Illum. Engr. 45:429.

Clark, C.N. 1956. The basis for appropriate lighting for meat displays. Proc. 8th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.83.

Erdman, A.M. and Watts, B.M. 1957. Spectrophotometric determination of color change in cured meat. J. Agr. Food Chem. 5:453.

Kampschmidt, R.F. 1955. Meat color and influence of light. Proc. 7th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.42.

Kraft, A.A. and Ayres, J.C. 1954. Color changes in packaged bologna. Food Technol. 8:22.

Kropf, D.H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recip. Meat Conf., Nat'l. Livestock and Meat Board, Chicago, (In Press).

Ramsbottom, J.M., Goeser, P.A., and Shultz, H.W. 1951. How light discolors the meat and what to do about it. Food Ind. 23:120.

Snedecor, G.W. and Cochran, W.G. 1967. "Statistical Methods," 6th ed. Iowa State Univ. Press, Ames Iowa.

Sylvania. No Date. Spectral energy distribution curves of Sylvania F40T12 fluorescent lamps. Engr. Bull. 0-283, Commercial Engr. Dept., Lighting Div., Salem, Mass.

Taylor, A.H. and Pracejus, W.G. 1950. Fading of colored materials by light and radiant energy. Illum. Engr. 45:149.

Walsh, K.A. and Rose, D. 1956. Factors affecting the oxidation of nitric oxide myoglobin. J. Agr. Food Chem. 4:352.

Watts, B.M., Erdman, A.M., and Wentworth, J. 1955. Relation of free sulfhydral groups to cured meat color. J. Agr. Food Chem. 3:147.

CHAPTER V

EFFECT OF LIGHTING INTENSITY, TYPE OF LIGHTING, AND TEMPERATURE ON WAFER SLICED CURED AND COOKED BEEF

ABSTRACT

Display conditions' influence on cured color fading of wafer sliced cured and cooked beef was visually estimated and measured by 570 nm/650 nm reflectance ratios. Standard plate counts and package oxygen were also determined. Product fading increased with increasing lighting intensities from 1076 to 3228 lm/m^2 and display time up to 72 hours. Vacuum processed product visually faded less at all times than nonvacuum. Incandescent Fluorescent and Natural lighting caused less visual fading than Deluxe Cool White or Supermarket White. Product fading was similar at 1.1 and 4.4°C but accelerated at 7.8°C. Between 24 and 72 hours, standard plate counts increased to log 4.9/g, whereas package oxygen decreased.

Introduction

Supermarkets utilize refrigerated display cases for the presentation of individually wrapped packages of meat and meat products. The cases utilize bright lighting to attract customers' attention and elicit favorable purchase responses. Meat color is a primary factor in determining consumer preferences.

The pigment responsible for the typical bright pink color in cured and cooked meats is nitrosohemochrome. Upon oxidation this pigment is denatured with the pink color fading to brown/gray. Sensitivity of nitrosohemochrome to photooxidation and subsequent color fading in a short period of time is an economic problem in highly illuminated self-service display cases. Consumers, relying upon the bright pink cured meat color as a means of determining product freshness and wholesomeness, reject cured meats and meat products with faded appearance.

Packaged cured meats and meat products, fully cooked and ready to serve, are convenient and popular menu items for today's mobile society. Many new items have been developed for sale, including cured and fully cooked wafer sliced beef.

Despite approximately 30 years of research concerning the photooxidation of nitrosohemochrome, the color fading of cured meats continues to be a problem in retail stores. Wide variation can be found in sources of display illumination, light intensity at the product surface, and product holding temperatures.

Our study had the following objectives: 1) to determine the effects of various display conditions, (type of lighting, lighting intensity, and temperature), upon color stability of wafer sliced, cured and cooked beef in an 84 g gas flush package, 2) to determine any contributing role of package microbial numbers, pH, and oxygen level to cured color fade during and after display conditions, 3) to determine the importance of processing method (vacuum versus nonvacuum) in maintaining cured color, and 4) to form the basis for recommendations to retailers concerning controllable display conditions.

Experimental

Commercially prepared wafer sliced (.711 mm thick) cured and cooked beef in an 84 g nitrogen flushed package was furnished to Kansas State University by Land O' Frost Corp., Lansing, Il. Product composition was approximately 20% protein, 70% water, 3.7 to 3.8% salt, 5 to 6% fat, plus sodium erythorbate, sodium nitrite, and seasonings. The wafer sliced cured and cooked beef was packaged with a laminated film of saran-cellophane-saran-polyethylene with oxygen permeability of .55 cc/24 hr/m^2 at 22.2^{o}C and moisture permeability < 1 cc. The pouches were opaque except for a transparent product viewing area on the principal display panel, and a hole was punched outside the package seal for pegboard type display. Product from 2 methods of processing was evaluated; 1 method being product produced in nonvacuum equipment and in the other

method product produced with vacuumizing equipment.

All samples were transported to the Kansas State University Meat Science Laboratory by commercial refrigerated truck from Land O' Frost. Packages were checked for seal integrity and color, then randomly assigned to predetermined display treatments. Using a random sampling method, packages were removed at the initiation of the display study for the purpose of determining product microbial standard plate counts, pH of product surface, and package oxygen level.

Display treatments studied included all possible combinations of the following variables: 4 types of lighting (each 40 watt tubes), namely General Electric Deluxe Cool White, Sylvania Incandescent Fluorescent, General Electric Natural, and Westinghouse Supermarket White; 4 lighting intensities at product surface level, 1076 lm (lumens)/m^2 (100 fc, foot-candles), 1614 lm/m^2 (150 fc), 2152 lm/m^2 (200 fc), and 3228 lm/m^2 (300 fc); 3 display temperatures, 1.1°C (34°F), 4.4°C (40°F), and 7.8°C (46°F); and 2 processing systems, namely vacuumized and nonvacuumized.

Due to the large number of samples studied and limited display case space, retail display conditions were simulated on a large scale in refrigerated chill rooms meeting prescribed treatment requirements. Surfaces and background under each source of illumination were covered with white meat wrapping paper. Light intensity levels at the package surface level were determined by a General Electric Light Meter, Model No. 201. Distances in cm between the light sources and the sur-

face of the cured and cooked wafer sliced beef to achieve the desired intensities of light are given in the appendix. Lighting under the display conditions was a 12 hr on/12 hr off cycle, beginning with the lights on.

Subjective (visual) and objective (reflectance) color determinations were taken over a period of 3 days, at the following times: 0 hr (before light exposure), 6, 12, 24, 48, and 72 hr.

Subjective cured color scores were assigned to each package under every display condition treatment for all designated time periods by 2 trained visual panelists. The following visual color scale was used to the nearest 0.5 point: 1=Bright Pink cured color (all pink, no brown/gray), 2=Slight Fade (more pink, less brown/gray), 3=Moderate Fade (less pink, more brown/gray), and 4=Complete Fade (no pink, all brown/gray). Color scales were assigned to the product exposed to the light sources and visible through the transparent window on the principal display panel.

Reflectance was scanned from 560 nm to 660 nm through the clear film of the unopened packages on a Bausch and Lomb 600 Spectrophotometer (scan speed 250 nm/min) with reflectance attachment. Pure magnesium carbonate blocks were used to standardize 100% reflectance. Reflectance values were read to the nearest 0.1% at wavelengths of 570 and 650 nm and a ratio of the % reflectance was calculated as an objective measure of color fade using wavelengths suggested by Erdman and Watts (1957).

Microbial standard plate counts were determined on randomly selected preassigned packages in the following manner: 2 packages each from vacuum and nonvacuum treatments after display for 24 and 72 hr (arbitrarily considered as "Complete Fade"). Dilute phosphate buffer was prepared from 1.25 ml of stock solution diluted to 1000 ml (phosphate buffer stock solution of 3.4 g of KH_2PO_4 in 50 ml distilled water, pH adjusted to 7.2 with .01 N NaOH, then diluted to 100 ml). Packages were aseptically injected with 100 ml of sterile dilute phosphate buffer, and product slices thoroughly rinsed. Appropriate dilutions were made and plated onto standard methods tryptone glucose extract agar. Counts were made after incubation for 96 hr at 25°C.

In determining the pH of the product surface exposed to the light sources, the top layer of the wafer sliced beef was removed from the package, placed in a beaker, and minced with a knife. Distilled water (50 ml) was added to the mince and thoroughly mixed. pH readings were taken with a surface electrode of a Corning Digital 110 pH Meter. Sampling was limited to randomly preassigned product with 2 packages from each display treatment after 24 hr and again after 72 hr.

Again a preassigned package sampling method was used as described for microbial standard plate counts and pH determinations for identical time intervals for measuring package oxygen level. Readings were made to the nearest 0.1% with a Beckman C-2 Oxygen Analyzer which evacuated package gas by using a probe and vacuum pump.

Data were analyzed by analysis of variance and main effects were determined by the method of least significant differences as specified by Snedecor and Cochran (1967).

Results and Discussion

Visual color scores indicated increased fading with increasing light intensity from 1076 to 3228 lm/m^2 (Table 1). Although the relectance ratios for 1614 and 2152 lm/m^2 were not different, 570 nm/650 nm reflectance ratios also increased ($P<.05$) with increasing light intensity. Product color faded from pink to brown/gray as light accelerated the likely oxidation of nitrosohemochrome of oxidized porphyrins by either the light catalyzed dissociation mechanism cited by Kampschmidt (1955) or the active molecule mechanism of Walsh and Rose (1956). Only the top layer or slice (.711 mm thick) of the packaged product was faded after 72 hr exposure under the 4 fluorescent lighting systems. A similar observation was made by Ramsbottom et al. (1951) with cured meat and meat products illuminated under incandescent and fluorescent lamps and by Urbain and Jensen (1940) with cured meat surfaces exposed to air. In living systems, radiation absorption is limited to with a fraction of the exposed surface obeying the quantitative absorption laws of Bougier-Lambert and Beer (Blum, 1941).

After display initiation, product fade progressively increased with increasing time and lighting intensity. Beginning at display initiation, lighting was scheduled on a

Table 1. Mean visual color scores[y], 570nm/650nm reflectance ratios, and lumens/meter^2-hours values for the effect of lighting intensity and its interaction with display hours on wafer sliced cured and cooked beef.

Lighting Intensity lm/m^2[z]		Display Hours 0	6	12	24	48	72	All Times Score	Ratio
1076	Score	1.000^{a}	1.224^{b}	1.589^{cd}	1.688^{d}	2.215^{f}	2.551^{gh}	1.634^{m}	.4906^{q}
	lm/m^2-hrs		6,456	12,912	12,912	25,824	38,736		
1614	Score	1.000^{a}	1.316^{b}	1.932^{e}	2.026^{e}	2.805^{i}	3.171^{j}	1.972^{n}	.5134^{r}
	lm/m^2-hrs		9,684	19,368	19,368	38,736	58,104		
2152	Score	1.000^{a}	1.483^{c}	2.156^{f}	2.271^{f}	3.074^{j}	3.406^{k}	2.150^{o}	.5166^{r}
	lm/m^2-hrs		12,912	25,824	25,824	51,648	77,472		
3228	Score	1.016^{a}	1.664^{d}	2.478^{g}	2.696^{hi}	3.447^{k}	3.750^{l}	2.441^{p}	.5491^{s}
	lm/m^2-hrs		19,368	38,736	38,736	77,472	116,208		

[y]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z]Lighting Intensity: 1076 lm/m^2=100 foot-candles (fc), 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

a-l or m-p or q-s[Means with the same superscript letter are not different (P>.05).

12 hr on, 12 hr off cycle. For all light intensities product visually faded at a slower rate in the dark period between 12 and 24 hr under light. The fade for this dark period was higher for product displayed at the higher lighting intensity. The rate of product fading increased for all lighting intensities from 6 through 48 hr, except 12 through 24 hr, but decreased between 48 and 72 hr. Slowing of the cured color fading after 48 hr may be due to the product approaching "Complete Fade" or a total loss of pink color when viewed. A greater proportion of fading produced by higher lighting intensity was noted early in display, ie. by 12 hr.

The law of reciprocity of equivalence (Bunsen-Roscoe law) states the time required to absorb the same number of quanta must vary inversely as the intensity of the light flux is changed (Blum, 1941). Comparing the energy under which the product was exposed in lm/m^2-hr, visual color fading generally was similar for product exposed to equal accumulative illuminant energy. Clark (1956), using data from Archer and Bandfield (1950) and Ramsbottom et al. (1951), stated that cured meat fading was a function of exposure in fc-hr over a range of 20 to 200 fc (215.2 to 2152 lm/m^2).

There wasn't a significant interaction for visual scores, but 570 nm/650 nm reflectance ratios indicate the rate of photochemically induced nitrosohemochrome oxidation was somewhat sensitive to changes in temperature (Table 2). Trends weren't consistent for all light intensities and temperatures; however, for product held at 7.8°C, except under 1614 lm/m^2,

nitrosohemochrome oxidation was accelerated over product held at 1.1°C or 4.4°C with increasing light intensity. Archer and Bandfield's (1950) visual appraisal of veal loaf indicated time to least perceptible discoloration decreased with increasing temperature from 35 to 65°F (1.7°C to 18.3°C). Walsh and Rose (1956) showed increasing temperature from 0.5 to 26.3°C increased the oxidation rate of nitric oxide myoglobin in solution.

pH of product held under 1076 lm/m^2 was slightly lower than pH of product held at higher lighting intensities (Table 3). As the pH range between the light intensities and the chance of causing product fading differences were very small, little importance was attributed to the pH change.

Product viewed under Incandescent Fluorescent (IF) and Natural (N) lighting appeared less faded than product held under Deluxe Cool White (DCW) or Supermarket White (SW), which exhibited the most visual fade (Table 4). 570 nm/650 nm reflectance ratios did not confirm visual fading differences as differences in product nitrosohemochrome oxidation from pink to brown/gray in color, indicating visual fading differences were due to the lamps' color rendition or spectral energy distribution.

Early workers had suggested that product fading might be accelerated by absorption of selected wavelengths of visible light. Urbain and Ramsbottom (1948) found sliced boiled ham wrapped in red cellophane exhibited less fading than ham wrapped in colorless semi-moisture proof or amber cellophane after

Table 2. Mean 570 nm/650 nm reflectance ratios for the effect of temperature and its interaction with lighting intensity on wafer sliced cured and cooked beef.

	Temperature		
	1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Lighting Intensity (LI)			
1076 lm/m^2 (100 fc)	.4764^{a}	.4932^{b}	.5020^{bc}
1614 lm/m^2 (150 fc)	.5143^{cd}	.5185de	.5076^{bcd}
2152 lm/m^2 (200 fc)	.5180^{cde}	.4933^{b}	.5385^{fg}
3228 lm/m^2 (300 fc)	.5533^{gh}	.5309^{ef}	.5632^{h}
All LI	.5155^{j}	.5090^{i}	.5278^{k}

$^{a-h}$ or $^{i-k}$Means with the same superscript letter are not different (P>.05).

