THE UNIVERSITY OF MANITOBA

CENTRALIZED PACKAGING OF RETAIL MEAT CUTS

by

Gaurav Tewari

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF BIOSYSTEMS ENGINEERING

WINNIPEG, MANITOBA (CANADA)

MARCH, 2000

National Library of Canada
Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services
Acquisitions et services bibliographiques

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-51672-5

Canada

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION PAGE

Centralized Packaging of Retail Meat Cuts

BY

Gaurav Tewari

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

of

Doctor of Philosophy

GAURAV TEWARI © 2000

Permission has been granted to the Library of The University of Manitoba to lend or sell copies of this thesis/practicum, to the National Library of Canada to microfilm this thesis/practicum and to lend or sell copies of the film, and to Dissertations Abstracts International to publish an abstract of this thesis/practicum.

The author reserves other publication rights, and neither this thesis/practicum nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

Dedicated to my mummy

ABSTRACT

In conjunction with a study on centralized meat packaging, oxygen absorption kinetics of six commercial O_2 scavengers was determined. The scavengers were placed in bags, which were filled with 240 mL of air, 4.5 L N_2 + 15 mL of air, or 3.5 L CO_2 + 9 mL of air, and the O_2 concentration in each bag was measured at hourly intervals for 8 h. Significant ($p<0.05$) variation existed in the O_2 absorption rates among individual scavengers of the same type. In addition, effects of temperature, 25, 12, 2, and -1.5°C, and pack atmosphere, such as air and N_2 with initial O_2 concentrations of 20% and 500 ppm, respectively, on their O_2 absorption rates were significant ($p<0.05$). In general, high temperatures and initial O_2 concentrations gave faster O_2 absorption rates than low temperatures and initial O_2 concentration.

A retail-packaging system for centralized operations of retail-ready beef steaks or pork chops, was developed by evaluating 14 treatment combinations of retail packages. The presence of O_2 scavengers inside a lidded or over-wrapped retail tray having an absorbent pad or a grid or both, was necessary to prevent discoloration of meat cuts. In a subsequent experiment, the amount of O_2 absorbing capacity required in each retail tray was determined. A minimum of eight O_2 scavengers sachets with O_2 absorption rate high enough to deliver an O_2 half-life of 0.6-0.7 h in the pack atmosphere where O_2 concentration remains $\leq$500 ppm at any time of storage, were required in each retail tray.

Master-packaged steaks, under 100% N_2 atmosphere, with or without O_2 scavengers were stored at 1±0.5°C for up to 8 days. After a subsequent storage interval of 1 day, 3 master packs containing steaks packaged with or without O_2 scavengers were

opened and examined for visual characteristics and chemical states of myoglobin. It was concluded that to prevent transient discoloration of beef steaks, the O_2 concentration should be reduced to 0 ppm at 1±0.5°C within 3 h of pack closure.

The beef steaks were master-packaged under 100% N_2 atmosphere and were stored for up to 10 weeks. After subsequent storage intervals of 1 week, 2 master packs were opened and steaks were analyzed for visual, odor, flavor, and microbiological characteristics. In addition, reflectance spectra were obtained from the steaks' surface to estimate chemical states of myoglobin. These steaks were further displayed in a retail display case for 4 days, and were analyzed daily for visual characteristics and chemical states of myoglobin. On the 4th day of retail display, odor, flavor, and microbiological characteristics were also determined. Retail appearance was the limiting factor for the retail display life of the steaks. The present system can deliver a storage life of 10 weeks, with a subsequent retail display life of 3 days for master-packaged beef steaks.

ACKNOWLEDGMENTS

I express my heartfelt gratitude to Dr. D. S. Jayas for his competent guidance, advice, and constructive criticisms throughout the period of this study. I will always see him as my model.

I am thankful to Drs. R. A. Holley and S. Cenkowski for serving on my thesis committee.

Thanks to Messrs D. Bourns, M. Macdonalds, J. Putnam, and S. Jeyamkondan for design and fabrication of the liquid-N_2 refrigerated container.

I am highly thankful to Drs. L. E. Jeremiah and C. O. Gill, Agriculture and Agri-Food Canada Meat Research Center, Lacombe, AB, for granting me access to their facilities and for their help. I greatly acknowledge technical review of the scavenger-study by Dr. C. O. Gill.

I am thankful to technical staff at the Meat Research Center, Lacombe, AB, and to Ms. Jennifer L. Richardson, Department of Food Science, University of Manitoba for their technical help.

I am also thankful to Natural Sciences and Engineering Research Council of Canada (NSERC) for partial financial assistance.

I am thankful to Dr. R. L. Kushwaha uncle and Lata aunti for their love, affection, and blessings. I thank Dr. Steven R. Eckhoff, University of Illinois Urbana Champaign, Urbana, IL, for his moral support, and guidance. Thanks to Vijay, Suvrat, Akhilesh, Udai Bhan, Matthew and Tannis for their moral support and friendship.

I am extremely grateful to my papa, Dr. G. N. Tewari, Bhaiya, Bhabhiji, Anmol, Sonu, Puja, and my in-laws for their blessings, love, affection, and prayers. Heartiest thanks to my wife, Astha, whose love and affection keeps me alive. I can never thank her enough. Above all, thanks to my two and a half year old son, Anat, for his hugs, smiles, and kisses, which helped me to concentrate while working nights and weekends.

TABLE OF CONTENTS

ABSTRACT i

ACKNOWLEDGMENTS iii

TABLE OF CONTENTS v

LIST OF FIGURES x

LIST OF TABLES xi

1. INTRODUCTION 1

2. LITERATURE REVIEW 8

2.1 Basic Meat Chemistry 8

2.1.1 Postmortem changes in meat 8

2.1.1.1 Reactions during contraction and relaxation of muscle . . 8

2.1.1.2 Conversion of muscle to meat 9

2.2 Controlled and/or Modified Atmosphere Packaging of Meat: Application in Centralized Meat Operations 11

2.2.1 Modified atmosphere packaging and controlled atmosphere storage (CAS) 11

2.2.2 Earlier developments in MAP 12

2.2.3 Methods of atmosphere modification 14

2.2.3.1 Vacuum packaging 14

2.2.3.2 Vacuum skin packaging (VSP) 15

2.2.3.3 Gas packaging 15

2.2.3.4 Master packs 16

2.3 Microbiological and Sensory Characteristics of Meat 16

2.3.1 Microbiological and sensory evaluation of centrally packaged retail meat cuts 18

2.3.2 Detrimental effects of residual oxygen (O_2) on the color stability of beef 25

2.4 Distribution Systems for Centrally Packaged Retail Meat Cuts 28

3. OXYGEN ABSORPTION KINETICS OF OXYGEN SCAVENGERS 31

3.1 Summary 31

3.2 Introduction 32

3.3 Materials and methods 34

3.3.1 O_2 scavengers 34

3.3.2 Absorption of O_2 by scavengers 34

3.3.3 Data analysis 37

3.3.4 Validation of constants for Arrhenius equation 39

3.4 Results 39

3.5 Discussion 42

4. DEVELOPMENT OF A RETAIL PACKAGING SYSTEM FOR CENTRALIZED MASTER PACKAGING OF OXYGEN-SENSITIVE FRESH MEAT DISPLAY 54

4.1 Summary 54

4.2 Introduction 55

4.3 Materials and methods 56

4.3.1 Oxygen (O_2) scavengers 56

4.3.2 Measurement of O_2 concentration 56

4.3.3 Master-packaging and storage of steaks and chops 56

4.3.3.1 Experiment#1 56

4.3.3.2 Experiment#2 58

4.3.3.3 Experiment#3 58

4.3.4 Display and evaluation of retail trays 59

4.3.5 Estimation of the oxidative states of myoglobin 60

4.3.6 Statistical analysis 60

4.4 Results 61

4.4.1 Experiment#1 61

4.4.1.1 Oxygen concentration 61

4.4.1.2 Visual properties 61

4.4.1.3 Chemical states of myoglobin 62

4.4.2 Experiment#2 62

4.4.2.1 Oxygen concentration 62

4.4.2.2 Visual and reflectance properties 63

4.4.3 Experiment#3 63

4.4.3.1 Oxygen concentration 63

4.4.3.2 Visual and reflectance properties 64

4.5 Discussion 65

5. PREVENTION OF TRANSIENT DISCOLORATION OF BEEF 77

5.1 Summary 77

5.2 Introduction 78

5.3 Materials and Methods 81

5.3.1 Oxygen scavengers 81

5.3.2 Master-packaging, storage, and sampling of steaks 81

5.3.3 Display and sampling of retail trays 83

5.3.4 Visual assessment of master-packaged steaks 83

5.3.5 Estimation of myoglobin states 84

5.3.6 Statistical analysis 84

5.4 Results 85

5.4.1 Oxygen concentration 85

5.4.2 Visual assessment of steaks 85

5.5 Discussion 87

6. DISPLAY LIFE OF RETAIL-READY MASTER-PACKAGED BEEF STEAKS USING O_2 ABSORBENT TECHNOLOGY AFTER STORAGE IN A LIQUID-N_2 REFRIGERATED CONTAINER 96