Table 3. Mean pH values for the effect of lighting intensity on wafer sliced cured and cooked beef.

Lighting Intensity	
1076 lm/m^2 (100 foot-candles)	6.220^{a}
1614 lm/m^2 (150 foot-candles)	6.232^{b}
2152 lm/m^2 (200 foot-candles)	6.228^{b}
3228 lm/m^2 (300 foot-candles)	6.231^{b}

$^{a-b}$Means with the same superscript letter are not different ($P>.05$).

20 hr of exposure under 40 to 50 fc (430.4 to 538 lm/m^2 of fluorescent lighting. Archer and Bandfield (1950), using filters to absorb wavelengths up to 450 nm (blue) on veal loaf illuminated under 50 to 150 fc (538 to 1614 lm/m^2) of fluorescent light between 35 and 65°F (1.7 to 18.3°C), found a significant increase in time required for least perceptible discoloration over veal loaf illuminated without filters. Kampschmidt (1955) found nitrosomyoglobin in solution absorbed visible light energy between 380 to 580 nm increasing its dissociation.

Photopic vision's maximum sensitivity to light is at 555 nm or green-yellow wavelengths (Sylvania, No Date) and decreasing in sensitivity through the orange-red wavelengths. "As the color of a body depends on that part of the spectrum not absorbed, but reflected, it follows that the more red in the light source the more red will be reflected to the eye," (Francis and Clydesdale, 1975). IF and N lamps emitted a larger percent of their energy in the orange-red wavelengths than in the green-yellow wavelengths (Kropf, 1980) and their exposed product appeared less visually faded than product exposed under DCW, which emitted a larger proportion of its spectral energy in the green-yellow wavelengths than orange-red wavelengths. Spectral energy distribution curves were not available for SW; however, it also would be expected to emit a larger proportion of its spectral energy in the green-yellow wavelengths than in the red-orange wavelengths.

Type of lighting interacted ($P<.05$) with time for visual

color scores (Table 4). Under all lighting systems, product fading increased as display time increased for all treatments. Product visual fading continued slowly in the dark between 12 and 24 hr. Visual fading progressed for product illuminated under all treatments at 48 through 72 hr, but rate of fade after 48 hr declined. The slowing in product visual fade may have been due to increasing difficulty in evaluating fading differences as the product approached "Complete Fade" or a totally brown/gray color. Visual fading differences were not confirmed by 570 nm/650 nm reflectance ratios. The interaction was largely due to the higher mean visual scores at 6, 12, 24, 48, and 72 hr for product displayed under SW. This consistently higher score (more visual fade) may have been largely due to the effects of unfavorable rendition of product appearance under this lighting system.

Method of processing the wafer sliced beef also affected visual color scores (Table 5). For all treatments, product processed in vacuumized equipment had a slight appearance advantage over product processed with nonvacuumized equipment. Urbain and Ramsbottom (1948) suggested elimination of oxygen, a principal fading reactant, by vacuum packaging as a solution to the fading problem in cured meats. Kraft and Ayres (1954) found vacuum packaged bologna showed less discoloration by subjective and objective color determination than samples wrapped under atmospheric pressure when exposed under 45 to 60 fc (484.2 to 645.6 lm/m^2) of Soft White fluorescent light. Recently, Schmidt (1979) stated the use of vacuum in conjunc-

Table 4. Mean visual color scores[y] for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef.

	Display Hours						All Times
	0	6	12	24	48	72	
Types of Lighting[z]							
DCW	1.005^{a}	1.422^{b}	2.125^{ef}	2.240^{f}	2.921^{i}	3.227^{k}	2.157^{n}
IF	1.000^{a}	1.358^{b}	1.826^{d}	2.016^{e}	2.755^{h}	3.089^{j}	2.007^{m}
N	1.000^{a}	1.318^{b}	1.974^{d}	2.016^{e}	2.707^{h}	3.026^{ij}	2.007^{m}
SW	1.010^{a}	1.588^{c}	2.230^{f}	2.409^{g}	3.156^{k}	3.536^{l}	2.322^{o}

[y]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z]Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

a-l or m-o Means with the same superscript letter are not different (P>.05).

Table 5. Mean visual color scores[z] for the effect of type of lighting and its interaction with type of processing on wafer sliced cured and cooked beef.

	Type of Processing	
	Vacuum	Nonvacuum
Type of Lighting (TL)		
GE Deluxe Cool White (DCW)	2.089[ab]	2.225[b]
Sylvania Incandescent Fluorescent (IF)	1.943[a]	2.071[ab]
GE Natural (N)	1.994[ab]	2.019[ab]
Westinghouse Supermarket White (SW)	2.169[ab]	2.474[c]
All TL	2.049[d]	2.197[e]

[z]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[a-c or d-e]Means with the same superscript letter are not different (P>.05).

tion with bowl chopping prevented the whipping of excess air into meat products. As our product's laminate wrap had low oxygen permeability, visual fading differences for the nitrogen flushed packages suggest less oxygen incorporation into the vacuum processed beef. Compared with nonvacuum processed product, vacuum processed product exhibited less visual fade when illuminated under SW lamps. The vacuum processing tended to protect product from effects of an adverse type of lighting. This suggests vacuum processed beef can partially compensate for visual fading when viewed under lamps that emit a lower percentage of their spectral energy in the orange-red wavelengths or the apparent visual effect is partly due to product oxidation.

Mean package oxygen, expressed as % O_2 of package gas volume, decreased between 24 and 72 hr of display (Table 6). Package oxygen decrease with increasing display time may have resulted from an oxygen demand by aerobic or facultative organisms in an increasing microbial population between 24 and 72 hr (Table 8) or from oxygen consuming oxidative reactions.

Package oxygen means decreased between 24 and 72 hr for product exposed under DCW, N, and SW lamps (Table 6). Due to experimental error and packaging problems, a large variability was found in % package oxygen, indicating little reliability for package % oxygen differences of product exposed under the fluorescent lighting treatments.

Mean 570 nm/650 nm reflectance ratios indicated the oxidation of nitrosohemochrome was temperature sensitive (Table

Table 6. Mean package O_2 values[z] for the effect of type of lighting and its interaction with display hours on wafer sliced cured and cooked beef.

	Display Hours	
	24	72
Type of Lighting (TL)		
General Electric Deluxe Cool White (DCW)	2.097[e]	0.708[a]
Sylvania Incandescent Fluorescent (IF)	1.428[bcd]	1.234[abc]
General Electric Natural (N)	1.741[cde]	1.181[ab]
Westinghouse Supermarket White (SW)	1.861[de]	0.925[ab]
All TL	1.708[g]	0.964[f]

[z]% O_2 of package gas volume.

[a-e or f-g]Means with the same superscript letter are not different (P>.05).

2). More nitrosohemochrome oxidized in product stored under 7.8°C than under 1.1 or 4.4°C. Product stored under 1.1°C showed greater cured pigment oxidation than 4.4°C which may have been caused by undocumented display refrigeration fluctuations. Kampschmidt (1955) and Walsh and Rose (1956) both found nitrosomyoglobin to be temperature sensitive, increasing in oxidation rate between a range of 0.5 to 26.3°C; however, Kampschmidt stated the rate of dissociation for the cured meat pigment was not increased by an increase in storage temperature.

Visual and objective color determinations both showed product fading, once initiated, was a function of time (Table 7), increasing more so with illuminated display than in the dark.

Temperature interacted with display time for product visual fade estimation and 570 nm/650 nm reflectance ratio measurements (Table 7). Visual fading rate increased for all 3 temperature treatments between 6 and 48 hr, except between 12 and 24 hr when the display lights were off, but rate of fading decreased from 48 to 72 hr, especially at 7.8°C. Reflectance ratio measurements did not always parallel visual fading rates as the pigment oxidation rate decreased between 6 and 12 hr for product displayed at 1.1 and 7.8°C and rose slightly for product displayed at 4.4°C. The rate of nitrosohemochrome oxidation increased for all 3 temperature treatments between 12 and 48 hr, excepting the 12 through 24 hr dark display period, and decreased between 48 and 72 hr. The

Table 7. Mean visual color scores[z] and 570nm/650nm reflectance ratios for the effect of temperature and its interaction with display hours on wafer sliced cured and cooked beef.

		Display Hours					
		0	6	12	24	48	72
Temperature (T)							
1.1°C (34°F)	Ratio	.4086^{a}	.4784^{c}	.5115^{d}	.5186de	.5697^{f}	.6060^{g}
	Score	1.004^{i}	1.346^{j}	2.008^{k}	2.184^{lm}	2.855^{n}	3.160^{o}
4.4°C (40°F)	Ratio	.4226^{b}	.4585^{c}	.5037^{d}	.5051^{d}	.5582^{f}	.6058^{g}
	Score	1.008^{i}	1.453^{j}	2.016^{k}	2.086^{kl}	2.771^{n}	3.139^{o}
7.8°C (46°F)	Ratio	.3955^{a}	.4698^{c}	.5152^{d}	.5379^{e}	.6153^{gh}	.6333^{h}
	Score	1.000^{i}	1.465^{j}	2.092^{kl}	2.241^{m}	3.029^{o}	3.359^{p}
All T	Ratio	.4065^{q}	.4634^{r}	.5060^{s}	.5149^{t}	.5813^{u}	.6091^{v}
	Score	1.004^{w}	1.421^{x}	2.039^{y}	2.170^{z}	2.885$^{a'}$	3.220$^{b'}$

[z]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

a-h or i-p or q-v or w-b' Means with the same superscript letter are not different (P>.05).

decrease in fading rate between 48 and 72 hr by visual and reflectance color measurements indicated less fading as product approached "Complete Fade". At 72 hr visual and reflectance color measurements were not different ($P>.05$) for product displayed at 1.1 and 4.4°C while product displayed at 7.8°C exhibited greater nitrosohemochrome oxidation and visual fading.

Mean standard plate counts, expressed as $\log_{10}$ bacteria/g, increased by approximately 1 log between 24 and 72 hr of display (Table 8). Between 24 and 72 hr, microbial growth increased as display temperature increased from 1.1 to 7.8°C. The microbial population increased by approximately .75 of a log for product displayed at 1.1 and 4.4°C and by 1.9 log for product displayed at 7.8°C.

Mean product pH increased slightly between 24 and 72 hr of display (Table 9). Temperature interacted with display time for product pH values without establishing any consistent trend: at 1.1°C pH increased slightly, at 4.4°C pH decreased slightly, and at 7.8°C product pH did not change.

The influence of processing method on product pH (Table 10) showed lower pH means for vacuum processed than nonvacuum processed product. Product pH was lower for vacuum processed product at each temperature treatment. Product pH also declined for both vacuum and nonvacuum processed product as temperature increased from 1.1 to 4.4 and from 4.4 to 7.8°C. Ingram and Dainty (1971) found the bacterial population on Wiltshire bacon placed in an air impermeable package changed from predominantly micrococci to lactic acid producing bac-

Table 8. Mean standard plate count values[z] for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef.

	Display Hours	
	24	72
Temperature (T)		
1.1°C (34°F)	1.491[a]	2.880[b]
4.4°C (40°F)	1.744[a]	3.147[b]
7.8°C (46°F)	1.605[a]	4.850[c]
All T	1.626[d]	4.386[e]

[z] $\log_{10}$ bacteria/g.

[a-c or d-e] Means with the same superscript letter are not different ($P>.05$).

Table 9. Mean pH values for the effect of display hours and its interaction with temperature on wafer sliced cured and cooked beef.

	Display Hours	
	24	72
Temperature (T)		
1.1°C (34°F)	6.208[a]	6.330[c]
4.4°C (40°F)	6.254[b]	6.190[a]
7.8°C (46°F)	6.190[a]	6.194[a]
All T	6.217[d]	6.238[e]

a-c or d-e Means with the same superscript letter are not different (P>.05).

Table 10. Mean pH values for the effect of type of processing and its interaction with temperature on wafer sliced cured and cooked beef.

	Type of Processing	
	Vacuum	Nonvacuum
Temperature (T)		
1.1°C (34°F)	6.257[e]	6.281[f]
4.4°C (40°F)	6.216[c]	6.228[d]
7.8°C (46°F)	6.186[a]	6.198[b]
All T	6.220[g]	6.236[h]

a-f or g-h Means with the same superscript are not different (P>.05).

teria as microorganism numbers increased. Although the wafer sliced beef microflora was not identified, the changes in product pH could have been the result of an increasing selection for lactic acid producing bacteria by the internal package atmosphere differences of vacuum versus nonvacuum processed product and stimulated microbial growth in product with rising display temperature.

Processing method interacted ($P<.05$) with display time for visual color scores (Table 11) with fade progressing for both processing methods as display time increased. At each time interval after display initiation, vacuum processed product appeared less faded than nonvacuum processed product. The rate of visual fading for both processing methods increased between 6 and 48 hr, except when display lights were off between 12 and 24 hr, and then decreased between 48 and 72 hr. Reflectance ratios (570 nm/650 nm) did not show a significant processing by hr interaction.

Summary

Lighting intensity was a major factor responsible for inducing fading of cured and cooked wafer sliced beef. Product fade, determined by objective and subjective color measurements, increased as lighting intensity at the product surface level increased from 1076 to 3228 lm/m^2. Product fade was exhibited by only the top layer or wafer slice exposed to the light source.

Visual fading progressed as a function of time for all

Table 11. Visual color scores[z] for the interaction of type of processing and display hours on wafer sliced cured and cooked beef.

	Display Hours					
	0	6	12	24	48	72
Type of Processing						
Vacuum	1.003[a]	1.362[b]	1.956[d]	2.090[f]	2.767[h]	3.117[i]
Nonvacuum	1.005[a]	1.481[c]	2.121[e]	2.251[g]	3.003[i]	3.322[j]

[z]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[a-j]Means with the same superscript letter are not different (P>.05).

lighting intensity treatments. The reciprocity law was generally substantiated for product visual fading with equivalent fading estimated for product held under equal lm/m^2-hr within the lighting intensity treatments. Reflectance ratios (570 nm/650 nm) were not significant ($P>.05$) for the lighting intensity by display hr interaction.

Type of lighting affected product visual fade but not reflectance ratios, with fading differences caused by lamp spectral energy distribution differences. Product appeared less faded when viewed under light sources which emit a larger portion of their spectral energy in the orange-red wavelengths than in the green-yellow wavelengths. After display initiation, product viewed under IF and N lamps appeared less faded than product viewed under DCW and SW lamps throughout the 72 hr display study.

Vacuum processing of product reduced visual fading under the 4 fluorescent lighting systems compared with nonvacuum processed product. Vacuum processing of the wafer sliced cured and cooked beef appeared to compensate for visual fade under lighting systems emitting a lower percentage of their spectral energy in the orange-red wavelengths. After display initiation, vacuum processed product appeared less visually faded than nonvacuum processed product throughout all display times.

Both by objective and subjective color measurements, cured color fading for wafer sliced beef was found to be sensitive to increasing display temperatures. After display initiation, fading was accelerated for product held at $7.8^{\circ}C$

over product held at 1.1 or 4.4°C from 6 through 72 hr. Visual fading rates, as a function of time for the 3 temperatures, were generally substantiated as changes in nitrosohemochrome oxidation to oxidized porphyrins.

Microbial standard plate counts, expressed as $\log_{10}$ bacteria/g, increased between 24 and 72 hr of display and with increasing display temperature from 1.1 to 7.8°C.

Mean package oxygen values, expressed as % O_2 of package gas volume, were found to decrease between 24 and 72 hr of display, which may have resulted from an increasing oxygen demand by surviving aerobic or facultative organisms from the original beef microflora as the product microbial population increased or from oxygen consuming oxidative reactions.

REFERENCES

Archer, H. and Bandfield, R.E. 1950. The discoloration of veal loaf when exposed to high illumination. Illum. Engr. 45:429.

Blum, H.F. 1941. "Photodynamic Action and Diseases Caused by Light." Reinhold Publishing Corp., New York, N.Y.

Clark, C.N. 1956. The basis for appropriate lighting for meat displays. Proc. 8th Res. Conf., Am. Meat Inst., Univ. of Chicago, p.83.

Erdman, A.M. and Watts, B.M. 1957. Spectrophotometric determination of color change in cured meats. J. Agr. Food Chem. 5:453.

Francis, F.J. and Clydesdale, F.M. 1975. "Food Colorimetry: Theory and Applications," p.11. AVI Publishing Co., Inc., Westport, Conn.

Ingram, M. and Dainty, R.H. 1971. Changes caused by microbes in spoilage of meats. J. Appl. Bact. 34(1):21.

Kampschmidt, R.F. 1955. Effect of wavelength of light and discoloration of cured meats. J. Agr. Food Chem. 3:510.

Kraft, A.A. and Ayres, J.C. 1954. Color changes in packaged bologna. Food Technol. 8:22.

Kropf, D.H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recip. Meat Conf., Nat'l. Livestock and Meat Board, Chicago, (In Press).

Ramsbottom, J.M., Goeser, P.A., and Shultz, H.W. 1951. How light discolors the meat and what to do about it. Food Ind. 23:120.

Schmidt, G.R. 1979. New methods in meat processing. Proc. Meat Ind. Res. Conf., Am. Meat Inst. Found., 1600 Wilson Blvd., Arlington, Virg. p.31.

Snedecor, G.W. and Cochran, W.G. 1967. "Statistical Methods," 6th ed. Iowa State Univ. Press, Ames Iowa.

Sylvania. No Date. Spectral energy distribution curves of Sylvania F40T12 fluorescent lamps. Engr. Bull. 0-283, Commercial Engr. Dept., Lighting Div., Salem, Mass.

Urbain, W.M. and Jensen, L.B. 1940. Heme pigments of cured meats. I. Preparation of nitric oxide hemoglobin and stability of the compound. Food Res. 5:593.

Urbain, W.M. and Ramsbottom, J.M. 1948. Controlling quality changes in cured meats by packaging. Food Res. 13:432.

Walsh, K.A. and Rose, D. 1956. Factors affecting the oxidation of nitric oxide myoglobin. J. Agr. Food Chem. 4:352.

CHAPTER VI

REGRESSION PREDICTED DISPLAY TEMPERATURE TO COMPENSATE FOR LIGHTING INTENSITY IN CONTROLLING CURED COLOR FADING OF WAFER SLICED CURED AND COOKED BEEF

ABSTRACT

Display conditions' influence on cured color fading of wafer sliced cured and cooked beef was visually estimated. Data were tested by analysis of variance, fit into a second order linear regression with fixed intercept, and maximum allowable display temperatures predicted from lighting intensities ($P<.05$) to achieve indicated product fading. Temperatures to achieve specified fading decreased with increasing lighting intensities from 1076 to 3228 lm/m^2 at each time, decreased with increasing time from 12 to 48 hours at each lighting intensity, and increased with allowable fading from 1.5 to 3.0 at fixed times and intensities. Incandescent Fluorescent and Natural allowable temperatures were higher than Deluxe Cool White's or Supermarket White's.

Introduction

Supermarkets utilize refrigerated display cases for the presentation of individually wrapped packages of meat and meat products. The cases utilize bright lighting to attract customers' attention and elicit favorable purchase responses. Meat color is a primary factor in determining consumer preferences.

The pigment responsible for the typical bright pink color in cured and cooked meats is nitrosohemochrome. Upon oxidation this pigment is denatured with the pink color fading to brown/gray. Sensitivity of nitrosohemochrome to photooxidation and subsequent color fading in a short period of time is an economic problem in highly illuminated self-service display cases. Consumers, relying upon the bright pink cured meat color as a means of determining product freshness and wholesomeness, reject cured meats and meat products with faded appearance.

Packaged cured meats and meat products, fully cooked and ready to serve, are convenient and popular menu items for today's mobile society. Many new items have been developed for sale, including cured and fully cooked wafer sliced beef.

Despite approximately 30 years of research concerning the photooxidation of nitrosohemochrome, the color fading of cured meats continues to be a problem in retail stores. Wide variation can be found in sources of display illumination, light intensity at the product surface, and product holding temperatures.

Our study had the following objectives: 1) to determine the effects of various display conditions (type of lighting, lighting intensity, and temperature) upon color stability of wafer sliced, cured and cooked beef in an 84 g gas flush package, 2) to determine to what extent type of lighting, lighting intensity, and temperature of display conditions could compensate for each other in detering cured color fade, and 3) to form the basis for recommendations to retailers concerning controllable display conditions.

Experimental

Commercially prepared wafer sliced (.711 mm thick) cured and cooked beef in an 84 g nitrogen flushed package was furnished to Kansas State University by Land O' Frost Corp., Lansing, Il. Product composition was approximately 20% protein, 70% water, 3.7 to 3.8% salt, 5 to 6% fat, plus sodium erythorbate, sodium nitrite, and seasonings. The wafer sliced cured and cooked beef was packaged with a laminated film of saran-cellophane-saran-polyethylene with oxygen permeability of .55 cc/24 hr/m^2 at 22.2°C and moisture permeability < 1 cc. The pouches were opaque except for a transparent product viewing area on the principal display panel, and a hole was punched outside the package seal for pegboard type display. Product from 2 methods of processing was evaluated; 1 method being product produced in nonvacuum equipment and in the other method product produced with vacuumizing equipment.

All samples were transported to the Kansas State Univer-

sity Meat Science Laboratory by commercial refrigerated truck from Land O' Frost. Packages were checked for seal integrity and color, then randomly assigned to predetermined display treatments.

Display treatments studied included all possible combinations of the following variables: 4 types of lighting (each 40 watt tubes), namely General Electric Deluxe Cool White, Sylvania Incandescent Fluorescent, General Electric Natural, and Westinghouse Supermarket White; 4 lighting intensities at product surface level, 1076 lm (lumens)/m^2 (100 fc, foot-candles), 1614 lm/m^2 (150 fc), 2152 lm/m^2 (200 fc), and 3228 lm/m^2 (300 fc); 3 display temperatures, 1.1°C (34°F), 4.4°C (40°F), and 7.8°C (46°F); and 2 processing systems, namely vacuumized and nonvacuumized.

Due to the large number of samples studied and limited display case space, retail display conditions were simulated on a large scale in refrigerated chill rooms meeting prescribed treatment requirements. Surfaces and background under each source of illumination were covered with white meat wrapping paper. Light intensity levels at the package surface level were determined by a General Electric Light Meter, Model No. 201. Distances in cm between the light sources and the surface of the cured and cooked wafer sliced beef to achieve the desired intensities of light are given in the appendix. Lighting under the display conditions was a 12 hr on/12 hr off cycle, beginning with the lights on.

Subjective (visual) and objective (reflectance) color

determinations were taken over a period of 3 days, at the following times: 0 hr (before light exposure), 6, 12, 24, 48, and 72 hr.

Subjective cured color scores were assigned to each package under every display condition treatment for all designated time periods by 2 trained visual panelists. The following visual color scale was used to the nearest 0.5 point: 1=Bright Pink cured color (all pink, no brown/gray), 2=Slight Fade (more pink, less brown/gray), 3=Moderate Fade (less pink, more brown/gray), and 4=Complete Fade (no pink, all brown/gray). Color scales were assigned to the product exposed to the light sources and visible through the transparent window on the principal display panel.

Reflectance was scanned from 560 nm to 660 nm through the clear film of the unopened packages on an Bausch and Lomb 600 Spectrophotometer (scan speed 250 nm/min) with reflectance attachment. Pure magnesium carbonate blocks were used to standardize 100% reflectance. Reflectance values were read to the nearest 0.1% at wavelengths of 570 and 650 nm and a ratio of the % reflectance was calculated as an objective measure of color fade using wavelengths suggested by Erdman and Watts (1957).

Data were analyzed by analysis of variance and main effects or interaction effects were determined by the method of least significant differences as specified by Snedecor and Cochran (1967). The data were then fit into a 2nd order linear regression model with a fixed intercept (Draper and

Smith, 1966). The model intercept was fixed at -2.8°C (27°F) based on the observation that at this temperature wafer sliced cured and cooked beef's visual color score was estimated as 1=Bright Pink. Predictions were made only on lighting intensity data which were significant ($P<.05$) when analyzed by analysis of variance.

Results and Discussion

Retail display lighting source, lighting intensity, nad temperature can be altered and offer management possibilities for controlling fading of wafer sliced cured and cooked beef. Knowing product display turnover rates, prediction of its visual color score under defined display conditions and time could determine adjustments for one display condition to compensate for changes in another which could benefit product marketing.

Within the limits of the data, product visual scores were predicted for temperature at lighting intensity levels of 1076, 1614, 2152, and 3228 lm/m^2 where display illumination source (Deluxe Cool White=DCW, Incandescent Fluorescent=IF, Natural=N, or Supermarket White=SW fluorescent lamps), product processing method (nonvacuum versus vacuum), and time (12, 24, or 48 hr) were specified. Product visual scores of 1.5, 2.0, 2.5, and 3.0 were selected as various stages of product fading which would occur within marketing periods of 12 through 48 hr. Visual scores for times less than 12 hr were not predicted as product fading was generally within accept-

able levels. After 48 hr, product fading approached an estimated "Moderate Fade", which was considered unacceptable and more difficult to score.

Predicted display temperatures for desired visual color scores are presented in Tables 1 through 8. Discussion of results cover only the data most useful from a retail merchandizing viewpoint.

At each visual score for nonvacuum processed product held under DCW lighting, predicted display temperatures decreased as lighting intensities increased at each display time (Table 1). For example, to achieve a visual color score of 1.5 for product held at 12 hr under display conditions, predicted temperature decreased from 2.3 to -0.4°C as lighting intensity increased from 1076 to 3228 lm/m^2. Lower display temperature was required to overcome the fading acceleration of product under higher light intensities. Archer and Bandfield (1950) found fc-hr to least visual perceptible discoloration in veal loaf increased with decreasing lighting intensity (150 to 50 fc or 1614 to 538 lm/m^2) as temperature decreased from 60 to 40°F (15.6 to 4.4°C), suggesting that as display lighting intensity increased display temperature could be lowered to achieve equivalent processed product fading. This trend of decreasing display temperatures as lighting intensity increased to maintain equal product fading was repeated for nonvacuum processed product held under IF, N, and SW lighting (Tables 2,3, and 4), but display temperatures to achieve a specific product visual score at a display time

Table 1. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Deluxe Cool White Lighting, Nonvacuum Processed			
		Lighting Intensity, lm/m^2 [y]			
		1076	1614	2152	3228
Visual Score [z]	Hour				
1.5	12	2.3°C (36.2°F)	1.0°C (33.8°F)	0.6°C (33.0°F)	-0.4°C (31.3°F)
	24	1.6°C (34.8°F)	0.7°C (33.2°F)	-0.1°C (31.8°F)	-0.5°C (31.1°F)
	48	-0.1°C (31.9°F)	-0.7°C (30.8°F)	-0.9°C (30.3°F)	-1.2°C (29.9°F)
2.0	12	7.4°C (45.4°F)	4.7°C (40.5°F)	3.8°C (38.9°F)	2.1°C (35.7°F)
	24	5.9°C (24.7°F)	4.1°C (39.4°F)	2.6°C (36.6°F)	1.8°C (35.2°F)
	48	2.6°C (36.7°F)	1.4°C (34.5°F)	0.8°C (33.5°F)	0.4°C (32.8°F)
2.5	12	12.6°C (54.6°F)	8.5°C (47.3°F)	6.7°C (44.9°F)	4.4°C (40.0°F)
	24	10.3°C (50.5°F)	7.5°C (45.5°F)	5.2°C (41.4°F)	4.1°C (39.3°F)
	48	5.3°C (41.5°F)	3.5°C (38.3°F)	2.7°C (36.8°F)	2.1°C (35.7°F)
3.0	12	17.7°C (63.8°F)	12.2°C (54.0°F)	10.5°C (50.9°F)	6.9°C (44.4°F)
	24	14.6°C (58.3°F)	10.9°C (51.7°F)	7.9°C (46.2°F)	6.3°C (43.3°F)
	48	8.0°C (46.4°F)	5.6°C (42.1°F)	4.5°C (40.1°F)	3.7°C (38.6°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=complete Fade.