6.1 Summary 96

6.2 Introduction 97

6.3 Materials and Methods 99

6.3.1 Oxygen scavengers 99

6.3.2 Master-packaging, storage, and sampling of steaks 99

6.3.3 Display and sampling of retail trays 100

6.3.4 Visual assessment of master-packaged steaks 101

6.3.5 Odor assessments of master-packaged steaks 102

6.3.6 Flavor assessment of master-packaged steaks 102

6.3.7 Estimation of myoglobin forms 103

6.3.8 Microbial analysis 104

6.3.9 Statistical analysis 104

6.4 Results 104

6.4.1 Measurement of O_2 concentration 104

6.4.2 Storage and retail display temperature 105

6.4.3 Evaluation of steaks 105

6.5 Discussion 108

7. CONCLUSIONS 121

8. REFERENCES 123

APPENDICES A-I 136

LIST OF FIGURES

Fig	Title	Page
4.1	Mean discoloration scores for steaks stored with different numbers of O_2 scavengers.	74
4.2	Retail appearance scores of steaks stored with different numbers of O_2 scavengers.	75
4.3	Mean percentages of metmyoglobin on the surfaces of steaks stored with different numbers of O_2 scavengers.	76
6.1	Mean color scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	112
6.2	Mean discoloration scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	113
6.3	Mean retail appearance scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	114
6.4	Mean off-odor intensity scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	115
6.5	Mean odor acceptability scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	116
6.6	Mean flavor acceptability scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	117
6.7	Mean off-flavor intensity scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.	118
6.8	Mean microbial numbers (with standard deviation) on steaks stored in the liquid-N_2 refrigerated container.	119
6.9	Mean percentages of metmyoglobin (with standard deviation) on the surfaces of steaks stored in the liquid-N_2 refrigerated container.	120

LIST OF TABLES

Table	Title	Page
3.1	Manufacturers' specifications for O_2 scavengers.	47
3.2	Variability in O_2 half-life among single vs four O_2 scavengers of the same type in air at 25°C.	48
3.3	Half-life of O_2 in bags containing four scavengers and air, N_2, or CO_2 atmosphere.	49
3.4	Constants of first order kinetics equation for different scavengers.	50
3.5	Arrhenius equation rate constants for different O_2 scavengers.	53
4.1	Description of treatments for beef steaks and pork chops for experiment #1.	69
4.2	Oxygen (O_2) concentration in master packs containing beef and pork stored at 2°C in 100% nitrogen (N_2) atmosphere for 7 days.	70
4.3	Mean color, surface discoloration, and retail appearance scores and standard errors for pork chops and beef steaks after various treatments.	71
4.4	Mean values of the chemical states of myoglobin (% met-, % deoxy- and % oxy-myoglobin) and standard errors for pork chops and beef steaks after various treatments.	72
4.5	Means and standard errors for visual and reflectance properties of beef (LT) steaks stored in different packaging treatments.	73
5.1	The oxygen (O_2) concentration in master packs containing beef steaks stored under a nitrogen atmosphere for up to eight days at 1±0.5°C.	92
5.2	Sensory panel scores (average scores of five panelists) for beef (PM) steaks stored in master packs under a nitrogen atmosphere for up to eight days at 1±0.5°C.	93
5.3	Mean values for the oxidation states of myoglobin obtained from the surfaces of beef (PM) steaks, stored in master packs under a nitrogen atmosphere for up to eight days at 1±0.5°C. Steaks were prepared from beef tenderloins within 24 h of slaughter.	95

1. INTRODUCTION

Useful shelf life is the time required for a food to become unacceptable from a sensory, nutritional, microbiological, or safety perspective (Labuza 1996). Shelf life of a food product can be extended, provided the mechanism of causing spoilage of a food product is known and is manipulated using "safe techniques" which do not affect the sensory and nutritional characteristics of food. The shelf life of foods can be extended using various techniques such as thermal processing (retort and aseptic processing), freeze-drying, and cryogenic freezing (Individual Quick Frozen technique, IQF). These techniques are well adapted by the food industry to extend the shelf life of liquid foods (retort or aseptic processing), liquid foods with particulates (canning and retort), dehydrated foods (freeze drying), fruit and vegetable cuts (IQF), and meat (refrigeration or freezing). It is, however, to be noted that these techniques result in loss of "freshness (fresh taste)." Nutrients are also lost due to temperature change. Fresh vegetables, fruits, and meats are premium priced products in local and international markets.

Recently, the FDA (US) has approved irradiation of red meat, yet there is debate about the availability of suitable polymers for irradiated packages. There are currently only a handful of polymers approved in the CFR (Code of Federal Regulation) title 21§149.5 for use with irradiated foods. Of these only one, EVA (Ethylene Vinyl Acetate) can receive electron beam (e-beam) treatment. Most of the polymers listed in this section were approved in the 1960's. It is difficult to make a contemporary multilayer structure with currently approved polymers. From the standpoint of radiation

chemistry, e-beam, gamma, and x-ray treatment should have the same impact on polymer packaging materials. The fact that e-beam, gamma, and x-ray are treated differently in the CFR is due to the fact that initial requests for approval only mentioned gamma treatment. Therefore, until today, modified atmosphere packaging (CAP) is the only approved technique available which delays microbiological growth due to the inhibitory effect of carbon dioxide (CO_2) on bacteria and ensures freshness and long shelf life of fresh meat (Blickstad and Molin 1983; Gill and Harrison 1989; Gill and Tan 1980; Igbinedion et al. 1983). Nevertheless, modified atmosphere packaging should be coupled with strict temperature control to achieve maximum microbial inhibition. The rate of spoilage in muscle foods is high because they are a protein rich medium which encourages microbial growth. Muscle food tissue continues to metabolize just after slaughter, utilizing storage carbohydrates and fats. In the absence of further processing, microbial growth results as the energy stores deplete and metabolic products (low molecular-weight organic compounds) accumulate in the tissues. This results in off-odors and off-flavors of meat, and eventually microbiological decay occurs on the meat surface (Labuza 1996).

Optimized storage of fresh meat can yield 9-15 weeks of useful product storage life if meats are held at -1.5±0.5°C in saturated atmospheres of CO_2 or N_2, devoid of oxygen (O_2). These systems for long term storage and intercontinental transport are most useful for primal cuts of meat. Following such storage, products can be trimmed of surface imperfection, sliced and repackaged in convenient retail sizes on trays using films

permeable to oxygen and yield satisfactory meat color for up to 4 days of display in the store. In contrast, with centralized packaging of retail ready cuts, final trimming and portioning take place at the initial packaging step. The packaging film contacting the meat surface is oxygen permeable. Fabricated products must withstand 20-30 days storage in their original packages (which are usually grouped together in a controlled atmosphere) prior to display in the retail case at temperatures of about 7°C. Since there is no further manipulation of the cuts at retail other than to move packages to the display case, meat surfaces exposed at the central preparation facility must retain their attractiveness and appeal not only during the period of storage but also during subsequent display at retail for about 2 days.

Centrally packaged retail cuts of fresh red meats are economical because they require less manpower, equipment, space; and they have reduced chances of cross-contamination due to "continuous process operation" as majority of the personnel are HACCP (Hazard Analysis and Critical Control Point) trained. Tesco, a British supermarket chain, has converted its entire fresh meat operations to central packaging using MAP (Brody 1996). Brody (1996) also reported that the three most interesting technologies regarding "centralized packaging of fresh red meats" are Cryovac's (Saddle Brook, NJ, USA) vacuum skin packaging, Tesco's (London, UK) barrier foam trays, and master packs which were spawned by CVP Systems and M-Tek from the success of case-ready poultry packaging. Recently, W.R. Grace Limited, Australia (in collaboration with CSIRO, Canberra, Australia) has designed a retail ready master packs system for

transporting meat to distant countries.

Although work has been done in various labs using master packaging technology for centrally prepared retail meat cuts, several concerns remain unanswered:

(i) Centrally prepared retail beef cuts using high CO_2 or N_2 atmospheres are shown to be more susceptible to the formation of metmyoglobin due to residual O_2, resulting in poor sensory quality. Research has shown that beef color is highly sensitive to low concentrations of O_2 due to the formation of grey or brown metmyoglobin even in 100% CO_2 or N_2 atmospheres (Ledward 1970; Gill and Jones 1994a). Also, Penney and Bell (1993) reported that beef developed noticeable browning with more than 0.15% O_2 in high CO_2 atmospheres. Therefore, some innovative method needs to be developed to remove O_2 as the beef cuts are being stored under 100% CO_2 or N_2 atmospheres to prevent the premature browning. This is not of major concern if storage temperature is maintained at a sub-zero level and transportation takes several days (then metmyoglobin will be reduced by muscle enzyme activity) (Gill and McGinnis 1995b). However, transient metmyoglobin is a major concern where immediate use of part of a shipment is periodically required. The centrally prepared retail beef cuts may experience such situations quite frequently and transient metmyoglobin formation needs to be prevented. Gill and McGinnis (1995b) concluded that the O_2 concentration in the pack atmosphere has to be reduced below 10 ppm within 30 min at 2°C, or 2 h at -1.5°C to prevent transient discoloration of ground beef. The presently available commercial oxygen scavengers are able to provide such a rate of O_2 absorption provided large number of O_2

scavengers are used in the package and O_2 concentration during storage does not exceed 40-50 ppm. They further suggested that such a goal can be achieved if meat is held at -1.5°C with <100 ppm O_2 initially present. If the ratio of pack volume to mass of meat is small, this might also reduce the number of O_2 scavengers required. They studied O_2 absorption kinetics of only one type of commercial O_2 scavenger, and the initial O_2 concentration used in their study was too high to predict the O_2 absorption kinetics of an O_2 scavenger in a commercial meat operation. Additionally, they neither described the methodology of applying oxygen scavengers to the master packs, nor studied O_2 absorption kinetics of commercially available O_2 scavengers at low initial O_2 concentrations. It is possible that a specific method of applying O_2 scavengers or a combination of different O_2 scavengers with different O_2 affinity and capacity may result in a better O_2 absorption rate. Since there is a lack of information on O_2 absorption kinetics of commercially available O_2 scavengers at low initial O_2 concentrations, the usefulness of O_2 scavengers in preventing transient discoloration of retail-ready meat cuts packaged under an O_2-depleted controlled atmosphere is unknown. Thus, studies regarding O_2 absorption kinetics of O_2 scavengers need to be designed and conducted.