Table 2. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Incandescent Fluorescent Lighting, Nonvacuum Processed			
		Lighting Intensity, lm/m^2 [y]			
Visual Score[z]	Hour	1076	1614	2152	3228
1.5	12	10.5°C (50.9°F)	3.0°C (37.4°F)	0.9°C (33.7°F)	0.0°C (32.0°F)
	24	3.4°C (38.2°F)	2.1°C (35.7°F)	0.8°C (33.4°F)	-0.2°C (31.6°F)
	48	0.9°C (33.7°F)	-0.7°C (30.7°F)	-0.8°C (30.6°F)	-1.1°C (30.1°F)
2.0	12	23.8°C (74.8°F)	8.8°C (47.9°F)	4.7°C (40.4°F)	2.8°C (37.1°F)
	24	9.7°C (49.4°F)	6.9°C (44.4°F)	4.3°C (39.7°F)	2.4°C (36.3°F)
	48	4.6°C (40.3°F)	1.4°C (34.5°F)	1.2°C (34.2°F)	0.6°C (33.1°F)
2.5	12	37.0°C (98.6°F)	14.6°C (58.3°F)	8.4°C (47.1°F)	5.6°C (42.2°F)
	24	15.9°C (60.6°F)	11.7°C (53.1°F)	7.8°C (46.0°F)	4.9°C (40.9°F)
	48	8.3°C (47.0°F)	3.4°C (38.2°F)	3.2°C (37.8°F)	2.3°C (36.2°F)
3.0	12	50.3°C (122.5°F)	20.4°C (68.7°F)	12.1°C (53.8°F)	8.4°C (47.1°F)
	24	22.1°C (71.8°F)	16.6°C (61.8°F)	11.3°C (52.4°F)	7.5°C (45.5°F)
	48	12.0°C (53.6°F)	5.5°C (41.9°F)	5.2°C (41.4°F)	4.0°C (39.2°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Lighting Intensity: 1076 lm/m^2=100fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Table 3. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Natural Lighting, Nonvacuum Processed			
		Lighting Intensity lm/m^2[y]			
		1076	1614	2152	3228
Visual Score[z]	Hour				
1.5	12	4.6°C (40.2°F)	2.7°C (36.9°F)	0.7°C (33.6°F)	0.0°C (32.0°F)
	24	4.6°C (40.2°F)	2.3°C (36.1°F)	1.5°C (34.7°F)	-0.1°C (31.8°F)
	48	1.1°C (34.0°F)	-0.2°C (31.7°F)	-0.7°C (30.8°F)	-0.9°C (30.3°F)
2.0	12	11.8°C (53.3°F)	8.2°C (46.7°F)	4.6°C (40.2°F)	2.7°C (36.9°F)
	24	11.8°C (53.3°F)	7.3°C (45.2°F)	5.8°C (42.4°F)	2.5°C (36.5°F)
	48	5.0°C (41.0°F)	2.4°C (36.4°F)	1.4°C (34.5°F)	0.8°C (33.5°F)
2.5	12	19.2°C (66.5°F)	13.7°C (56.6°F)	8.2°C (46.7°F)	5.5°C (41.9°F)
	24	19.2°C (66.5°F)	12.4°C (54.3°F)	10.1°C (50.1°F)	2.7°C (36.8°F)
	48	8.9°C (48.0°F)	5.1°C (41.1°F)	3.4°C (38.2°F)	2.7°C (36.8°F)
3.0	12	26.4°C (79.6°F)	19.1°C (66.4°F)	11.8°C (53.3°F)	8.3°C (46.9°F)
	24	26.4°C (79.6°F)	17.4°C (63.3°F)	14.3°C (57.8°F)	7.8°C (46.0°F)
	48	12.8°C (55.0°F)	7.7°C (45.8°F)	5.6°C (42.0°F)	4.4°C (40.0°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Table 4. Sinple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

Supermarket White Lighting, Nonvacuum Processed					
		Lighting Intensity, lm/m^2[y]			
Visual Score[z]	Hour	1076	1614	2152	3228
1.5	12	1.4°C (34.6°F)	0.0°C (32.0°F)	-0.3°C (31.5°F)	-0.6°C (31.0°F)
	24	1.1°C (34.0°F)	-0.1°C (31.8°F)	-0.4°C (31.3°F)	-0.9°C (30.3°F)
	48	-0.6°C (30.9°F)	-1.2°C (29.9°F)	-1.2°C (29.9°F)	-1.3°C (29.7°F)
2.0	12	5.7°C (42.2°F)	2.8°C (37.1°F)	2.2°C (36.0°F)	1.7°C (35.0°F)
	24	5.0°C (41.0°F)	2.6°C (36.6°F)	2.0°C (35.6°F)	0.9°C (33.6°F)
	48	1.6°C (34.8°F)	0.5°C (32.9°F)	0.4°C (32.8°F)	0.2°C (32.4°F)
2.5	12	9.9°C (49.8°F)	5.6°C (42.1°F)	4.7°C (40.5°F)	3.9°C (39.0°F)
	24	8.8°C (47.9°F)	5.2°C (41.3°F)	4.4°C (39.9°F)	2.7°C (36.8°F)
	48	3.7°C (38.6°F)	2.1°C (35.8°F)	2.1°C (35.7°F)	1.7°C (35.1°F)
3.0	12	14.1°C (57.4°F)	8.4°C (47.1°F)	7.2°C (45.0°F)	6.1°C (43.0°F)
	24	12.7°C (54.9°F)	7.8°C (46.1°F)	6.8°C (44.2°F)	4.5°C (40.1°F)
	48	5.8°C (42.5°F)	3.7°C (38.7°F)	3.7°C (38.6°F)	3.2°C (37.8°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

were different for each lighting source.

Achievement of the same product visual score at 12, 24, or 48 hr required a progressively lower display temperature for the longer times. For instance, to achieve a visual score of 1.5 under DCW light (1614 lm/m^2 intensity) at display times of 12, 24, or 48 hr, temperatures of 1.0, 0.7, and $-0.7^{\circ}C$ were predicted as necessary. This suggests that not only does processed cured product respond to the reciprocity law of lighting intensity and time described by several researchers (Clark, 1956; Ramsbottom et al., 1951; and Taylor and Pracejus, 1950), but that fading can also be altered by changing temperature in relation to lighting intensity and display time under a defined lighting source to attain a specific visual score. This decreasing trend for predicted display temperature for fixed visual scores with increasing display time was also noted for product held under IF, N, and SW lighting (Tables 2, 3, and 4). Predicted temperatures to achieve the score and time specifications differed between the lighting systems.

Predicted display temperatures for each lighting intensity at a specific hr increased as visual score increased for nonvacuum procedded product held under DCW lighting (Table 1). Again using 1614 lm/m^2 as an example, if visual scores were to be 1.5, 2.0, 2.5, or 3.0 after 12 hr of display, progressively warmer temperatures could be utilized with temperatures of 1.0, 4.7, 8.5, or $12.2^{\circ}C$ respectively resulting

in these scores. Although predicted temperature varied with the different lighting systems, this trend was noted for non-vacuum processed product held under IF, N, and SW lighting (Tables 2, 3, and 4).

Comparison of predicted temperatures between the lighting systems for nonvacuum precessed product showed them to influence rendition of faded product. Predicted temperatures were generally slightly higher for product held under IF and N lighting than for product held under DCW and SW lighting for equal score and display time and lighting specifications. Product could tolerate higher temperatures under IF and N than under DCW and SW lighting. IF and N lamps emit a larger portion of their spectral energy in the orange-red wavelengths than in the green-yellow wavelengths (Kropf, 1980). This would improve product color rendition over lamps that emit a greater portion of their spectral energy in the green-yellow wavelengths, the region of greatest eye sensitivity (Francis and Clydesdale, 1975). This suggests type of display lighting can partially compensate for product fading when all other display conditions are held constant.

For product processed under vacuum, for each visual score and display time, predicted temperature decreased as lighting intensity increased from 1076 to 3228 lm/m^2 with DCW illumination (Table 5). This trend was noted for all predicted temperatures of vacuum processed product held under IF, N, and SW lighting (Tables 6, 7, and 8) with temperatures to achieve

a specific score varying under the different lighting treatments when all other display specifications were the same. This trend was similar to that observed for the nonvacuum processed product.

As display time increased for each visual score, predicted display temperature decreased for each lighting intensity level of the vacuum processed product under DCW lighting. Although Kraft and Ayres (1954) did not vary display temperature from 2.5°C, they found vacuum packaged bologna fading increased as Soft White fluorescent lighting increased from 30 to 35 fc (322.8 to 376.6 lm/m^2) to 50 to 60 fc (538 to 645.6 lm/m^2), indicating adherance to the reciprocity law. This decreasing trend of predicted display temperature with increasing display time at fixed lighting source and intensity and score was also noted for vacuum processed product illuminated under IF, N, and SW lamps (Tables 6, 7, and 8) with the exceptions of 1076 and 2152 lm/m^2 under N lighting. Predicted temperatures to achieve a specific set of display conditions varied among the lighting sources.

For vacuum processed DCW illuminated product a trend of increasing allowable display temperature was exhibited as visual scores increased at fixed times and lighting intensities (Table 5). This pattern was repeated for vacuum processed product illuminated under IF, N, and SW lamps. Again temperatures to achieve a desired visual score under similar fixed conditions varied with the lighting source. This same

Table 5. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Deluxe Cool White Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2 [y]			
Visual Score[z]	Hour	1076	1614	2152	3228
1.5	12	5.1°C (41.1°F)	0.8°C (33.5°F)	0.9°C (33.6°F)	-0.1°C (31.8°F)
	24	3.8°C (38.9°F)	1.0°C (33.8°F)	0.9°C (33.6°F)	-0.6°C (31.0°F)
	48	0.5°C (32.9°F)	-0.4°C (31.3°F)	-0.4°C (31.2°F)	-1.0°C (30.2°F)
2.0	12	12.9°C (55.2°F)	4.4°C (40.0°F)	4.6°C (40.2°F)	2.6°C (36.7°F)
	24	10.5°C (50.9°F)	4.8°C (40.7°F)	4.5°C (4o.1°F)	1.7°C (35.1°F)
	48	3.8°C (38.9°F)	2.0°C (35.6°F)	1.9°C (35.4°F)	0.8°C (33.4°F)
2.5	12	20.8°C (69.4°F)	8.1°C (46.5°F)	8.3°C (46.9°F)	5.3°C (41.5°F)
	24	17.1°C (62.8°F)	8.6°C (47.5°F)	8.1°C (46.6°F)	3.9°C (39.1°F)
	48	7.1°C (44.8°F)	2.0°C (35.6°F)	1.9°C (35.5°F)	2.6°C (36.6°F)
3.0	12	28.6°C (83.5°F)	11.7°C (53.0°F)	11.9°C (53.5°F)	7.9°C (46.3°F)
	24	23.8°C (74.8°F)	12.4°C (54.3°F)	11.8°C (53.2°F)	6.2°C (43.2°F)
	48	10.4°C (50.7°F)	6.8°C (44.2°F)	6.5°C (43.7°F)	4.3°C (39.7°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Table 6. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Incandescent Fluorescent Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2[y]			
		1076	1614	2152	3228
Visual Score[z]	Hour				
1.5	12	11.4°C (52.5°F)	5.4°C (41.8°F)	1.6°C (34.9°F)	1.0°C (33.8°F)
	24	4.9°C (40.9°F)	3.6°C (38.5°F)	0.7°C (33.2°F)	0.1°C (32.2°F)
	48	1.3°C (34.4°F)	0.4°C (32.7°F)	-0.7°C (30.8°F)	-1.0°C (30.2°F)
2.0	12	25.5°C (77.9°F)	13.6°C (56.5°F)	6.0°C (42.8°F)	4.8°C (40.7°F)
	24	12.6°C (54.7°F)	10.0°C (50.0°F)	4.1°C (39.4°F)	3.0°C (37.4°F)
	48	5.4°C (41.7°F)	3.5°C (38.3°F)	1.5°C (43.7°F)	0.8°C (33.5°F)
2.5	12	39.7°C (103.4°F)	21.8°C (71.3°F)	10.3°C (50.6°F)	8.6°C (47.5°F)
	24	20.3°C (68.6°F)	16.4°C (61.6°F)	7.6°C (45.6°F)	5.9°C (42.7°F)
	48	9.5°C (49.1°F)	6.7°C (44.0°F)	3.6°C (38.5°F)	2.6°C (36.7°F)
3.0	12	53.8°C (128.8°F)	30.0°C (86.0°F)	14.7°C (58.5°F)	12.4°C (54.4°F)
	24	28.1°C (82.5°F)	22.8°C (73.1°F)	11.0°C (51.8°F)	8.8°C (47.9°F)
	48	13.6°C (56.4°F)	9.8°C (49.7°F)	5.7°C (42.3°F)	4.4°C (39.9°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Light Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Table 7. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Natural Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2[y]			
		1076	1614	2152	3228
Visual Score[z]	Hour				
1.5	12	5.4°C (41.8°F)	3.0°C (37.4°F)	0.7°C (33.3°F)	0.2°C (32.3°F)
	24	7.4°C (45.4°F)	2.0°C (35.6°F)	1.1°C (34.0°F)	0.0°C (32.0°F)
	48	1.6°C (34.9°F)	0.2°C (32.3°F)	0.2°C (30.4°F)	-1.2°C (29.9°F)
2.0	12	13.6°C (56.5°F)	8.8°C (47.8°F)	4.2°C (39.5°F)	3.2°C (37.7°F)
	24	17.7°C (63.8°F)	6.8°C (44.2°F)	5.0°C (41.0°F)	2.7°C (36.9°F)
	48	6.1°C (42.9°F)	3.1°C (37.6°F)	0.9°C (33.7°F)	0.5°C (32.9°F)
2.5	12	21.8°C (71.3°F)	14.6°C (58.2°F)	7.7°C (45.8°F)	6.1°C (43.0°F)
	24	27.8°C (82.1°F)	11.6°C (52.8°F)	8.8°C (47.9°F)	5.5°C (41.9°F)
	48	10.4°C (50.8°F)	6.1°C (42.9°F)	2.8°C (37.1°F)	2.1°C (35.8°F)
3.0	12	30.0°C (86.0°F)	20.3°C (68.5°F)	11.1°C (52.0°F)	9.1°C (48.4°F)
	24	38.1°C (100.5°F)	16.3°C (61.4°F)	12.7°C (54.9°F)	8.2°C (46.8°F)
	48	14.8°C (58.7°F)	9.0°C (48.2°F)	4.7°C (40.4°F)	3.8°C (38.8°F)

[x] Score=1 + $\hat{\beta}$ (Temperature-27).

[y] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2= 300 fc.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Table 8. Simple linear regression[x] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Supermarket White Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2[y]			
		1076	1614	2152	3228
Visual Score[z]	Hour				
1.5	12	3.1°C (37.5°F)	1.0°C (33.8°F)	1.1°C (34.0°F)	0.0°C (32.0°F)
	24	2.2°C (35.9°F)	0.4°C (32.7°F)	0.4°C (32.8°F)	-0.3°C (31.5°F)
	48	0.4°C (32.8°F)	-0.9°C (30.4°F)	-0.7°C (30.8°F)	-1.1°C (30.0°F)
2.0	12	3.3°C (48.0°F)	4.7°C (40.5°F)	5.0°C (41.0°F)	2.8°C (37.0°F)
	24	7.1°C (44.8°F)	3.6°C (38.4°F)	3.6°C (38.5°F)	2.2°C (35.9°F)
	48	3.7°C (38.6°F)	1.1°C (33.9°F)	1.4°C (34.6°F)	0.6°C (33.0°F)
2.5	12	14.7°C (58.7°F)	8.5°C (47.3°F)	8.9°C (48.1°F)	5.6°C (42.0°F)
	24	12.1°C (53.7°F)	6.7°C (44.1°F)	6.8°C (44.3°F)	4.7°C (40.4°F)
	48	6.9°C (44.4°F)	2.9°C (37.3°F)	3.6°C (38.4°F)	2.2°C (36.0°F)
3.0	12	20.5°C (68.9°F)	12.3°C (54.1°F)	12.8°C (55.1°F)	8.3°C (47.0°F)
	24	17.0°C (62.6°F)	9.9°C (49.8°F)	10.0°C (50.0°F)	7.2°C (44.9°F)
	48	10.1°C (50.1°F)	4.9°C (40.8°F)	5.7°C (42.2°F)	3.9°C (39.0°F)

[x]Score=1 + B (Temperature-27).

[y]Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[z]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

pattern of increasing predicted display temperatures with increasing visual scores at specific time and lighting intensities was noted for nonvacuum processed product held under DCW, IF, N, and SW lamps.

When comparing predicted display temperatures between the 4 illumination sources for vacuum processed product under similar display specifications, lamp spectral energy distribution again gives a slight advantage to product exposed under IF and N lighting over DCW and SW exposed product. Product under IF and N lighting could tolerate a higher temperature at each intensity than product under DCW and SW lighting.

These data do not lend themselves to a direct comparison between nonvacuum and vacuum processed product at any specific lighting type and intensity.

Summary

Predictions of display temperatures necessary to achieve visual color scores ranging from 1.5 to 3.0 were made for wafer sliced cured and cooked beef for various display times, lighting sources and intensities.

Three general trends noted for nonvacuum and vacuum processed product illuminated under DCW, IF, N, and SW lamps were: 1) predicted display temperatures decreased as lighting intensity increased from 1076 to 3228 lm/m^2 at each display time for each visual score, 2) at each visual score predicted allowable display temperatures decreased for all light-

ing intensities as time increased from 12 to 48 hours, and 3) for each lighting intensity at a fixed hour, predicted allowable display temperatures increased as visual score increased from 1.5 to 3.0.

Predicted display temperatures suggested that type of display lighting influences the fading of wafer sliced beef processed under vacuum or nonvacuum conditions. Product required lower display temperatures when exposed under lighting systems which emitted a larger portion of their spectral energy in the green-yellow wavelengths than product illuminated under lamps which emitted a larger portion of their spectral energy in the orange-red wavelengths.

REFERENCES

Archer, H. and Bandfield, R.E. 1950. The discoloration of veal loaf when exposed to high illumination. Illum. Engr. 45:429.

Clark, C.N. 1956. The basis for appropriate lighting for meat displays. Proc. 8th Res. Conf. Am. Meat Inst., Univ. of Chicago, p.83.

Draper, N.R. and Smith, H. 1966. "Applied Regression Analysis." John Wiley & Sons, Inc., New York.

Erdman, A.M. and Watts, B.M. 1957. Spectrophotometric determination of color change in cured meat. J. Agr. Food Chem. 5:453.

Francis, F.J. and Clydesdale, F.M. 1975. "Food Colorimetry: Theory and Applications." AVI Publishing Co., Inc., Westport, Conn.

Kraft, A.A. and Ayres, J.C. 1954. Color changes in packaged bologna. Food Technol. 8:22.

Kropf, D.H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recip. Meat Conf., Nat'l. Livestock and Meat Board, Chicago, (In Press).

Ramsbottom, J.M., Goeser, P.A., and Shultz, H.W. 1951. How light discolors the meat and what to do about it. Food Ind. 23:120.

Snedecor, G.W. and Cochran, W.G. 1967. "Statistical Methods," 6th ed. Iowa State Univ. Press, Ames Iowa.

Taylor, A.H. and Pracejus, W.G. 1950. Fading of colored materials by light and radiant energy. Illum. Engr. 45:149.

CHAPTER VII

SUMMARY

Display conditions' influence on cured color fading of wafer sliced cured and cooked beef in a nitrogen flushed oxygen impermeable package was determined by visual evaluations of 2 trained panelists and by the % reflectance ration of 570 nm/650 nm. Microbial standatd plate counts, surface pH, and % oxygen of package gas volume were also determined. Treatment design included all possible combinations of: 1) 1076, 1614, 2152, or 3228 lm/m^2 lighting intensities, 2) Deluxe Cool White, Incandescent Fluorescent, Natural, or Supermarket White lighting sources, 3) 1.1, 4.4, or 7.8^{o}C temperatures, and 4) vacuum versus nonvacuum processing. Subjective and objective criteria were determined at 0, 6, 12, 24, 48, and 72 hr of display. Data were tested by analysis of variance. Maximum allowable display temperatures were predicted from lighting intensities ($P<.05$) to achieve specific product fading by a second-order linear regression model with a fixed intercept.

For nonvacuum processed product, light induced nitrosohemochrome oxidation increased as lighting intensity increased from 1076 to 3228 lm/m^2. Product perceptibly faded within 6 hr of display and approached "Complete Fade" at 72 hr. Visual color did not regenerate during dark display between 12 and 24 hr. Similar visual fading was observed between product illuminated under equivalent lm/m^2-hr. Product appeared less faded under Incandescent Fluorescent and Natural than under

Deluxe Cool White or Supermarket White lighting, due to differences in lamp spectral energy distribution. Nitrosohemochrome oxidation was slightly influenced by display temperature, with product at 1.1 and 4.4°C exhibiting similar fade while fading accelerated at 7.8°C beginning at 48 hr. Between 24 and 72 hr, standard plate counts increased to log 2.6/g for product at 1.1°C, to log 3.2/g for product at 4.4°C, and to log 5.1/g for product at 7.8°C; package oxygen decreased below 1% of gas volume; and product pH dropped slightly as display temperatures increased from 1.1 to 7.8°C.

For vacuum processed wafer sliced cured and cooked beef, nitrosohemochrome oxidation increased as lighting intensity increased from 1076 to 3228 lm/m^2. Cured color regeneration wasn't observed between 12 and 24 hr display in the dark. Visual fading was equal for product illuminated under equal lm/m^2-hr. Incandescent Fluorescent and Natural lamps, which emit a large portion of their spectral energy in the orange-red wavelengths, caused less visual fading than Deluxe Cool White or Supermarket White, which emit a larger portion of their spectral energy in the green-yellow wavelengths. Fading, measured by reflectance, was similar at 1.1 and 4.4°C, but beginning at 48 hr accelerated at 7.8°C. Between 24 and 72 hr, standard plate counts increased to log 3.1/g at 1.1 and 4.4°C and to log 4.2/g at 7.8°C; and package oxygen decreased below 1% of gas volume.

Evaluating combined vacuum and nonvacuum processed beef, again light induced nitrosohemochrome oxidation increased with

increasing lighting intensity from 1076 to 3228 lm/m^2. Wafer sliced beef did not visually regenerate cured color after light exposure during dark storage between 12 and 24 hr. Product exposed to equivalent lm/m^2-hr appeared similarly faded. Incandescent Fluorescent and Natural lighting caused less visual fading than Deluxe Cool White or Supermarket White lighting, probably due to differences in color rendition. Vacuum processed product was estimated as less visually faded under all lighting types and at all display hr than nonvacuum processed product. Vacuumizing during production helped to reduce product visual fading under lighting sources which emitted a greater portion of their spectral energy in the green-yellow wavelengths than in the orange-red wavelengths. Nitrosohemochrome oxidation was slightly influenced by temperature. Fading at 1.1 and 4.4°C was similar, but was slightly accelerated at 7.8°C. Between 24 and 72 hr, as temperature increased from 1.1 to 7.8°C, standard plate counts increased from log 2.9/g to 4.9/g; package oxygen decreased below 1% of gas volume; and product pH change was small and without any detectable pattern.

Regression predicted maximum allowable display temperatures to achieve specified product fading decreased with increasing lighting intensities from 1076 to 3228 lm/m^2 at 12, 24, or 48 hr for vacuum and nonvacuum processed product under each lighting source. For both vacuum and nonvacuum processed product, at each lighting intensity, predicted display temperatures decreased with increasing time from 12 to 48 hr for

product fading at score 1.5, 2.0, 2.5, or 3.0 under each lighting source. Temperature predictions increased at fixed times and lighting intensities as tolerated fading increased from score 1.5 to 3.0 for specified processing method and light source. Incandescent Fluorescent and Natural lighting's allowable temperatures were higher than Deluxe Cool White's or Supermarket White's for both processing methods, indicating partial product fading compensation by lamps emitting a large portion of their spectral energy in the orange-red wavelengths. The regression data did not lend itself to comparisons between processing methods. Selection of data points for temperature predictions were based upon conditions that could be controlled at the retail level.

APPENDICES

Appendix Table A. Distance in cm between light sources and wafer sliced cured and cooked beef product surfaces to achieve designated lighting intensities.

		Type of Lighting[x]			
		DCW	IF	N	SW
Temperature	Lighting Intensity lm/m^2 [y]				
7.8°C (46°F)	1076	90.17	91.44	88.90	93.98
	1614	80.01	69.85	81.28	77.47
	2152	57.15	44.45	68.58	68.58
	3228	22.86	20.32	38.10	34.29
4.4°C (40°F)	1076	113.03	81.28	99.06	96.52
	1614	93.98	71.12	80.01	88.90
	2152	72.39	54.61	63.50	66.04
	3228	33.02	29.21	38.10	43.18
1.1°C (34°F)	1076	92.71	74.93	67.31	86.36
	1614	76.20	66.04	57.15	76.20
	2152	66.04	54.61	41.91	66.04
	3228	38.10	31.75	21.59	48.26

[x]Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[y]Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table B1. Effect of display treatments on characteristics of wafer sliced cured and cooked beef processed under nonvacuum.

Analysis of Variance probability levels for variance ratios of main treatment and interaction effects.

	570 nm/650 nm Ratio	Score	Log/g Plate Count	pH	Package Oxygen
Replication (R)	.0094	.7998	.0380	.8892	.2597
Temperature (T)	.0807	.6086	.0963	.1034	.7302
(Error a, T*R)					
Type of Lighting (TL)	.1298	.0001	.7255	.3705	.9941
TL*T	.4810	.2952	.4311	.6336	.5752
(Error b, TL*T*R)					
Lighting Intensity (LI)	.0001	.0001	.5003	.0010	.9972
TL*LI	.5904	.9888	.9284	.1840	.4203
LI*T	.0623	.8368	.5298	.0003	.2524
TL*LI*T	.1092	.7116	.5946	.0202	.2132
(Error c, TL*LI*T*R)					
Hour (HR)	.0001	.0001	.0001	.0935	.0001
TL*HR	.9430	.0001	.4934	.4568	.0478
LI*HR	.4860	.0001	.6266	.9912	.4907
TL*LI*HR	.8585	.2803	.9694	1.0000	.8445
T*HR	.0065	.0016	.0001	.0001	.1342
TL*T*HR	.9796	.7105	.8505	.5725	.8835
LI*T*HR	.9810	.0001	.6780	.9996	.8389
TL*LI*T*HR	.8179	.4769	.5354	1.0000	.3974
T*R	.6890	.0001	.2728	.1667	.4558
TL*T*R	.2362	.0002	.8597	.5533	.7763
TL*LI*T*R	.0844	.0001	.6816	1.0000	.4769
(Error d, TL*LI*T*HR*R)					

Appendix Table B2. Mean visual color scores[y'] for the interaction of lighting intensity *temperature*display hours on wafer sliced cured and cooked beef processed under nonvacuum.

		Display Hours					
		0	6	12	24	48	72
LI lm/m^2 [z']	Temperature						
		a	abc	abcdefg	cdefgh	ghijklm	ijklmno
1076	1.1°C (34°F)	1.000	1.188	1.594	1.656	2.156	2.313
		a	abcde	bcdefg	defghijk	jklmnop	lmnop
	4.4°C (40°F)	1.000	1.344	1.625	1.844	2.375	2.513
		a	abc	cdefghi	defghijkl	lmnop	qrstuvw
	7.8°C (34°F)	1.000	1.219	1.719	1.844	2.519	3.281
		a	abc	fghijkl	fghijkl	mnopqr	qrstuvw
1614	1.1°C (34°F)	1.000	1.219	1.969	2.031	2.750	3.219
		a	abcdef	fghijkl	defghijkl	pqrst	qrstuvw
	4.4°C (40°F)	1.000	1.438	2.000	1.938	2.938	3.231
		a	abcd	fghijkl	hijklmn	qrstuvw	tuvwx
	7.8°C (46°F)	1.000	1.325	2.031	2.250	3.175	3.500
		a	abcdef	ghijklm	klmnop	qrstuvw	vwx
2152	1.1°C (34°F)	1.000	1.469	2.188	2.425	3.250	3.594
		a	abcdefg	ghijklm	ghijklm	pqrstu	rstuvwx
	4.4°C (40°F)	1.000	1.581	2.156	2.188	2.969	3.344
		a	cdefghi	klmnop	klmnop	stuvwx	uvwx
	7.8°C (46°F)	1.000	1.700	2.406	2.438	3.375	3.563
		ab	abcdef	lmnop	mopqrs	wx	x
3228	1.1°C (34°F)	1.031	1.531	2.469	2.813	3.656	3.906
		ab	cdefghij	lmnop	mnopq	qrstuvw	wx
	4.4°C (40°F)	1.031	1.800	2.550	2.675	3.250	3.781
		a	efghijkl	mnopqr	opqrst	wx	wx
	7.8°C (46°F)	1.000	1.956	1.750	2.906	3.625	3.625

[y'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z'] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-x] Means with the same superscript letter are not different (P>.05).

Appendix Table B3. Mean pH values for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef processed under nonvacuum.

Type of Lighting[y]	Lighting Intensity[z] lm/m^2	Temperature 1.1 C (34 F)	4.4 C (40 F)	7.8 C (46 F)
DCW	1076	6.323^{q}	6.215^{efghi}	6.198^{bcd}
	1614	6.343^{r}	6.228^{ijklm}	6.210^{defgh}
	2152	6.295^{p}	6.228^{ijklm}	6.210^{defgh}
	3228	6.295^{p}	6.228^{ijklm}	6.205^{cdefg}
IF	1076	6.240^{mn}	6.218^{fghij}	6.175^{a}
	1614	6.258^{o}	6.220^{ghijk}	6.188^{ab}
	2152	6.255^{no}	6.210^{defgh}	6.190^{abc}
	3228	2.260^{o}	6.223^{hijkl}	6.188^{ab}
N	1076	6.265^{o}	6.238^{lm}	6.195^{bcd}
	1614	6.268^{o}	6.233^{jklm}	6.210^{defgh}
	2152	6.258^{o}	6.240^{mn}	6.210^{defgh}
	3228	6.255^{no}	6.258^{o}	6.198^{bcd}
SW	1076	6.290^{p}	6.218^{fghij}	6.188^{ab}
	1614	6.305^{p}	6.233^{jklm}	6.203^{bcdef}
	2152	6.300^{p}	6.233^{jklm}	6.203^{bcdef}
	3228	6.290^{p}	6.235^{klm}	6.200^{bcde}

[y]Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[z]Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-r]Means with the same superscript letter are not different (P>.05).