(ii) Transient discoloration of centrally prepared meat cuts limits the economies of centralized meat operations. Beef muscles like *psoas major* (PM) discolor rapidly at -1.5°C even if the residual O_2 concentration is < 100 ppm (Gill and McGinnis 1995a). Thus, a study needs to be designed and conducted to prevent transient discoloration of expensive beef cuts, such as PM.

(iii)Another important parameter to be considered during centralized meat operations is selection of a suitable retail package for master packaging of retail-ready meat cuts. Factors, such as entrapment of O_2 in the over-wrap, improper meat-mass to gas (CO_2 or N_2) volume ratio, or insufficient evacuation time during gas-flushing operations of a controlled atmosphere packaging machine, may increase the O_2 concentration in the package, and result in limited retail shelf life of meat cuts. Therefore, a suitable retail packaging system for centralized meat operations needs to be developed.

(iv) Controlled atmosphere packaging works best with strict temperature control, but frequent temperature fluctuations affecting meat quality have been observed during transportation and retail storage (Bailey et al. 1997). For meats like pork and beef, which can expect premium prices in export markets, shelf-life extension and excellent quality are the major issues. Although techniques for centralized preparation of meats are available, successful distribution of meats like pork and beef which have relatively short shelf life, is still unpredictable because of the absence of an efficient and reusable refrigerated distribution system having strict temperature control (-1.5±0.5°C) (Gill and Jones 1992; Gill et al. 1994). Recently, Jeyamkondan (1999) has designed, fabricated, and tested a refrigerated chamber (using liquid N_2 as refrigerant) for uniform and stable temperature distribution. However, this present chamber needs to be tested for the microbiological and sensory attributes using retail cuts of meat.

Therefore, the specific objectives of the present research were:

1. to determine the O_2 absorption kinetics of six commercial O_2 scavengers at several temperatures and initial O_2 concentrations;
2. to design an improved retail packaging system for centralized meat operations;
3. to determine optimum O_2 absorbent capacity required for preventing transient discoloration of retail-ready beef cuts; and
4. to determine the retail display life of centrally packaged beef cuts packaged under O_2-depleted controlled atmospheres and stored in the liquid-N_2 refrigerated container (Jeyamkondan 1999).

2. LITERATURE REVIEW

2.1 Basic Meat Chemistry

2.1.1 Postmortem changes in meat

Package designers must understand the chemistry behind postmortem changes in meat before designing a centralized meat distribution system to extend its shelf life (Coulate 1990, Eskin 1990).

2.1.1.1 Reactions during contraction and relaxation of muscle

Contraction and relaxation of voluntary muscle is based upon interaction between myosin (key muscle protein possessing the ability to catalyze the splitting of ATP), actin (filamentous key muscle protein contributing the nutritive value of meat), and adenosine triphosphate (Adenine-D-ribose-P~P~P) (ATP). Hydrolytic splitting of ATP provides a high source of energy for muscle contraction because hydrolysis of phosphate groups is a very exergonic reaction. If muscle is in its relaxed state, ATP is in the form of an inert magnesium complex (Mg-ATP). When muscle receives a stimulus from the central nervous system, calcium ions become released into the sarcoplasmic reticulum (a fine network of tubules surrounding intracellular myofibrils and joined to the plasma membrane of the muscle cell), which has two results:

(a) Ca^{2+} releases ATP from Mg-ATP

(b) Ca^{2+} stimulates Myosin-ATPase (myosin-adenosine triphosphatase).

As a result, energy is released from the high energy phosphate bond, which initiates muscle contraction due to the sliding action of actin filaments over myosin filaments and

we get the construction of a temporary actin-myosin (actinomyosin) complex.

During relaxation, Ca^{2+} ions are removed by a relaxing factor (calsequestrin), i.e., Ca^{2+} are pulled back to the membrane of the sarcoplasmic reticulum. Then inhibition of myosin-ATPase activity takes place and the actin-myosin complex dissociates. Next, new ATP has to be regenerated to allow subsequent contraction and this can be from two sources:

(a) in living muscle, the primary source of ATP is through aerobic respiration, and

(b) ATP can also be formed by the "Lohmann reaction" (Eq.1) utilizing residual creatine P in the tissue:

```
ADP (Adenosine di phosphate) +
creatine P (creatine phosphate)                    (1)
⇌ ATP + creatine
```

2.1.1.2 Conversion of muscle to meat

After the death of an animal, muscle tissue is in the relaxed stage, i.e., ATP is in the form of a Mg-ATP complex. At this time, muscle tissue is soft and pliable (capable of a high degree of extension). Until meat is acceptable for human consumers, there are three main stages through which the tissue passes:

(a) Pre-rigor stage

Muscle tissue is still soft and pliable. In biochemical terms, there is a continuing decline in the level of ATP and creatine phosphate. Also, anaerobic respiration takes place (less ATP) because muscle tissue does not receive O_2.

(b) Rigor mortis

Rigor mortis begins within 10-12 h after the death of an animal and lasts for about 15-20 h. Conversion of glycogen to lactic acid also begins, and actinomyosin forms as Ca^{2+} ions are released into the sarcoplasmic reticulum which, in turn, yields muscle inflexibility.

(c) Post-rigor state

During the post-rigor state, muscle tissue becomes more tender and acceptable, in part due to proteolytic enzyme activity (the process is not fully understood). Also, the pH of meat falls from 7.2-7.4 to 5.3-5.5 (due to conversion of glycogen to lactic acid). Low pH (5.3-5.5) retards the growth of some microorganisms and high pH (6.0-6.5) usually means greater risk of microbial spoilage. Therefore, pH of meat plays an important role in the extension of shelf life.. Also, there is a relationship between pH and meat color, i.e., pH 5.3 (light pink-red color) and pH 6.0 (dark color-unacceptable).

There are other changes during postmortem glycolysis:

(i) color change: dark red to a lighter greyish-pink,

(ii) exudation (water loss): decrease in water holding capacity, and

(iii) textural changes (closely packed muscle fibers yield relatively smooth texture).

Apart from meat becoming tender, flavor development also takes place during the post- rigor state. The ATP (its degradation products like inosine monophosphate) and breakdown of cytoplasmic proteins contribute to the final flavor of meat. Therefore, when designing a centralized meat packaging system, it is very important to select an

efficient packaging technique which delays further color and flavor changes of the meat until it is presented to the consumer.

2.2 Controlled and/or Modified Atmosphere Packaging of Meat: Application in Centralized Meat Operations

Central packaging of retail meat cuts involves use of controlled (CAP) and/or modified atmosphere packaging (MAP), which reduces the growth rate of spoilage microorganisms. It is to be noted that, MAP works best only with "strict temperature control" of the food product, because anaerobic lactic acid bacteria (LAB) are dominant under reduced O_2 levels and cause early spoilage of meat at uncontrolled temperatures.

2.2.1 Modified atmosphere packaging and controlled atmosphere storage (CAS)

Modified atmosphere packaging is defined as "the packaging of a perishable product in an atmosphere which has been modified so that its composition is other than that of air" (Hintlian and Hotchkiss 1986). This is in contrast with CAS, which involves active and continuous control of the atmosphere surrounding the food and is prominent in warehouse storage of vegetables and fruits. The CAS systems for meat use static atmospheres containing saturated concentrations of CO_2. In MAP, the initial atmosphere surrounding a food is altered by the addition of CO_2 or a combination of gases (O_2, N_2, and CO_2). The function of CO_2 is to decrease the growth rate of microorganisms by increasing their lag phase and reducing product respiration, whereas N_2 is used to displace O_2 and acts as an inert filler, which prevents the package from collapsing when some of the CO_2 is absorbed by moisture in the product.

2.2.2 Earlier developments in MAP

The preservative effect of CO_2 has been known for a long time. Real development of MAP started in 1922 when Brown (1922) investigated the effect of different concentrations of O_2 and CO_2 at various temperatures on the germination and growth of fruit-rotting fungi. He recommended the use of gas storage in combination with cold storage to extend the shelf life of fruits. Kidd and West (1927) examined the effect of atmosphere modification on the storage life of fruits. This experimentation resulted in the first commercial controlled atmosphere storage of apples in Kent, England, in 1929. Killefer (1930) found that pork and lamb remained fresh twice as long in 100% CO_2 at 4-7°C compared with storage in air at the same temperature. Callow (1932) also reported similar improvements in keeping quality of pork and bacon. Tomkins (1932) and Moran et al. (1932) reported that mold growth on meat could be retarded with as little as 4% CO_2 in the storage atmosphere. The higher the CO_2 concentration and the lower the storage temperature, the more effective was the inhibition. Haines (1933) found that it took twice as long for some common meat bacteria to multiply to the same number if stored in 10% CO_2 at 0°C, rather than in air at the same temperature.

Controlled atmospheres have been used in commercial storage, for example, to delay physiological changes such as ripening in fruits and vegetables (Day 1990; Tomkins 1932), and to transport chilled beef carcases from New Zealand and Australia (Scott 1989). By 1938, 26% of chilled carcass beef shipped from Australia and 60% of

that shipped from New Zealand were being held in a controlled atmosphere of 10% CO_2 for 40 to 50 days without any spoilage (Parry 1993). Coyne (1933) demonstrated that fillets or whole fish could be kept twice as long at ice temperature if stored in an atmosphere containing 25% CO_2 than in air.

By the 1960's vacuum packaging became popular for fresh meat. Ogilvy and Ayres (1951) did a comprehensive study on the use of CO_2 enriched atmospheres for extending the shelf life of chicken portions and found that shelf life was increased linearly as CO_2 concentration increased, however, meat discoloration was observed at high CO_2 concentration. By the 1970's, bulk packs of fresh chicken evacuated and then flushed with CO_2 were introduced commercially in the USA to extend the shelf life to 18-21 days in chill storage (Parry 1993). In 1979, Marks and Spencer test-launched MAP meat and are responsible for Britain's dominancy today in the world marketplace for modified atmosphere products. Within two years, they extended their product range to include bacon, loin chops, sliced cooked cured meats, fresh and smoked fish, and cooked shell fish (Parry 1993).

In North America, the science and technology of gas preservation of food evolved slowly perhaps because of highly developed refrigeration, transportation, and distribution systems (Eskin 1990; Oraikul and Stiles 1991). The rising costs of raw food products, labor and energy, the tightened controls on use of some preservatives and additives by the Food and Drug Administration (FDA), and the availability of better packaging films with reduced O_2 permeability as well as the versatility of packaging equipment have

promoted MAP products in North America.

In modern MAP systems, the cumbersome continuous control of the atmosphere surrounding the product is eliminated, which makes it much cheaper for a large-scale operation to be developed. Research and development activities on MAP were accelerated during the 1980s and 1990s, resulting in successful commercial applications (Oraikul and Stiles 1991).

2.2.3 Methods of atmosphere modification

Various modified atmosphere packaging techniques are available, their advantages and disadvantages should be considered while adapting these techniques for centralized meat packaging.

2.2.3.1 Vacuum packaging

Vacuum packaging was the earliest form of modified atmosphere packaging developed commercially and is still used for products such as primal cuts of fresh red meat, cured meats, hard cheeses, and ground coffee (Parry 1993). Since product is packed in film of low O_2 permeability (air is evacuated), entry of O_2 from outside is restricted. In the case of vacuum packaged fresh meat, CO_2 increases to 10-20% within the package as the respiration of the meat quickly consumes the residual O_2.

Vacuum packaged fresh beef is unsuitable for the retail market because of the change in color of meat from red to purple (myoglobin → deoxymyoglobin due to the low O_2 level), which is considered unacceptable by the consumer. This is a reversible reaction, but the formation of the oxidation product metmyoglobin (brown) does occur to

a small extent and is less easily reversed as time of storage increases. These changes also take place in pork but are less noticeable. Also, there is accumulation of exudate during prolonged storage of meat in vacuum packs and is probably related to the lack of package headspace (Parry 1993).

2.2.3.2 Vacuum skin packaging (VSP)

In VSP, a vacuum is used to apply a thermoformable film (softened by heating) as a skin over the meat placed on a rigid backboard (Shay and Egan 1986). This method promotes longer storage life of meat depending on meat species and muscle pH because exudate development and precipitation of denatured meat pigment on the meat surface is not so pronounced as in the regular vacuum packages. However, dark meat color is more noticeable in meat cuts using VSP. Its application is more popular for consumer packages of cured meat products where color differences are not as apparent.

2.2.3.3 Gas packaging

Gas packaging can be done either by mechanical replacement of air with gas mixtures or by generating the atmosphere within the package (passively or actively by using suitable atmosphere modifiers such as O_2 absorbents). The latter are not very effective for this application. Mechanical air replacement can be done either by gas flushing or by compensated vacuum (Parry 1993). Gas flushing is usually performed on a form-fill-seal machine by injecting a continuous stream of gas into the package to replace the air. After removal of most of the air, the package is sealed. In the compensated vacuum process, a vacuum is first created in a preformed or thermoformed

container holding the food and then the desired gas or gas mixture is introduced. Gas-flushing techniques can be very fast and lend themselves to continuous operation. Ordinarily, O_2 levels in gas-flushed packs are 2-5%, and therefore are not suitable for packaging O_2-sensitive foods. For longer term storage of fresh meats, more sophisticated flushing systems are used to reduce O_2 levels to ≤300 ppm (e.g., Captech®, AuckLand, New Zealand).

2.2.3.4 Master packs

Master packaging involves placement of MAP products (wrapped in a permeable film) into a gas impermeable package in a manner that eliminates O_2 from the atmosphere surrounding meat (Bailey et al. 1997). The MAP packaged products are placed in the impermeable package prior to shipping (the internal atmosphere can be up to 100% CO_2, minimizing the growth of microorganisms). The gas impermeable barrier is removed at the retail level resulting in the development of a desirable bright red color of meat due to the entry of O_2 into the permeable package. Master packs must be coupled with an excellent temperature control system during distribution (-1.5±0.5°C) to achieve optimal shelf life extension of meat cuts.

2.3 Microbiological and Sensory Characteristics of Meat

Borch et al. (1996), Kraft (1986), Gill (1985, 1995), Offer and Knight (1988), and Stiles (1991) have reviewed the microbiology and techniques used in the meat industry for shelf life extension. Microbial growth is caused by a combination of intrinsic and extrinsic factors. The intrinsic factors are related to the food (chemical and

physical composition of food, water activity (a_w), pH, O_2-reduction potential, and natural factors inhibitory to bacteria that are present in food). The extrinsic factors are related to the environment surrounding the food (storage temperature, packaging, gas atmospheres, preservatives, cleaning, disinfection, and hygiene). These factors influence survival or growth of microorganisms in the food. By manipulating these factors, "hurdles" can be created to prevent microbial growth (Scott 1989). For MAP foods, refrigeration or strict temperature control at temperatures close to those causing freezing is an important hurdle assuring product quality. This is because psychrotrophic bacteria can grow at temperatures lower than -2°C where most meat freezes. Adequate refrigeration must be maintained throughout the food distribution system.

Good sanitation practices during slaughter control the extent of surface contamination because the exterior of animals is often heavily soiled (Ayres 1955; Jeremiah and Gibson 1997a). Chilling of meat creates a selective environment which favors the growth of psychrotrophic strains of microorganisms (Stiles 1991). Psychrotrophic bacteria have optimum growth temperatures of 25-30°C but they can grow at <5°C and even at -3°C (ICMSF 1980). Psychrotrophic fungi cannot grow if relative humidity is <80%, but storage of carcasses in relatively dry conditions is not favored because of some loss in the sensory quality of meat (ICMSF 1980). Composition of the gas atmosphere creates an environment for selective growth of microbes on meat. Growth of Gram negative, rod-shaped bacteria like *Pseudomonas*, *Moraxella*, and *Acinetobacter* spp. is favored by aerobic, chilled storage (Ayres 1955,

1960). Off-flavor develops at 10^7 cfu of bacteria per cm^2 of meat. Under reduced O_2 and high CO_2 conditions, growth of aerobic spoilage bacteria is discouraged, while that of slower growing spoilage bacteria, like *Lactobacillus* is encouraged (Roth and Clark 1972). Microflora change from aerobic to anaerobic organisms in the packaged meat is the main factor extending the storage life of vacuum and modified atmosphere packaged meat with high levels of CO_2. Benedict et al. (1975) reported that LAB do not produce off-flavors or off-odors in vacuum packaged meat stored at 0 to 5°C as quickly as the aerobic spoilage microflora and myoglobin conversion to metmyoglobin is delayed. Gill (1988a) suggested that red meats (prepared with high hygiene standards) in saturated levels of 100% CO_2 in a gas-impermeable film, packaged using the Captech® system, and stored at -1.5°C can have a storage life of up to 6 months. Anaerobically, spoilage is often not noticed until bacteria reach $>10^8$ cells/cm^2.

2.3.1 Microbiological and sensory evaluation of centrally packaged retail meat cuts

Several researchers have studied effects of different compositions of gases on the microbiological and sensory quality of meat during centralized meat packaging. Shay and Egan (1986) used MAP for extending retail storage life of beef and lamb. They stored meat under 80% O_2 and 20% CO_2 at 5°C and found that storage life was three times better than the storage life in conventional overwrapped trays. They also noted that in most situations, storage life was limited due to poor color rather than by excessive microbial growth. Also, storage life was dependent on muscle type, species, and length of time meat had been stored previously in vacuum. Pork color was more stable than

beef or lamb in response to low levels of O_2 (Penney and Bell 1993).

Scholtz et al. (1992) examined the potential value of prepackaging pork centrally by comparing the retail shelf life of pork loin chops packaged under an atmosphere of 25% CO_2 plus 75% O_2 with parallel samples packaged using the vacuum skin technique (VSP) and with PVC overwrapped (essentially aerobic) samples as controls. All samples were stored at 0°C for up to 21 days. Results from this group of trials were compared with those from similarly prepared retail packaged chops placed on PVC overwrapped trays that were packaged in groups of 6 in a master pack sealed following an application of a 100% CO_2 atmosphere. Samples stored using either VSP or 25% CO_2 plus 75% O_2 were acceptable 7 days after packaging and retail display. Microbiological results were similar to those obtained from conventionally packed PVC overwrapped trays at only 4 days of storage at 0°C. The 100% CO_2 treatment yielded the most promising results with samples stored safely for 21 days and capable of 4 days subsequent retail display. Shelf life was limited by color acceptability.