Appendix Table C1. Effect of display treatments on characteristics of wafer sliced cured and cooked beef processed under vacuum.

Analysis of Variance probability levels for variance ratios of main treatment and interaction effects.

	570 nm/650 nm Ratio	Score	Log/g Plate Count	pH	Package Oxygen
Replication (R)	.0062	.1348	.0492	.9531	.1210
Temperature (T)	.0063	.2273	.1983	.1056	.0676
(Error a, T*R)					
Type of Lighting (TL)	.3887	.1367	.6363	.6290	.0363
TL*T	.6313	.1653	.5161	.7636	.0781
(Error b, TL*T*R)					
Lighting Intensity (LI)	.0001	.0001	.4637	.0033	.6746
TL*LI	.7187	.2902	.1259	.1717	.4014
LI*T	.1752	.9258	.8770	.6362	.5355
TL*LI*T	.6101	.0349	.8151	.6616	.0128
(Error c, TL*LI*T*R)					
Hour (HR)	.0001	.0001	.0001	.0728	.0032
TL*HR	.9472	.0127	.4933	.3559	.4059
LI*HR	.5633	.0001	.8290	.9281	.9649
TL*LI*HR	.9842	.2554	.8056	.9994	.6071
T*HR	.0219	.2262	.0001	.0001	.5055
TL*T*HR	.7163	.0161	.1969	.4506	.6495
LI*T*HR	.2985	.6310	.3475	.9982	.3862
TL*LI*T*HR	.9833	.8480	.7820	1.0000	.6697
T*R	.9630	.2532	.0643	.2333	.8776
TL*T*R	.0136	.0001	.2095	.3096	.9143
TL*LI*T*R	.0007	.0001	.8674	1.0000	.9286
(Error d, TL*LI*T*R)					

Appendix Table C2. Mean visual color scores[y'] for the interaction of type of lighting by temperature by display hours on wafer sliced cured and cooked beef processed under vacuum.

Type of Lighting[z']	Temperature	Display Hours 0	6	12	24	48	72
DCW	1.1°C (34°F)	1.000^{a}	1.394^{bcde}	2.125^{mnopqrs}	2.231^{qrst}	3.125^{xyz}	3.188^{yz}
	4.4°C (40°F)	1.000^{a}	1.188^{ab}	1.906^{jklmno}	1.856^{ijklm}	2.388st	2.937^{uvwxy}
	7.8°C (46°F)	1.000^{a}	1.594^{efghi}	2.188^{pqust}	2.363st	2.906^{uvwx}	3.219^{z}
IF	1.1°C (34°F)	1.000^{a}	1.406^{bcde}	1.969^{jklmnopq}	2.125^{mnopqrs}	2.750^{u}	3.031^{vwxyz}
	4.4°C (40°F)	1.000^{a}	1.256^{abc}	1.563^{defgh}	1.781^{ghijk}	2.344st	2.750^{u}
	7.8°C (46°F)	1.000^{a}	1.313^{bcd}	1.706^{fghij}	2.000^{klmnopq}	2.800^{uvw}	3.188^{yz}
N	1.1°C (34°F)	1.000^{a}	1.250^{abc}	1.875^{jklmn}	2.156^{opqrst}	2.406^{t}	2.906^{uvwx}
	4.4°C (40°F)	1.000^{a}	1.500^{cdef}	2.188^{pqrst}	2.063^{lmnopqr}	2.938^{uvwxy}	3.063^{wxyz}
	7.8°C (46°F)	1.000^{a}	1.206^{ab}	1.813^{hijkl}	1.813^{hijkl}	2.788^{uv}	2.938^{uvwxy}
SW	1.1°C (34°F)	1.000^{a}	1.313^{bcd}	1.875^{jklmn}	2.031^{klmnopq}	2.750^{u}	3.125^{xyz}
	4.4°C (40°F)	1.031^{a}	1.519^{cdefg}	2.144^{nopqrst}	2.344st	2.969^{uvwxyz}	3.500$^{a'}$
	7.8°C (46°F)	1.000^{a}	1.406^{bcde}	2.125^{mnopqrs}	2.313^{rst}	3.044^{vwxyz}	3.563$^{a'}$

[y'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z'] Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[a-a'] Means with the same superscript letter are not different (P>.05).

Appendix Table C3. Mean visual color scores[x] for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cooked and cured beef processed under vacuum.

Type of Lighting[y]	Lighting Intensity lm/m^2[z]	Temperature 1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
DCW	1076	1.750^{def}	1.717^{cdef}	1.604^{bcd}
	1614	2.229^{klmn}	1.871^{fgh}	2.146^{ijkl}
	2152	2.175^{ijklm}	1.875^{fgh}	2.229^{klmn}
	3228	2.554^{qrs}	2.050^{hijk}	2.867^{t}
IF	1076	1.313^{a}	1.458^{ab}	1.729^{def}
	1614	1.813^{defg}	1.617^{bcde}	1.833^{efgh}
	2152	2.458^{opqrs}	1.846^{fgh}	2.146^{ijkl}
	3228	2.604^{rs}	2.208^{jklmn}	2.296^{lmnop}
N	1076	1.708^{cdef}	1.479^{ab}	1.500^{abc}
	1614	1.875^{fgh}	2.146^{ijkl}	1.500^{abc}
	2152	2.000^{ghij}	2.292^{lmnop}	2.242^{klmno}
	3228	2.146^{ijkl}	2.583^{qrs}	2.463^{opqrs}
SW	1076	1.708^{cdef}	1.833^{efgh}	1.804^{defg}
	1614	1.979^{ghi}	2.242^{klmno}	2.408^{nopqr}
	2152	2.000^{ghij}	2.250^{klmnop}	2.283^{lmnop}
	3228	2.375^{mnopq}	2.679^{st}	2.471^{pqrs}

[x]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[y]Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[z]Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-t]Means with the same superscript letter are not different (P>.05).

Appendix Table C4. Mean package oxygen values[x] for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef processed under vacuum.

Type of Lighting[y]	Lighting Intensity lm/m^2[z]	Temperature 1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
DCW	1076	1.350^{abcdefgh}	1.150^{abcdefg}	1.100^{abcdefg}
	1614	3.450^{j}	0.888^{abcd}	1.425^{abcdefghi}
	2152	1.200^{abcdefg}	0.838^{abcd}	0.375^{a}
	3228	0.400^{ab}	2.413^{ghij}	2.313^{efghij}
IF	1076	1.307^{abcdefgh}	0.875^{abcd}	1.300^{abcdefgh}
	1614	0.850^{abcd}	0.763^{abcd}	1.863^{cdefghi}
	2152	1.238^{abcdefg}	1.750^{abcdefghi}	0.900^{abcd}
	3228	2.750^{ij}	0.975^{abcdef}	0.413^{ab}
N	1076	0.963^{abcdef}	2.663^{hij}	0.913^{abcd}
	1614	1.775^{bcdefghi}	1.213^{abcdefg}	0.500^{abc}
	2152	1.863^{cdefghi}	2.075^{defghij}	1.013^{abcdef}
	3228	1.700^{abcdefghi}	2.338^{fghij}	0.738^{abcd}
SW	1076	0.725^{abcd}	1.175^{bcdefghi}	0.813^{abcd}
	1614	0.763^{abcd}	1.588^{abcdefghi}	0.513^{abc}
	2152	0.913^{abcd}	0.888^{abcd}	0.938^{abcde}
	3228	0.613^{abc}	0.888^{abcd}	1.175^{abcdefg}

[x] % O_2 of gas volume.

[y] Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-j] Means with the same superscript letter are not different (P>.05).

Appendix Table D1. Effect of display treatments on characteristics of wafer sliced cured and cooked beef.

Analysis of Variance probability levels for variance ratios of main treatment and interaction effects.

	570 nm/650 nm Ratio	Score	Log/g Plate Count	pH	Package Oxygen
Replication (R)	.0079	.8683	.0440	.9185	.5466
Temperature (T)	.0340	.5144	.1460	.1046	.3937
(Error a, R*T)					
Type of Lighting (TL)	.1937	.0007	.6083	.5106	.1108
TL*T	.5141	.0892	.6528	.7084	.3305
(Error b, TL*T*R)					
Lighting Intensity (LI)	.0001	.0001	.2543	.0001	.9366
TL*LI	.8847	.5833	.4140	.1009	.8448
LI*T	.0177	.8470	.4867	.0679	.5053
TL*LI*T	.1226	.3548	.7031	.0261	.5151
(Error c, TL*LI*T*R)					
Type of Processing (P)	.1384	.0001	.0605	.0001	.1768
TL*P	.2074	.0494	.8587	1.0000	.3241
LI*P	.7180	.9898	.8874	.2241	.8551
T*P	.4736	.4591	.3391	.0033	.0949
TL*LI*P	.5074	.9708	.5504	.2046	.0819
TL*T*P	.5220	.2702	.2729	.6414	.1141
LI*T*P	.6012	.9378	.8582	.1489	.1805
TL*LI*T*P	.7319	.3128	.5872	.9996	.0022
(Error d, TL*LI*T*P*R)					

Appendix Table D1 Continued.

	570 nm/650 nm Ratio	Score	Log/g Plate Count	pH	Package Oxygen
Hour (HR)	.0001	.0001	.0001	.0140	.0001
TL*HR	.8335	.0001	.2214	.1225	.0179
LI*HR	.1877	.0001	.5404	.9641	.7389
TL*LI*HR	.9150	.0090	.9313	.9994	.7202
T*HR	.0001	.0001	.0001	.0001	.0773
TL*T*HR	.9199	.0064	.2071	.1260	.5439
LI*T*HR	.4551	.0005	.3237	.9971	.5750
TL*LI*T*HR	.9870	.2900	.9113	1.0000	.5275
P*HR	.9285	.0004	.3911	.9802	.1927
TL*P*HR	.9923	.4101	.9342	.9952	.7325
LI*P*HR	.9055	.3121	.9121	.9560	.6651
TL*LI*P*HR	.9705	.9531	.8940	1.0000	.7637
T*P*HR	.5700	.8934	.8245	.9768	.7766
TL*T*P*HR	.8772	.7246	.8599	.9992	.9660
LI*T*P*HR	.9303	.1288	.7269	1.0000	.6530
TL*LI*T*P*HR	.8333	.9669	.3654	1.0000	.4963
T*R	.7352	.0001	.0209	.0389	.7642
TL*T*R	.1545	.0001	.2328	.0422	.9433
TL*LI*T*R	.0126	.0001	.7451	1.0000	.3512
TL*LI*T*P*R	.0004	.0001	.9303	1.0000	.9562
(Error e, TL*LI*T*HR*P*R)					

Appendix Table D2. Visual Color Scores[x'] for the interaction of type of lighting by lighting intensity by display hours on wafer sliced cured and cooked beef.

Type of Lighting[y']	Lighting Intensity lm/m^2[z']	Display Hours 0	6	12	24	48	72
DCW	1076	1.000^{a}	1.146^{abc}	1.667^{jklmn}	1.708^{klmno}	2.354^{wxyz}	2.683$^{b'c'd'}$
	1614	1.000^{a}	1.279^{cde}	2.083^{rstu}	2.125^{rstuv}	2.854$^{e'f'g'h'}$	3.225$^{i'j'k'}$
	2152	1.000^{a}	1.417^{defgh}	2.125^{rstuv}	2.313^{vwxy}	3.042$^{h'i'j'}$	3.354$^{k'}$
	3228	1.021^{a}	1.846^{nopq}	2.625$^{b'c'd'}$	2.813$^{d'e'f'g'}$	3.438$^{k'l'}$	3.646$^{l'm'}$
IF	1076	1.000^{a}	1.146^{abc}	1.292^{cde}	1.542^{ghijkl}	1.938^{pqrs}	2.396$^{xyza'}$
	1614	1.000^{a}	1.304^{cdef}	1.646^{ijklmn}	1.729^{lmnop}	2.604$^{a'b'c'd'}$	2.958$^{f'g'h'}$
	2152	1.000^{a}	1.504^{fghijk}	2.083^{rstu}	2.250^{tuvwx}	3.021$^{g'h'i'}$	3.271$^{k'}$
	3228	1.000^{a}	1.479^{efghij}	2.283^{uvwx}	2.542$^{za'b'}$	3.458$^{k'l'}$	3.729$^{m'n'}$
N	1076	1.000^{a}	1.125^{abc}	1.563^{ghijkl}	1.542^{ghijkl}	1.979^{qrs}	2.271^{tuvwx}
	1614	1.000^{a}	1.238^{bcd}	1.792^{mnopq}	1.917^{opqrs}	2.521$^{yza'b'}$	2.771$^{c'd'e'f'}$
	2152	1.000^{a}	1.383^{defg}	2.167^{stuvw}	2.063^{rst}	3.033$^{h'i'j'}$	3.354$^{k'}$
	3228	1.000^{a}	1.525^{ghijkl}	2.375^{wxyz}	2.542$^{za'b'}$	3.296$^{k'}$	3.708$^{m'n'}$
SW	1076	1.000^{a}	1.479^{efghij}	1.833^{mnopq}	1.958^{qrs}	2.588$^{a'b'c'}$	2.854$^{e'f'g'h'}$
	1614	1.000^{a}	1.442^{defghi}	2.208^{tuvwx}	2.333^{vwxyz}	3.242$^{j'k'}$	3.729$^{m'n'}$
	2152	1.000^{a}	1.625^{hijklm}	2.250^{tuvwx}	2.248^{tuvwx}	3.200$^{i'j'k'}$	3.646$^{l'm'}$
	3228	1.042^{a}	1.804^{mnopq}	2.629$^{b'c'd'}$	2.888$^{e'f'g'h'}$	3.596$^{l'm'}$	3.917$^{n'}$

[x'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[y'] Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[z'] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-n'] Means with the same superscript letter are not different (P>.05).

Appendix Table D3. Visual color scores[y'] for the interaction of temperature by lighting intensity by display hours on wafer sliced cured and cooked beef.

Temperature	Lighting Intensity[z'] lm/m^2	Display Hours 0	6	12	24	48	72
1.1°C (34°F)	1076	1.000^{a}	1.266^{cd}	1.594^{ghi}	1.625^{ghij}	2.047^{mn}	2.281^{pqr}
	1614	1.000^{a}	1.219^{cd}	1.594^{ghi}	1.703^{hij}	2.234^{opq}	2.466^{stu}
	2152	1.000^{a}	1.188^{bc}	1.578^{ghi}	1.734^{ijk}	2.363^{qrs}	2.906^{yz}
	3228	1.000^{a}	1.250^{cd}	1.906^{klm}	2.000^{mn}	2.734^{vwxy}	3.125$^{a'}$
4.4 C (40°F)	1076	1.000^{a}	1.347^{cde}	1.953^{lmn}	1.984^{mn}	2.756^{wxyz}	3.138$^{a'}$
	1614	1.000^{a}	1.350^{cde}	1.938^{lmn}	2.094^{no}	2.925^{z}	3.250$^{a'}$
	2152	1.000^{a}	1.391^{def}	2.109^{nop}	2.391^{qrst}	3.109$^{a'}$	3.438$^{b'}$
	3228	1.000^{a}	1.519^{efg}	2.094^{no}	2.094^{no}	2.875^{xyz}	3.234$^{a'}$
7.8 C (46°F)	1076	1.000^{a}	1.538^{fgh}	2.266^{pqr}	2.328^{qrs}	3.238$^{a'}$	3.547$^{b'}$
	1614	1.016^{ab}	1.478^{efg}	2.422^{rstu}	2.719^{vwx}	3.531$^{b'}$	3.797$^{d'}$
	2152	1.031^{ab}	1.728^{ij}	2.425^{rstu}	2.563^{tuv}	3.219$^{a'}$	3.719$^{c'd'}$
	3228	1.000^{a}	1.784^{jkl}	2.588^{uvw}	2.806^{xyz}	3.591$^{b'c'}$	3.734$^{c'd'}$

[y'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z'] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-d'] Means with the same superscript letter are not differnet (P>.05).

Appendix D4. Visual color scores[y'] for the interaction of type of lighting by temperature by display hours on wafer sliced cured and cooked beef.

Type of Lighting[z']	Temperature	Display Hours 0	6	12	24	48	72
DCW	1.1°C (34°F)	1.016^{a}	1.322^{bc}	2.094^{jklmn}	2.219^{lmnop}	3.047^{yz}	3.172$^{za'b'}$
	4.4°C (40°F)	1.000^{a}	1.359^{bc}	2.031^{ijk}	2.053^{ijklm}	2.631^{uv}	3.088^{yz}
	7.8°C (46°F)	1.000^{a}	1.584^{de}	2.250^{nopq}	2.447^{rst}	3.088^{yz}	3.422$^{c'd'}$
IF	1.1°C (34°F)	1.000^{a}	1.344^{bc}	1.969^{ghij}	2.125^{jklmno}	2.813^{vw}	3.125$^{za'}$
	4.4°C (40°F)	1.000^{a}	1.341^{bc}	1.688^{e}	1.828^{fg}	2.547^{stu}	2.844^{wx}
	7.8°C (46°F)	1.000^{a}	1.391^{bc}	1.822^{fg}	2.094^{jklmn}	2.906^{wxy}	3.300$^{a'b'c'}$
N	1.1°C (34°F)	1.000^{a}	1.250^{b}	1.953^{ghij}	2.156^{klmno}	2.547^{stu}	3.031^{yz}
	4.4°C (40°F)	1.000^{a}	1.447^{cd}	2.063^{ijklm}	2.047^{ijkl}	2.766^{vw}	3.031^{yz}
	7.8°C (46°F)	1.000^{a}	1.256^{b}	1.906^{ghi}	1.844^{fgh}	2.809^{vw}	3.016^{xyz}
SW	1.1°C (34°F)	1.000^{a}	1.256^{cd}	1.906^{hijk}	1.844^{mnopq}	2.809^{xyz}	3.016$^{a'b'c'}$
	4.4°C (40°F)	1.031^{a}	1.666^{ef}	2.284^{opqr}	2.416^{qrst}	3.141$^{za'b'}$	3.593$^{d'e'}$
	7.8 C (46°F)	1.000^{a}	1.628^{de}	2.391^{pqrs}	2.578^{tu}	3.313$^{a'b'c'}$	3.703$^{e'}$

[y'] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

[z'] Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[a-e'] Means with the same superscript letter are not different (P>.05).

Appendix Table D5. Mean pH values for the interaction of type of lighting by lighting intensity by temperature on wafer sliced cured and cooked beef.

Type of Lighting[y]	Lighting Intensity[z] lm/m^2	Temperature 1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
DCW	1076	6.298^{r}	6.205^{efgh}	6.188^{bcd}
	1614	6.324^{s}	6.211^{fghi}	6.198^{cdef}
	2152	6.276^{pq}	6.224^{ijk}	6.196^{cdef}
	3228	6.289^{qr}	6.219^{hi}	6.201^{defg}
IF	1076	6.219^{hi}	6.211^{fghi}	6.171^{a}
	1614	6.244^{lmn}	6.216^{ghi}	6.178^{ab}
	2152	6.249^{mno}	6.209^{fghi}	6.184^{abc}
	3228	6.256^{no}	6.223^{ij}	6.188^{bcd}
N	1076	6.248^{mn}	6.229^{jkl}	6.191^{bcde}
	1614	6.265^{op}	6.240^{klmn}	6.204^{defgh}
	2152	6.246^{mn}	6.234^{jklm}	6.200^{cdefg}
	3228	6.245^{lmn}	6.246^{mn}	6.190^{bcde}
SW	1076	6.281^{pq}	6.211^{fghi}	6.188^{bcd}
	1614	6.289^{qr}	6.223^{ij}	6.196^{cdef}
	2152	6.290^{qr}	6.226^{jk}	6.201^{defg}
	3228	6.288^{qr}	6.226^{jk}	6.200^{cdefg}

[y]Type of Lighting: DCW=GE Deluxe Cool White, IF=Sylvania Incandescent Fluorescent, N=GE Natural, SW=Westinghouse Supermarket White.

[z]Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

[a-s]Means with the same superscript letter are not different ($P>.05$).

Appendix Table E1. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Deluxe Cool White Lighting, Nonvacuum Processed			
		Lighting Intensity, lm/m^2 [z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	3.6°C (38.4°F)	4.7°C (40.5°F)	3.1°C (37.6°F)	3.8°C (38.9°F)
	24	6.7°C (44.1°F)	2.0°C (35.6°F)	3.1°C (37.6°F)	3.6°C (38.5°F)
	48	2.6°C (36.6°F)	1.1°C (34.0°F)	1.5°C (34.7°F)	1.8°C (35.2°F)
.52	12	4.2°C (39.5°F)	5.4°C (41.8°F)	3.7°C (38.6°F)	4.4°C (40.0°F)
	24	7.7°C (45.8°F)	2.5°C (36.5°F)	3.7°C (38.6°F)	4.2°C (39.6°F)
	48	3.1°C (37.5°F)	1.5°C (34.7°F)	1.9°C (35.4°F)	2.2°C (36.0°F)
.58	12	7.9°C (46.3°F)	9.9°C (49.8°F)	7.2°C (44.9°F)	8.4°C (47.1°F)
	24	13.3°C (56.0°F)	5.3°C (41.6°F)	7.2°C (44.9°F)	8.0°C (46.4°F)
	48	6.2°C (43.2°F)	3.8°C (38.9°F)	4.4°C (40.0°F)	4.9°C (40.8°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}\ (\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E2. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Incandescent Fluorescent Lighting, Nonvacuum Processed			
		Lighting Intensity, lm/m^2[z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	8.1°C (46.5°F)	6.3°C (43.3°F)	10.4°C (50.8°F)	3.7°C (38.7°F)
	24	6.7°C (44.0°F)	3.7°C (38.7°F)	6.8°C (44.2°F)	2.1°C (35.8°F)
	48	2.7°C (36.9°F)	2.8°C (37.0°F)	1.6°C (34.9°F)	0.8°C (33.4°F)
.52	12	9.1°C (48.4°F)	7.2°C (44.9°F)	11.7°C (53.1°F)	4.3°C (39.8°F)
	24	7.6°C (45.6°F)	4.4°C (39.9°F)	7.7°C (45.9°F)	2.6°C (36.7°F)
	48	3.2°C (37.8°F)	3.3°C (38.0°F)	2.1°C (35.7°F)	1.1°C (34.0°F)
.58	12	15.6°C (60.0°F)	12.5°C (54.5°F)	19.6°C (67.2°F)	8.2°C (46.7°F)
	24	13.2°C (55.7°F)	8.3°C (46.9°F)	13.4°C (56.1°F)	5.5°C (41.9°F)
	48	6.5°C (43.7°F)	6.6°C (43.9°F)	4.6°C (40.3°F)	3.2°C (37.8°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E3. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Natural Lighting, Nonvacuum Processed			
		Lighting Intensity, lm/m^2[z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	14.3°C (57.8°F)	6.6°C (43.9°F)	4.5°C (40.1°F)	3.7°C (38.7°F)
	24	7.1°C (44.8°F)	5.5°C (41.9°F)	4.4°C (39.9°F)	2.6°C (36.6°F)
	48	2.5°C (36.5°F)	1.2°C (34.2°F)	3.6°C (38.5°F)	1.6°C (34.9°F)
.52	12	16.1°C (60.9°F)	7.5°C (45.5°F)	5.2°C (41.4°F)	4.3°C (39.8°F)
	24	8.1°C (46.5°F)	6.3°C (43.4°F)	5.1°C (41.2°F)	3.1°C (37.5°F)
	48	2.9°C (37.3°F)	1.7°C (35.0°F)	4.3°C (39.7°F)	2.1°C (35.7°F)
.58	12	26.2°C (79.2°F)	13.1°C (55.5°F)	9.6°C (49.2°F)	8.2°C (46.7°F)
	24	13.9°C (57.1°F)	11.3°C (52.3°F)	9.3°C (48.8°F)	6.2°C (43.2°F)
	48	6.1°C (43.0°F)	4.0°C (39.2°F)	8.1°C (46.5°F)	4.7°C (40.4°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E4. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Supermarket White Lighting, Nonvacuum Processed			
		Lighting Intensity, lm/m^2[z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	8.3°C (46.9°F)	4.8°C (40.7°F)	3.6°C (38.4°F)	2.3°C (36.1°F)
	24	6.3°C (43.4°F)	4.9°C (40.8°F)	2.9°C (37.3°F)	2.6°C (33.1°F)
	48	3.4°C (38.1°F)	2.8°C (37.0°F)	2.1°C (35.7°F)	0.6°C (33.1°F)
.52	12	9.4°C (48.9°F)	5.6°C (42.1°F)	4.2°C (39.5°F)	2.8°C (37.0°F)
	24	7.2°C (45.0°F)	5.6°C (42.1°F)	3.6°C (38.4°F)	3.1°C (37.5°F)
	48	4.0°C (39.2°F)	3.3°C (38.0°F)	2.5°C (36.5°F)	0.9°C (33.7°F)
.58	12	15.9°C (60.7°F)	10.1°C (50.2°F)	7.9°C (46.3°F)	5.8°C (42.5°F)
	24	12.7°C (54.8°F)	10.2°C (50.3°F)	6.9°C (44.5°F)	6.4°C (43.2°F)
	48	7.7°C (45.9°F)	6.6°C (43.9°F)	5.4°C (41.7°F)	2.9°C (37.3°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=150 fc, 3228 lm/m^2=300 fc.

Appendix Table E5. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Deluxe Cool White Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2[z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	6.5°C (43.7°F)	6.7°C (44.1°F)	5.2°C (41.3°F)	4.4°C (40.0°F)
	24	6.9°C (44.4°F)	9.1°C (48.4°F)	6.1°C (42.9°F)	2.5°C (36.5°F)
	48	4.1°C (39.3°F)	1.5°C (34.7°F)	2.1°C (35.8°F)	0.8°C (33.4°F)
.52	12	7.4°C (45.3°F)	7.7°C (45.8°F)	5.9°C (42.7°F)	5.2°C (41.3°F)
	24	7.8°C (46.0°F)	10.3°C (50.6°F)	6.9°C (44.4°F)	3.0°C (37.4°F)
	48	4.7°C (40.5°F)	1.9°C (35.5°F)	2.6°C (36.7°F)	1.1°C (34.0°F)
.58	12	12.9°C (55.3°F)	13.3°C (56.0°F)	10.7°C (51.2°F)	9.4°C (49.0°F)
	24	13.6°C (58.4°F)	17.4°C (63.3°F)	12.1°C (53.8°F)	2.9°C (37.2°F)
	48	8.8°C (47.9°F)	4.5°C (40.1°F)	5.5°C (41.9°F)	3.2°C (37.8°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E6. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Incandescent Fluorescent Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2[z]			
570 nm/ 650 nm Ratio	Hour	1076	1614	2152	3228
.51	12	8.3°C (46.9°F)	9.2°C (48.6°F)	10.1°C (50.2°F)	4.4°C (40.0°F)
	24	9.4°C (48.9°F)	4.9°C (40.8°F)	2.9°C (37.3°F)	4.1°C (39.3°F)
	48	2.2°C (36.0°F)	2.3°C (36.1°F)	1.1°C (34.0°F)	1.3°C (34.3°F)
.52	12	9.3°C (48.8°F)	10.4°C (50.8°F)	11.4°C (52.5°F)	4.1°C (41.3°F)
	24	10.6°C (51.1°F)	5.7°C (42.2°F)	3.6°C (38.4°F)	4.7°C (40.5°F)
	48	2.7°C (36.9°F)	2.8°C (37.0°F)	1.4°C (34.6°F)	1.7°C (35.1°F)
.58	12	15.9°C (60.6°F)	17.6°C (63.6°F)	19.1°C (66.3°F)	9.5°C (49.1°F)
	24	17.8°C (64.1°F)	10.2°C (50.4°F)	6.9°C (44.5°F)	8.8°C (47.8°F)
	48	5.7°C (42.2°F)	5.7°C (42.3°F)	3.8°C (38.8°F)	4.1°C (39.4°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1976 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E7. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Natural Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2 [z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	13.8°C (56.8°F)	10.9°C (51.7°F)	3.9°C (39.1°F)	2.7°C (36.8°F)
	24	6.2°C (43.2°F)	6.7°C (44.1°F)	4.9°C (40.9°F)	2.8°C (37.1°F)
	48	3.9°C (39.1°F)	1.7°C (35.0°F)	1.1°C (33.9°F)	0.6°C (33.0°F)
.52	12	15.4°C (59.8°F)	12.3°C (54.1°F)	4.6°C (40.3°F)	3.3°C (37.9°F)
	24	7.1°C (44.7°F)	7.7°C (45.8°F)	5.7°C (42.3°F)	3.4°C (38.1°F)
	48	4.6°C (40.3°F)	2.1°C (35.8°F)	1.4°C (34.6°F)	0.9°C (33.6°F)
.58	12	25.3°C (77.5°F)	20.4°C (68.8°F)	8.6°C (47.4°F)	6.4°C (43.6°F)
	24	12.4°C (54.3°F)	13.3°C (55.9°F)	10.3°C (50.6°F)	6.8°C (44.2°F)
	48	8.6°C (47.4°F)	4.7°C (40.5°F)	4.7°C (40.5°F)	2.8°C (37.1°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E8. Simple linear regression[y] predicted display temperatures to compensate for lighting intensities of wafer sliced cured and cooked beef.