In an attempt to improve pork color stability following suggestions by Taylor (1990), Buys et al. (1993a) included O_2 at 25% or 80% in PVC wrapped retail pork chop packages and overwrapped these with barrier bags having an O_2 transmission rate (OTR) of 39 mL/(m^2 24 h) at 1 atm, 23°C, and 75% RH. These were subsequently back flushed with either 100% CO_2 or 25% CO_2:50% N_2:25% O_2. No significant differences were seen following 21 days storage and samples achieved 2 days subsequent acceptable retail display. A trend to greater meat pigment instability was seen in high O_2-containing PVC

overwrapped packages. Buys et al. (1993b) then explored the use of either vacuum or 100% CO_2 to preserve unsliced pork loins for up to 21 days at 0°C or 5°C and evaluated the subsequently sliced loin chops for color and microbiological condition during retail display, again in PVC overwrapped trays. Chops prepared from loins stored at 0°C for 21 days were still acceptable 4 days after retail display. Initial packaging treatments did not yield different retail shelf life. It is unfortunate that barrier bags used to simulate master packs in the trials by Buys et al. (1993a, b) and Scholtz et al. (1992) had OTRs significantly greater than the ≤ 15 mL/(m^2 24h) at 1 atm, 23°C and 75% RH currently used to create an acceptable O_2 barrier. Results from these studies did not clearly demonstrate effects that could be attributed to differences in package atmosphere composition.

Gill and Penney (1988) studied the effect of initial gas volume to meat mass ratio and pH on the storage life of chilled beef packaged under CO_2. They reported that *Enterobacteriaceae* fractions were larger in number on high pH (>6.0) meat than on normal pH meat (5.5-5.7) during storage at 1°C. Grau (1981) reported that *Enterobacteriaceae* were unable to grow on muscle tissue of normal pH under anaerobic conditions. Later, Grau (1983) and Vanderzant et al. (1986) observed that *Enterobacteriaceae* show slow growth on vacuum packaged, normal pH muscle tissue in packs that were prepared using film of low, but measurable O_2 permeability. Gill and Penney (1988) reported that all vacuum packaged meat was spoiled by putrid flavors (high pH meat was spoiled at 7 weeks and normal pH meat at 12 weeks). They also

reported that the increasing amount of added CO_2 progressively retarded putrid spoilage (due to slow microbial growth rate) while the relative number of LAB in the flora was enhanced. This was due to the inhibitory effect of CO_2 on Gram negative organisms on both normal and high pH meat because CO_2 extends the lag phase of microbial growth. The LAB dominate these environments at low temperatures and form less offensive metabolic by-products than organisms of other genera. This study showed that CO_2 can greatly extend the shelf life of packaged chilled meat but saturating levels of CO_2 are required for extended storage of these products (about 2 L CO_2/kg meat).

Gill and McGinnis (1993) studied the changes in microflora on commercial beef trimming during collection, distribution, and preparation for its retail sale as ground beef, using current Good Manufacturing Practices (GMPs). They reported that during storage up to 18 days before grinding, meat trimmings developed a LAB flora of up to 10^7 cfu/g, which would spoil within 3 days if packaged in O_2 permeable film and stored under refrigeration conditions (5-7°C). They mentioned that two factors which govern the degradation of ground beef prepared with current GMPs are (i) delayed grinding of meat as it is dependent upon the wholesalers' and retailers' requirements, which results in high microbial numbers in freshly ground beef, and (ii) loss of temperature-control of retail-ready product. They concluded that current GMPs are not adequate for proper control of spoilage and pathogen-growth. Therefore, they recommended centralized meat distribution systems for retail- ready cuts and strict control over storage and distribution temperature for extending the shelf life of meat.

Gill and Jones (1994a) compared the display life of retail ready beef steaks using vacuum packaging (-1.5°C) or master packing (2°C) under various gas atmospheres of N_2, CO_2, or $O_2 + CO_2$. The product was assessed after a storage time of 60 days. At each assessment, a vacuum package and a master pack were withdrawn from storage. Three retail packs were prepared from vacuum packaged meat and were displayed with retail packaged meat from a master pack in a retail cabinet, at air temperatures between 3-5.7°C. Steaks from vacuum packaged product were considered desirable, with little metmyoglobin in the surface pigment. Numbers of bacteria on steaks from vacuum packs and N_2, CO_2, $O_2 + CO_2$ atmospheres were $<10^4$, $<10^6$, $<10^5$, and $<10^4$ cfu/cm^2, respectively. The flora from steaks stored under CO_2 were composed entirely of LAB. Small fractions (<5%) of *Enterobacteriaceae* and *Brochrothrix thermosphacta* were present in the steak prepared from vacuum packaged product stored for 39, 46, or 53 days. Large fractions (>20%) of *Enterobacteriaceae* or *B. thermosphacta* were present in the flora of steaks stored under $O_2 + CO_2$ atmospheres for 8, 12, or 20 days. They suggested that master packs would minimize the deterioration of meat. The numbers attained by spoilage flora on steaks under CO_2 were insufficient to cause organoleptic effects. They concluded that master packs under CO_2 could be an appropriate technique for extending shelf life of beef for up to 7 weeks and is useful when distribution involves < 4 days.

Holley et al. (1993, 1994a, b) did microbiological analysis of CO_2-packaged retail ready pork. They stored wrapped boneless pork loin roasts and slices at 4°C in bulk under constant CO_2 concentrations of 50% and 100% for one and two weeks. In both treatments, levels of psychrotrophs, mesophiles, and LAB were $\leq 10^4$ cfu/cm^2 during the initial two weeks storage under CO_2. *Enterobacteriaceae* were $\leq 10^2$ cfu/cm^2 in all samples but *Brochrothrix* were one log higher in 50% CO_2-stored samples than in 100% CO_2-stored samples at 14 days. They concluded that samples stored under 50% CO_2 and 100% CO_2 for two weeks could be aerobically displayed subsequently without being unacceptable for three and six days, respectively. Earlier, Spahl et al. (1981) and Greer et al. (1993) also reported long shelf life of pork stored under saturated atmospheres of CO_2. Jeremiah et al. (1992a) showed that a master pack system where high levels of CO_2 and very low levels of O_2 are maintained at chill temperatures, can extend shelf life of pork up to 15 weeks.

Holley et al. (1994a, b) examined the microbiological, biochemical, and physical characteristics of fresh pork loin slices packaged under 100% N_2, 100% CO_2, and 50% N_2 + 50% CO_2 at storage temperatures of -1°C and 4°C in reusable, gas impermeable metal boxes. They found that samples stored under N_2, CO_2, and N_2-CO_2 atmospheres gave shelf lives of 18, 21, and 21 days, respectively at 4°C and shelf life was improved by three to four days at -1°C. They also concluded that physicochemical characteristics do not limit the shelf life of pork. Earlier, Gill (1988a, b) reported that during prolonged storage (20-24 weeks) under vacuum or CO_2, chilled red meats become very tender, lose

desirable texture characteristics, and also develop liver-like aged flavors highly objectionable to some consumers. Jeremiah et al. (1992b) studied the effect of prolonged storage under vacuum or CO_2 on the flavor and texture profiles of chilled pork at -1.5°C. Jeremiah et al. (1992a, b) found that all vacuum packaged samples showed 10^7 cfu/cm^2 of bacteria at 18 weeks and no adverse sensory changes were noted until week 15, after which off-odors were noted. For samples packaged under CO_2, the maximum number of LAB (10^5 cfu/cm^2) was obtained after 18 weeks and this figure was not exceeded even after 24 weeks storage. Samples stored for 6 and 21 weeks gave the highest flavor and texture scores. This study showed that pork is resistant to autolytic and oxidative deterioration during prolonged chilled storage in vacuum or CO_2. Thus, chilled pork could be stored up to 18-24 weeks at -1.5°C.

Jeremiah and Gibson (1997a) studied the influence of different packaging atmospheres upon shelf life of retail ready pork cuts. They used 100% N_2, 100% CO_2 and a mixture containing 70% O_2 and 30% CO_2. They suggested that 20 days storage life would provide the opportunity to prepare and distribute centrally packed retail ready cuts to North American customers and yield satisfactory retail display. Tests were conducted at -1.5, 2, or 5°C storage in master packs for up to 28 days followed by 30 h aerobic chilled display at 6.8°C. All three packaging atmospheres and storage temperatures yielded similar results with some differences noted in terms of texture and flavor as a result of treatments. They concluded that storage life of those products was limited by growth of LAB and implied that use of pork with low initial numbers of bacteria would

yield consistent success in satisfying consumer quality requirements. They concluded that either 100% N_2, 100% CO_2, or a mixture of 70% O_2 plus 30% CO_2 should be satisfactory for centralized distribution of retail ready pork cuts. Storage temperatures of up to 5°C would be somewhat satisfactory but consistent satisfactory performance would be achieved under 100% CO_2 with storage at -1.5°C to retard growth by LAB which limited product shelf life.