		Supermarket White Lighting, Vacuum Processed			
		Lighting Intensity, lm/m^2[z]			
		1076	1614	2152	3228
570 nm/ 650 nm Ratio	Hour				
.51	12	10.6°C (51.1°F)	7.9°C (46.3°F)	5.5°C (41.9°F)	2.1°C (35.8°F)
	24	8.3°C (47.0°F)	5.3°C (41.6°F)	8.1°C (46.6°F)	2.7°C (36.9°F)
	48	4.8°C (40.6°F)	3.1°C (37.6°F)	2.4°C (36.3°F)	1.4°C (34.6°F)
.52	12	11.9°C (53.5°F)	9.0°C (48.2°F)	6.3°C (43.4°F)	2.6°C (36.7°F)
	24	9.4°C (49.0°F)	6.2°C (43.2°F)	9.2°C (48.6°F)	3.3°C (37.9°F)
	48	5.6°C (42.0°F)	3.7°C (38.7°F)	2.9°C (37.2°F)	1.9°C (35.4°F)
.58	12	19.8°C (67.7°F)	15.4°C (59.7°F)	11.3°C (52.3°F)	5.4°C (41.8°F)
	24	16.0°C (60.8°F)	10.9°C (51.7°F)	15.7°C (60.2°F)	6.5°C (43.7°F)
	48	10.1°C (50.1°F)	7.2°C (45.0°F)	5.9°C (42.7°F)	4.4°C (39.9°F)

[y] $\text{Ratio} = .408915 + \hat{\beta}(\text{Temperature} - 27)$.

[z] Lighting Intensity: 1076 lm/m^2=100 fc, 1614 lm/m^2=150 fc, 2152 lm/m^2=200 fc, 3228 lm/m^2=300 fc.

Appendix Table E9. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Deluxe Cool White Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	86.7	83.3	76.9
	24	76.3	75.1	68.4
	48	49.0	53.7	45.5
2.0	12	173.3	166.7	153.9
	24	152.6	150.3	136.8
	48	98.1	107.4	91.0
2.5	12	260.0	250.0	230.8
	24	228.9	225.4	205.3
	48	147.2	161.2	136.5
3.0	12	346.7	333.3	307.7
	24	305.2	300.6	307.7
	48	196.2	214.9	182.0

[y] $\text{Score} = 1 + \hat{\beta}(\text{Light Intensity})$.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E10. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Incandescent Fluorescent Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	97.7	112.1	96.3
	24	82.3	115.0	79.8
	48	49.4	56.5	50.9
2.0	12	195.5	224.1	192.6
	24	164.6	230.1	159.5
	48	98.9	113.0	101.8
2.5	12	293.2	336.2	288.9
	24	246.8	336.2	288.9
	48	148.3	169.6	152.7
3.0	12	391.0	448.3	385.2
	24	329.1	460.2	319.0
	48	197.7	226.1	203.6

[y] $\text{Score} = 1 + \hat{\beta}(\text{Light Intensity})$.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E11. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Natural Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	97.0	104.0	91.6
	24	82.8	94.6	104.8
	48	58.3	65.0	52.3
2.0	12	194.0	208.0	183.1
	24	165.6	188.4	209.7
	48	116.6	130.0	104.6
2.5	12	291.0	312.0	274.7
	24	248.4	282.6	314.5
	48	174.9	195.0	156.9
3.0	12	388.1	416.0	366.2
	24	331.2	376.8	419.4
	48	233.2	260.0	209.2

[y]Score=1 + $\hat{\beta}$(Light Intensity).

[z]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E12. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Supermarket White Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	87.8	70.4	60.5
	24	69.9	67.2	52.6
	48	45.0	45.5	40.1
2.0	12	175.7	140.8	120.9
	24	139.8	134.3	105.3
	48	90.0	90.9	80.2
2.5	12	263.5	211.3	181.4
	24	209.7	201.5	157.9
	48	135.0	136.4	120.3
3.0	12	351.4	281.7	241.9
	24	279.6	268.6	210.5
	48	179.9	181.8	160.4

[y]Score=1 + B(Light Intensity).

[z]1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E13. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Deluxe Cool White Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	87.3	114.0	78.3
	24	78.0	114.6	68.2
	48	47.5	78.2	50.4
2.0	12	174.5	228.1	156.6
	24	156.1	229.3	136.4
	48	94.9	156.4	100.8
2.5	12	261.7	342.1	234.9
	24	234.1	343.9	204.6
	48	142.3	234.7	151.2
3.0	12	349.0	456.1	313.3
	24	312.1	458.6	272.8
	48	189.8	312.9	201.6

[y] $\text{Score} = 1 + \hat{\beta}(\text{Light Intensity})$.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E14. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Incandescent Fluorescent Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	94.2	168.8	130.5
	24	78.8	118.2	98.5
	48	51.8	69.9	56.1
2.0	12	188.4	337.7	261.0
	24	157.6	236.4	197.0
	48	103.6	139.8	112.3
2.5	12	282.6	506.5	391.6
	24	236.4	354.6	295.5
	48	155.4	209.7	168.4
3.0	12	376.8	675.3	522.1
	24	315.2	472.7	393.9
	48	207.2	279.6	224.5

[y] $\text{Score} = 1 + \hat{\beta}(\text{Light Intensity})$.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E15. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Natural Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	117.1	81.8	111.1
	24	86.7	91.6	107.4
	48	70.3	50.0	52.4
2.0	12	234.2	163.5	222.2
	24	173.3	183.1	220.3
	48	140.5	100.0	104.8
2.5	12	351.4	245.3	333.3
	24	260.0	274.7	322.3
	48	210.8	150.0	157.3
3.0	12	468.5	327.0	444.4
	24	346.7	366.2	429.8
	48	281.1	200.0	209.7

[y] $\text{Score} = 1 + \hat{\beta}(\text{Light Intensity})$.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E16. Simple linear regression[y] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Supermarket White Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
Visual Score[z]	Hour			
1.5	12	111.1	84.1	90.3
	24	96.3	73.9	75.6
	48	56.3	50.6	50.0
2.0	12	222.2	168.2	180.6
	24	192.6	147.7	152.9
	48	113.5	101.2	100.0
2.5	12	333.3	252.3	270.8
	24	288.9	221.6	229.4
	48	170.3	151.8	150.0
3.0	12	444.4	336.4	361.1
	24	385.2	295.5	305.9
	48	227.1	202.3	200.0

[y] $\text{Score} = 1 + \hat{\beta}(\text{Light Intensity})$.

[z] 1=Bright Pink, 2=Slight Fade, 3=Moderate Fade, 4=Complete Fade.

Appendix Table E17. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Deluxe Cool White Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	197.4	233.0	130.0
	24	176.6	161.0	154.2
	48	125.0	125.9	106.9
.52	12	216.8	256.1	152.0
	24	194.1	177.0	169.4
	48	138.0	213.2	117.5
.58	12	334.1	394.4	234.1
	24	298.9	272.6	261.0
	48	211.6	213.2	181.0

[z]Ratio=.408915 + $\hat{\beta}$(Light Intensity).

Appendix Table E18. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Incandescent Fluorescent Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	1.1°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	228.9	220.8	227.8
	24	205.0	246.4	133.4
	48	120.2	156.5	91.9
.52	12	251.5	242.7	250.3
	24	225.3	270.8	146.6
	48	132.1	172.0	101.0
.58	12	387.3	373.8	385.5
	24	347.0	417.1	225.7
	48	203.5	264.8	155.6

[z]Ratio=.408915 + $\hat{\beta}$(Light Intensity).

Appendix Table E19. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Natural Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	193.4	381.6	159.5
	24	160.6	197.6	167.3
	48	118.1	142.6	120.2
.52	12	212.5	419.3	175.3
	24	176.5	217.2	183.8
	48	129.8	156.7	132.1
.58	12	327.3	645.8	269.9
	24	271.9	334.4	283.1
	48	200.0	241.3	203.5

[z]Ratio=.408915 + $\hat{\beta}$(Light Intensity).

Appendix Table E20. Simple linear regression[z] Predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Supermarket White Lighting, Nonvacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	46°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	153.2	164.3	170.3
	24	240.3	187.1	133.3
	48	151.1	133.9	95.1
.52	12	168.4	180.5	187.1
	24	264.1	205.6	146.5
	48	166.1	147.1	104.5
.58	12	259.3	278.0	288.2
	24	406.7	316.6	225.6
	48	255.8	226.6	161.0

[z]Ratio=.408915 + $\hat{\beta}$(Light Intensity).

Appendix Table E21. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Deluxe Cool White Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	217.9	221.3	202.0
	24	149.5	258.2	179.2
	48	101.2	161.8	96.6
.52	12	239.4	243.2	222.0
	24	164.2	283.8	196.9
	48	111.3	177.8	106.1
.58	12	368.7	374.6	342.0
	24	253.0	437.0	303.2
	48	171.3	273.9	163.4

[z]Ratio=.418915 + $\hat{\beta}$(Light Intensity).

Appendix Table E22. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Incandescent Fluorescent Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	198.4	288.4	253.2
	24	145.3	232.9	178.1
	48	126.3	143.9	94.3
.52	12	218.0	316.9	278.3
	24	159.6	255.9	195.7
	48	138.8	158.1	103.7
.54	12	335.8	488.1	428.6
	24	245.9	394.2	301.4
	48	213.8	243.5	159.7

[z]Ratio=.418915 + $\hat{\beta}$(Light Intensity).

Appendix Table E23. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Natural Lighting, Vacuum Processed				
		Temperature		
		1.1 C°(34°F)	4.4°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	148.1	195.0	217.0
	24	183.5	245.8	159.7
	48	131.7	116.2	89.1
.52	12	162.8	214.3	238.4
	24	201.7	270.1	175.5
	48	144.7	127.7	97.9
.58	12	250.7	330.0	367.2
	24	310.6	416.0	270.3
	48	222.9	196.6	150.7

[z]Ratio=.408915 + $\hat{\beta}$(Light Intensity).

Appendix Table E24. Simple linear regression[z] predicted display lighting intensities (foot-candles) to compensate for temperatures of wafer sliced cured and cooked beef.

Supermarket White Lighting, Vacuum Processed				
		Temperature		
		1.1°C (34°F)	4.4°C (40°F)	7.8°C (46°F)
570 nm/ 650 nm Ratio	Hour			
.51	12	210.4	179.2	178.7
	24	246.9	237.4	164.2
	48	162.7	156.7	113.2
.52	12	231.2	197.0	196.4
	24	271.3	260.9	180.5
	48	178.8	172.2	124.4
.58	12	356.1	303.3	302.4
	24	417.9	401.8	278.0
	48	275.3	265.2	191.6

[z]Ratio=.408915 + $\hat{\beta}$(Light Intensity).

EFFECT OF DISPLAY CONDITIONS ON COLOR FADING OF WAFER SLICED CURED AND COOKED BEEF

by

MITZI ANNETTE PONTIOUS SCHWAB

B.S., University of Illinois, Urbana-Champaign, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

ABSTRACT

Display conditions' influence on cured color fading of wafer sliced cured and cooked beef was visually estimated and measured by 570 nm/650 nm reflectance ratios. Microbial standard plate counts, pH, and percent package oxygen were also determined. Experimental design included all possible combinations of the following: 1) lighting intensities of 1076, 1614, 2152, or 3228 lm/m^2, 2) lighting types of Deluxe Cool White, Incandescent Fluorescent, Natural, or Supermarket White 40 watt fluorescent lamps, 3) temperatures of 1.1, 4.4, or 7.8°C, and 4) processing method of vacuumized versus nonvacuumized. Data were tested by analysis of variance. Maximum allowable display temperatures were predicted from lighting intensities ($P<.05$) to achieve indicated product fading by a second-order linear regression model with fixed intercept.

For nonvacuum processed wafer sliced cured and cooked beef, light induced nitrosohemochrome oxidation increased with increasing lighting intensities from 1076 to 3228 lm/m^2 up to 72 hr. Product perceptibly faded within 6 display hr approaching "Complete Fade" after 72 display hr. Visual cured color did not regenerate during dark display between 12 and 24 hr. Color rendition of Incandescent Fluorescent and Natural lamps caused less visual fading than Deluxe Cool White or Supermarket White lamps. Subjectively and objectively measured fading was similar at 1.1 and 4.4°C, but accelerated between 6 and 72 display hr at 7.8°C. Between 24 and 72 hr,

standard plate counts increased from log 2.6/g up to log 5.1/g, pH decreased slightly, and package oxygen decreased below 1% of gas volume.

For vacuum processed wafer sliced cured and cooked beef, light induced nitrosohemochrome oxidation also increased with increasing lighting intensities from 1076 to 3228 lm/m^2 up to 72 hr. Visually, product color did not regenerate during dark display between 12 and 24 hr. Visual fading was similar for equal lm/m^2-hr exposure. Incandescent Fluorescent and Natural lighting caused less visual fading than Deluxe Cool White or Supermarket White, probably resulting from greater red wavelength emissions. Fading, measured by reflectance, was similar at 1.1 and 4.4°C, but beginning at 48 hr accelerated at 7.8°C. Between 24 and 72 hr, standard plate counts increased up to log 4.2/g. Package oxygen decreased below 1% of gas volume.

When considering vacuum and nonvacuum processed beef together, light induced nitrosohemochrome oxidation increased with increasing lighting intensities from 1076 to 3228 lm/m^2 up to 72 hr. Visually estimated product fading was similar for equal lm/m^2-hr exposure. Product color did not regenerate during dark display between 12 and 24 hr. Incandescent Fluorescent and Natural lighting caused less visual fading than Deluxe Cool White or Supermarket White, probably due to color rendition differences. Vacuum processed product appeared less visually faded under all lighting types and at all display hr than nonvacuum processed product. Visual and reflectance measured fading was similar at 1.1 and 4.4°C, but be-

ginning at 48 hr accelerated at 7.8°C. Between 24 and 72 hr, standard plate counts increased to log 4.9/g. Package oxygen decreased.

Predicted maximum allowable display temperatures to achieve particular product fading decreased with increasing lighting intensities from 1076 to 3228 lm/m^2 at 12, 24, or 48 hr for vacuum and nonvacuum processed product under each lighting source. At each lighting intensity, predicted temperatures decreased with increasing time from 12 to 48 hr for specified product fading under fixed display conditions. At fixed times and intensities, temperature predictions increased as allowable fading increased from visual score 1.5 to 3.0 at controlled display conditions. Incandescent Fluorescent and Natural lightings' allowable temperatures were higher than Deluxe Cool White's or Supermarket White's for both processing methods.