2.3.2 Detrimental effects of residual oxygen (O_2) on the color stability of beef

Although research has been done on microbiological and sensory aspects of meat during centralized meat packaging under various modified atmospheres, problems regarding color stability of beef remain to be answered. A bright red color is desired for retail sale of beef, but due to the presence of low residual O_2 concentration, beef-color is initially degraded even under controlled atmospheres of CO_2 or N_2 (O'keefe and Hood 1982). Gill and Jones (1994a), during their study on the display life of retail-packaged beef steaks under various master pack atmospheres, reported that the color of beef-steaks was degraded by short storage under N_2 or CO_2. The reason offered was the formation of metmyoglobin at the surfaces of steaks by the scavenging-action of the myoglobin toward the residual oxygen in the nominally anoxic atmospheres (Ledward 1970). Metmyoglobin formed has to be reduced by the metmyoglobin-reducing activity (MRA) of the muscle tissue before the steaks can bloom in air to a desirable color (Gill and Jones 1994a; O'Keeffe and Hood 1982). Gill and Jones (1994a) also reported that more than 2 days were required for the reduction of sufficient metmyoglobin to achieve a desirable

color. Such a condition is highly undesirable for commercial conditions, where rapid distribution of centrally packaged beef cuts will be periodically required. Due to uncontrollable discoloration (although transient), the overall advantage of centrally packaged retail beef cuts using oxygen-depleted master packaging technology is limited. Gill and McGinnis (1995a) studied the effects of residual oxygen concentration and temperature on beef color degradation under O_2-depleted atmospheres. They used controlled atmospheres of N_2 or CO_2 and varied O_2 concentrations (100-1000 ppm) to prepare retail-ready beef cuts (*longissimus dorsi*, LD or *psoas major*, PM), and stored them at 5, 1, 0 or -1.5°C for times between 4 and 48 h. Overall, the LD samples stored at -1.5°C for 48 h ($O_2 < 400$ ppm) had the lowest metmyoglobin formation. They concluded that beef of high color stability (LD) was least susceptible to metmyoglobin formation if atmospheres contained < 600 ppm of O_2 at temperatures < 0°C. In contrast, beef of low color stability (PM) degraded even at low O_2 concentrations irrespective of storage temperatures, which contradicted conclusions drawn by Penney and Bell (1993). To provide a solution to the transient degradation of ground beef color, Gill and McGinnis (1995b) performed a study using commercially available oxygen scavengers (FreshPax®, Multiform Desiccants, Inc. Buffalo, NY). They determined the rates of O_2 absorption by individual scavengers and reported that the transient discoloration could be prevented by these scavengers at -1.5°C if large numbers were used in each package.

Sorheim et al. (1995b) also studied the color stability of beef stored under vacuum or CO_2 with commercial O_2 scavengers (Ageless®, Mitsubishi Gas Chem. Co. Inc., Tokyo, Japan). One O_2 scavenger, Ageless FX-100®, was inserted in each bag with CO_2. After packaging, the bags with CO_2 (initial CO_2 to meat ratio was more than 1.5:1 by volume) had O_2 concentrations <0.5%, and after 3 days storage no O_2 was detected in packages with O_2 scavengers. As discussed before, in a typical CO_2 environment, low O_2 concentrations are expected to facilitate greyish brown metmyoglobin formation. When all the O_2 is consumed (by O_2 scavengers), the metmyoglobin should change back to dark red deoxymyoglobin, due to reducing activity in the muscle. This conversion of muscle pigment in CO_2 packaged beef may take up to 48 h (Gill and Jones 1994a). A study by Sorheim et al. (1995b) also showed an increase in a^* values (redness) (L, a, b convention used are as per HunterLab colorimeter, Detroit, MI) on the beef loin sections from day 1 to 3 of storage (muscle pigment conversion). However, they were unable to explain the discoloration of beef stored under high CO_2 atmosphere, even with an oxygen scavenger and suggested that exposure to low O_2 concentrations during the early storage period (3 days) may irreversibly damage the beef color. However, they did not examine whether the rate of O_2 absorption by the scavenger was constant or varied with time and O_2 concentration. Also, only one O_2 scavenger was placed in the bag, which might not be enough to absorb O_2 at a higher rate as suggested by the manufacturers' literature (Gill and McGinnis 1995b). In addition, the ratio of CO_2 to meat used was around 1.5:1 whereas the recommended ratio is at least 2:1 (Gill and Penney 1988).

2.4 Distribution Systems for Centrally Packaged Retail Meat Cuts

Although master pack technology for centralized meat packaging exists, an efficient meat distribution system having strict temperature control to maximize product quality is still needed. Gill and Jones (1992) studied the efficiency of a commercial process for the storage and distribution of vacuum packaged beef. They used a time-temperature integration technique to assess the microbiological consequences of temperature regimes to which the product was exposed. This technique involved the collection and integration of appropriate product temperature histories with respect to models describing the effect of temperature on the growth of microorganisms of concern (Gill 1986). Their data showed that the product would achieve on average only about 25% of the potential storage life due to the failure in equilibrating product to near the optimum storage temperature before the product was loaded to transport. They used the models developed by Gill et al. (1988) to assess the remaining storage life of chilled red meats from product temperature histories. The loading of product to transport when product temperatures were above the optimum affected the storage life in transit because refrigerated transport systems are designed to maintain product temperature not to reduce the temperature within loads (Scrine 1985). Gill and Jones (1992) examined a typical North American vacuum packaged beef handling process where product temperatures of 2°C are considered satisfactory (Savell 1986), but not achieved when speedy dispatch of product is a management priority. This rapid dispatch results in the failure to properly control product temperature and gives only about 25% of potential storage life of

product, provided that trailer refrigeration systems function adequately during product transport. If product temperature is adequately controlled, such product can attain a storage life of about 12 weeks (Gill and Penney 1988; Johnson 1974).

Woolfe (1992) has given a detailed description of temperature monitoring and measurement techniques during meat distribution. He reported that liquid N_2 cooled transport vehicles were much quieter and had better temperature control than mechanically refrigerated vehicles. However, an adequate supply of liquid N_2 is required for shipping which can limit the range and number of stops these non-mechanically refrigerated trucks can make. Recently, Bailey et al. (1997) designed a refrigerated chamber using liquid N_2 for distributing centrally-packaged retail meat cuts. They discussed the advantages of liquid N_2 as a refrigerant over mechanical systems, but also pointed out the liquid N_2 usage for maintaining the product temperature in a narrow range (-1.5±0.5°C) was not economically feasible. They used fans for uniform distribution of liquid N_2 within the chamber. The heat generated by the fans resulted in more demand for liquid N_2 than is necessary. This work was extended in the Department of Biosystems Engineering using different techniques, e.g., using one fan with motor placed outside for distributing liquid N_2 in the chamber (Habok 1999). This design resulted in reduced variable N_2 use of 4.8 kg/h compared with 5.5 kg/h, obtained with the design of Bailey et al. (1997) at 30°C outside temperature. In parallel, the concept of a jacketed design was pursued (Jeyamkondan 1999). The jacketed design required 4.3kg/h liquid N_2 to maintain uniform temperatures in the container at 30°C outside temperature.

The container required further testing using master-packaged meat cuts which was done in the present study.

3. OXYGEN ABSORPTION KINETICS OF OXYGEN SCAVENGERS

3.1 Summary

The oxygen (O_2) absorption kinetics of six commercial O_2 scavengers were determined. The scavengers were placed in bags, which were filled with 240 mL of air, 4.5 L N_2 + 15 mL of air, or 3.5 L CO_2 + 9 mL of air. The O_2 concentration in each bag was measured at hourly intervals for 8 h. The effects of variability among individual scavengers, nominal initial O_2 concentrations of 20% and 500 ppm, temperatures of 25, 12, 2, and -1.5°C, and scavenger capacity on the O_2 absorption rate were quantified. In addition, the effect of placing scavengers within over-wrapped trays within bags, was determined. Substantial variation in O_2 absorption rates existed among individual O_2 scavengers of the same type, with O_2 half-lives having a range from 2.8 to 4.6 h. The O_2 half-lives were longer at low temperatures than at higher temperatures, e.g., O_2 half-lives of 7.1 and 1 h at -1.5 and 25°C, respectively, were obtained for one scavenger-type. Shorter O_2 half-lives were obtained in air than in N_2 atmospheres at the same temperature, e.g., O_2 half-lives of 1 and 3.3 h in air and N_2, respectively, were obtained for one scavenger-type at 25°C. The O_2 absorption reactions were first-order for both high and low initial O_2 concentrations. Scavengers, when placed within over-wrapped trays within bags had up to eight times longer O_2 half-lives, indicating that the O_2 permeable film acts as a O_2 barrier when pack atmosphere has low O_2 concentrations. To obtain consistent and reproducible results, it is recommended that multiple scavengers be used in packaging systems. The appropriate number should be based on scavenger-type, desired O_2 absorption rate, storage temperature, and pack atmosphere (air/N_2/CO_2).

Keywords O_2 scavengers, O_2 absorption kinetics, Arrhenius equation, food preservation.

3.2 Introduction

Oxygen scavengers have been used for food preservation for the last 20 years. The purpose of O_2 scavengers is to create low O_2 atmosphere in sealed packs of products, thereby slowing or preventing deterioration due to oxidation of product components and/or growth of microorganisms or survival of insects (Anonymous 1998). Oxygen scavengers are extensively used in Japan to prevent: discoloration of cured meats and teas, rancidity problems in high fat foods, and mold spoilage of intermediate and high moisture bakery products; in the USA, they are used to delay oxidative flavor changes in coffee and to prevent mold growth, rancidity, and staling in bakery products (Smith et al. 1995). Their use for the preservation of color and flavor and the prevention of microbial spoilage in cooked, cured meats has also been reported (Smith et al. 1995).

The current uses of O_2 scavengers generally involve packs in which the atmosphere contains some substantial fraction of O_2, if not air at the time of pack sealing, and the inhibition of chemical reactions or proliferation of microorganisms that proceed relatively slowly. Consequently, commercial O_2 scavengers are designed to remove a specified amount of O_2 from a relatively high O_2 atmosphere over periods of a day or more. The rate of O_2 absorption has then not been a principal concern in the design of commercial O_2 scavengers. However, there may be applications for O_2 scavengers where the rate of O_2 absorption is of prime importance. For example, meat packaged under O_2-depleted, controlled atmospheres discolors in the presence of the low O_2 concentrations in the initial atmospheres of such packs (Gill and Jones 1994a, b).

The discoloration resolves after 2 or 3 days, when the meat has stripped all O_2 from the pack atmosphere. However, such transient discoloration may be disadvantageous in some circumstances, such as in the use of controlled atmospheres to preserve centrally prepared master packaged, retail-ready meat when some of the meat may have to be displayed a short time after master packaging (Gill and Jones 1994a, b; Gill and McGinnis 1995a). To prevent transient discoloration, the O_2 concentration has to be reduced to < 10 ppm within 2 h when the storage temperature is -1.5°C, and more rapidly at higher temperatures (Gill and McGinnis 1995b). Effective reduction of O_2 concentration at higher temperatures might be possible with the appropriate O_2 scavenger.

The O_2 absorption rates of O_2 scavengers may vary with the nature of their reactants and other materials used in their construction. Rates of absorption may also be affected by factors such as temperature and the compositions of the atmospheres to which they are exposed. Therefore, to identify commercial O_2 scavengers that might be suitable when rapid removal of O_2 from pack atmospheres is required, the O_2 absorption kinetics of six commercial O_2 scavengers were determined experimentally. The effects of initial O_2 concentrations, temperature, and scavenger capacity on O_2 absorption rates were quantified.

3.3 Materials and methods

3.3.1 O_2 scavengers

The O_2 scavengers which were evaluated were: Ageless® FX-100 (Mitsubishi Gas Chemical Co. Inc., Tokyo, Japan); FreshPax® M-100, R-300, and R-2000 (Multiform Desiccants Inc., Buffalo, NY); and Bioka® S-75 and S-100 (Bioka Ltd., Kantvik, Finland). Their characteristics are given in Table 3.1.

3.3.2 Absorption of O_2 by scavengers

Oxygen scavengers were placed in bags composed of a laminate of polyester, oriented nylon, and an EVOH/EVA coextrusion (ESOPAEV2E 121575 R, WinPak, Winnipeg, MB, Canada), with an O_2 transmission rate of 0.55 mL/(m^2 24 h) at 1 atm, 23°C, and 70% RH. The bag size was 550 x 440 mm. Bags containing scavengers were either emptied of air by flattening each bag around the scavengers it contained, or were evacuated and then filled with a known volume of N_2 or CO_2, using a controlled atmosphere packaging (CAP) machine (CAPTRON® Model# ZR897, Securefresh Pacific Limited, Auckland, New Zealand), before being sealed. Then, a quantity of air was injected into each bag using a gas-tight syringe (Model#8881-114030, Sherwood Medical, Bally-money, North Ireland) inserted through a stick-on septum (Modern Controls Inc., Minneapolis, MN, USA). Immediately after the injection of air, the puncture point was sealed using a hot iron. Each filled bag was stored at room or a constant temperature. Samples (8 mL) of the atmosphere in each bag were obtained every hour for 8 h by means of a gas tight syringe inserted through a stick-on septum. If no substantial O_2 absorption was noticed within 8 h, samples were taken after every 12 h

for up to 48 h. Immediately after each sampling, the O_2 concentration in the sample was determined using an O_2 analyzer (Mocon MS-450, Modern Controls Inc., Minneapolis, MN) with a zirconium oxide sensor, and the puncture point was then sealed using a hot iron. The specifications and calibration steps for the O_2 analyzer are outlined in Appendices A-1 and A-2, respectively.

To determine the effect of variability among individual O_2 scavengers on rates of O_2 absorption, an Ageless® FX-100 scavenger on a moist absorbent pad (MP-30620, Paper Pak® Corp., La Verne, CA), was placed in each of five bags. Each bag was emptied of air and sealed, then 240 mL of air was injected into each bag. The bags were stored at room temperature. Five bags each with a FreshPax® R-300 scavenger, five bags each with a Bioka® S-100 scavenger, and five bags each with a FreshPax® R-2000 scavenger, were similarly prepared.

To determine the effect of temperature and initial O_2 concentrations on O_2 absorption rates, four Ageless® FX-100 scavengers on a moist absorbent pad (MP-30620, Paper Pak® Corp., La Verne, CA) were placed in each of six bags. The scavengers, in their original sealed package, were held overnight at room temperature for temperature equilibration. Three of the bags were emptied of air and sealed, then 240 mL of air was injected into each. The other three were each filled with 4.5 L of N_2 before being sealed, then 15 mL of air was injected into each. The bags were stored at 25°C. Three similar groups of six bags were prepared and stored at 12, 2, or -1.5°C. Four sets of six bags, with each bag containing four scavengers of the same type (Bioka® S-100, FreshPax® R-300, or FreshPax® M-100 scavengers), were similarly prepared and

stored. Three sets of six bags, with each bag containing four FreshPax® R-2000 scavengers were similarly prepared and stored at 25, 2, or -1.5°C. In a similar fashion, one set of six bags, with each bag containing four Bioka® S-75 scavengers was prepared and stored at 25°C. In addition, four sets of three bags, with each bag containing four FreshPax® M-100 scavengers were prepared. Each bag was filled with 3.5 L of CO_2 and sealed. Then, 9 mL of air was injected into each bag. A set of bags was stored at 25, 12, 2, or -1.5°C.

To characterize O_2 absorption when O_2 scavengers were placed inside overwrapped retail trays within master packs, a retail tray (clear plastic tray # 2D, Western Paper & Food Distributors (Intl') Ltd., Calgary, AB) overwrapped with a film of O_2 transmission rate 8000 mL/(m^2 24 h) at 1 atm, 25°C and 70% RH (Vitafilm 'Choice Wrap', Goodyear Canada Ltd., Calgary, AB), containing four FreshPax® R-300 scavengers was placed in each of six bags. A 5 mm hole was made at one corner of the overwrapped film to allow free exchange of atmospheres during gas flushing. Three bags were emptied of air and sealed, then 240 mL of air was injected into each. The other three bags were each filled with 4.5 L of N_2 to which 15 mL of air was added by injection. The bags were stored at 25°C. Similarly, three bags, each containing a retail tray with four Ageless® FX-100 scavengers on a moist absorbent pad and 240 mL of air, were prepared and stored at 25°C.

3.3.3 Data analysis

The half-life of O_2 in a pack atmosphere was calculated as the time required for the O_2 concentration in the pack atmosphere to be reduced to half the initial value. The half-life was calculated from the volumes of O_2 present at successive time intervals during the storage of the pack. In calculating volumes of O_2 absorbed from atmospheres of air by the scavenger, the initial volume was taken to be 240 mL added to the pack plus x mL of residual air. Residual air in the emptied bag was measured as the volume of water displaced by the emptied bag. The volumes of O_2 in the pack at any period was calculated as the volume of atmosphere at the end of the period multiplied by the concentration of O_2 in the atmosphere at the end of the period. The volume of atmosphere at the beginning of each period was taken to be the volume of atmosphere at the beginning of the previous period less the volume of the atmosphere removed as a sample at the end of the period and the volume of O_2 calculated as having been absorbed during the previous period. The volume of O_2 absorbed during a period was calculated as the volume of atmosphere at the start of the previous period multiplied by the concentration of O_2 in the atmosphere at the beginning of the period less the volume of atmosphere at the start of the period multiplied by the concentration of O_2 at the end of the period. In calculating the volumes of O_2 remaining in the pack in atmospheres of N_2 or CO_2 to which air was added, the volumes of the atmosphere removed during sampling and the volumes of O_2 absorbed during a sampling period were assumed to be negligible.

To determine the order of reaction, plots were prepared of the natural logs ($\log_n$) and the reciprocals of the volumes of O_2 remaining in the pack atmosphere against time. If the $\log_n$ plot approximated a straight line, the reaction was regarded as first order. If the reciprocal plot approximated a straight line, the reaction was regarded as second order. Rate constants were calculated using the following equations (Brown et al. 1994): for first-order reactions:

$$\ln[A]_t = -kt + \ln[A]_0 \qquad (2)$$

and for second-order reactions:

$$\frac{1}{[A]_t} = kt + \frac{1}{[A]_0} \qquad (3)$$

where, $[A]_t$=amount of reactant A at time t (h),

k= the rate constant (h^{-1}), and

$[A]_0$=the initial amount of reactant.

Frequency factors and activation energies were calculated from the Arrhenius equation in the form (Brown et al. 1994):

$$\ln(k) = \left(\frac{-E_a}{R}\right)\left(\frac{1}{T}\right) + \ln(A)$$

where, A=frequency factor (frequency of collisions),

E_a=activation energy (J/mol),

R=universal gas constant (8.314 J/(mol. K)), and

T=temperature (K).

3.3.4 Validation of constants for Arrhenius equation

Validation of the experimentally determined constants for the Arrhenius equation was performed using FreshPax® R-300. Four FreshPax® R-300 scavengers were placed in each of six bags. Three bags were each emptied of air and sealed, then 240 mL of air was injected into each bag. The other three bags were each filled with 4.5 L of N_2 to which 15 mL of air was added. The bags were stored at 7°C, and the O_2 concentrations were measured at hourly intervals for 8 h. The volume of O_2 in the pack atmosphere containing FreshPax® R-300 scavengers at every hour at 7°C was also calculated using the previously determined constants from the Arrhenius equation.

3.4 Results

The residual O_2 in each bag which were emptied of air was 1.5 ±0.5 mL. With a single scavenger in each bag, the half-lives of O_2 in bags containing air differed up to 2 h (Figs. A1, A10, A33, A40), whereas, when four scavengers were placed in each bag (Figs. A2, A11, A34, A41), the O_2 half-lives were not statistically different ($p>0.05$) at 25°C (among replicates) (Table 3.2). The O_2 absorption curves for different scavengers (4 in number unless otherwise mentioned) under different circumstances are given in Appendix A.

With four Ageless® FX-100 scavengers in bags containing air, the O_2 half-life was four times longer at -1.5°C than at 25°C (Figs. A2 and A8), but with four such scavengers in bags containing N_2 atmospheres, the half-life at -1.5°C was only double that at 25°C (Figs. A3 and A9; Table 3.3). The O_2 half-life in bags containing air and four Bioka® S-100 scavengers was seven times longer at -1.5°C than at 25°C (Figs. A41

and A50), but the O_2 half-life was only two and a half times longer at -1.5°C when compared with that at 25°C with bags containing four such scavengers and N_2 atmospheres (Figs. A42 and A51). With four FreshPax® R-300 scavengers in bags containing air, there were no statistical differences ($p>0.05$) between O_2 half-lives at different temperatures (Figs. A11, A13, A15, and A17), but with four such scavengers in bags containing N_2 atmospheres the O_2 half-life was two and a half times longer at -1.5°C than at 25°C (Figs. A12 and A18). With four FreshPax® M-100 scavengers in bags containing air, the O_2 half-lives were longer than with other scavenger types (Figs. A21, A23, A25, and A27). The O_2 absorption rate was also relatively slow in the N_2 atmosphere (Figs. A22, A24, A26, and A28). However, in bags containing four scavengers and a CO_2 atmosphere, the O_2 half-lives were shorter compared with the half-life of O_2 in bags containing FreshPax® M-100 scavengers and air or N_2 atmospheres at the same temperature (Figs. A29, A30, A31, and A32).

With four FreshPax® R-2000 scavengers in each bag containing air, the average O_2 half-lives were 0.7, 0.8, and 0.8 h at 25, 2, and -1.5°C, respectively (Figs. A34, A36, A38). Similarly short O_2 half-lives of 0.9, 0.9, and 1.3 h at 25, 2, and -1.5°C, respectively (Figs. A35, A37, A39), were obtained in bags containing four FreshPax® R-2000 scavengers and N_2 atmospheres, which were statistically different ($p<0.05$) from that of FreshPax® R-300 under same conditions. With four Bioka® S-75 scavengers in bags containing air or N_2 atmosphere, the O_2 half-lives were 1.6 and 6.5 h, respectively, at 25°C (Figs. A44, A45).

When four Ageless® FX-100 scavengers were placed in an over-wrapped tray which was placed in a bag containing air, at 25°C, the O_2 half-life was ~6.0 h, which was eight times longer than when four such scavengers were placed directly in a bag containing air (Figs. A52 and A2). Similarly, O_2 half-lives were five and two times longer when four FreshPax® R-300 scavengers were placed in over-wrapped trays than when four such scavengers were placed directly in a bag containing air or N_2 atmosphere at 25°C, respectively (Figs. A19, A20, A11, and A12).

The O_2 absorption reaction was first-order for all the commercial O_2 scavengers. Rate-constants were therefore calculated from the first-order kinetics equations, and generally increased with increasing temperatures (Table 3.4). For Ageless® FX-100, Bioka® S-100, and FreshPax® R-300 scavengers, the rate constants for the O_2 absorption reaction were larger for air than for N_2 atmospheres at any temperature, and the rate constants tended to decrease with decreasing temperature (Table 3.4). However, for FreshPax® M-100, k was generally smaller for air than for N_2 or CO_2 atmospheres at the same temperature, although A_0 for air was generally larger. In most cases, the calculated and observed O_2 half-lives were not statistically different ($p>0.05$).

Constants for the Arrhenius equation for the various types of scavenger were obtained using the rate constants at different temperatures for each type of scavenger (Table 3.5). Upon validation of these constants for FreshPax® R-300 scavengers at 7°C, observed and calculated O_2 half-lives were 0.8 and 0.9 h, and 3.9 and 3.8 h in bags containing air and N_2 atmospheres, respectively (Figs. A55 and A56).

3.5 Discussion

Commercial O_2 scavengers are composed of powders in sachets of plastic-coated paper which is perforated to allow the ingress of O_2. The powder contains particles of non-uniform sizes, and materials placed in the pouches are rapidly mixed immediately before each sachet is filled, to limit O_2 absorption before pouch formation, which might reduce O_2 absorbing capacities of the scavengers. As mixing is likely to be imperfect and the film perforation is variable, incomplete reaction of these chemicals may occur. Considerable variability in the O_2 absorption rates among individual O_2 scavengers must be expected (Gill and McGinnis 1995b). Therefore, results are likely to be reproducible only when multiple scavengers are used for each test, and generalizations from previous studies which involved systems with single scavengers must be treated with caution (Sorheim et al. 1995a, b; Allen et al. 1996; Rousset and Renerre 1990; Doherty and Allen 1998; Isdell et al. 1999).

The O_2 concentrations affected the O_2 half-lives substantially for any scavenger-type resulting in longer O_2 half-lives for low initial O_2 concentration of 500 ppm in N_2 atmospheres than for high initial O_2 concentration of 200 000 ppm in air at the same temperature. The magnitude of such effects varied for different scavenger types depending upon their formulation. FreshPax® M-100 are designed for high CO_2 atmospheres, hence, generally longer O_2 half-lives were obtained in air and N_2 atmospheres than in CO_2 atmospheres.

It was proved from the kinetics data that the O_2 absorption reaction was first-order at both high (20% or 200 000 ppm) and low (500 ppm) initial O_2 concentrations. Due to the first-order nature of the O_2 absorption reactions, the limiting factor for O_2 absorption rates at both high and low initial O_2 concentrations is O_2 concentration. However, at high initial O_2 concentration other factors such as the scavenger's surface area and environment may also affect O_2 absorption rates. In contrast at low initial O_2 concentrations, diffusion-phenomena, which are derivatives of O_2 concentration, had the dominant influence as compared to surface area and environmental factors, and hence the low O_2 absorption rate. This is in accordance with Fick's Law of Diffusion which states that the rate of diffusion of a species in a given direction is proportional to the concentration gradient in that direction. Therefore, a threshold O_2 concentration exists where there is a dramatic decrease in O_2 absorption rate. Thus, O_2 concentration became the primary limiting factor for O_2 absorption rate in atmospheres having low O_2 concentration. This result was supported by Gill and McGinnis (1995b) who also reported that at concentrations of $< 1\%$, O_2 concentration is the limiting factor for O_2 absorption rates. Consequently, different rate-constants were observed for the same O_2 absorption curve at same temperature depending upon initial O_2 concentration. Therefore, the overall O_2 absorption curve produced by the scavenger will be bi-phasic with higher O_2 absorption rates at higher O_2 concentration followed by a substantial low O_2 absorption rate as a critical threshold O_2 concentration is reached.

Higher temperatures gave shorter O_2 half-lives and the reverse was also true. Generally, the rate constants increased with increasing temperature, as expected. However, the magnitude of the temperature effect was dependent upon the scavenger types due to the differences in their formulations. For some scavengers, the temperature effects on both O_2 half-lives and rate constants were more dramatic in air than in N_2 or CO_2 atmospheres. For others the reverse occurred, which may have been due to differences in their formulations.

The Arrhenius equation calculated for different scavengers may find an application in the computer simulation of varying O_2 concentrations in a package atmosphere at specific temperatures and at known initial O_2 concentrations. Such computer models may further be modified to predict possible deterioration of food products as related to the scavenger's O_2 absorption rate with a known initial microbial population and using a predictive modeling approach. However, a relationship between microbial growth and O_2 concentration needs to be determined. Another approach would be their use to consume O_2 that might permeate the package seal or film which otherwise would result in decreased shelf-life of O_2 sensitive food products, and enhanced scalping of flavor (due to increase in rate of food x packaging interactions). However, these areas require further research.

Oxygen scavengers with more capacity also tended to absorb O_2 at a higher rate than scavengers with less capacity, which was expected and was caused by increased surface area for O_2 absorption. Although scavengers with greater capacity have low formula weight per cm^2 than scavengers with less capacity, they undergo faster reactions

due to high collision-frequency of the reactant generating more heat, and this results in high O_2 absorption rates (Personal communication: Dr. Tom Powers, Research Scientist, Multisorb Technologies Inc., Buffalo, NY). However, measurements of heat generated were not done and this area also requires further research.

The effect of the positioning of scavengers within packs was also substantial, which suggests the film acted as an O_2 barrier at low O_2 concentrations despite its high O_2 permeability. Additionally, this barrier effect may increase with decreasing temperature. Consequently, the size of the hole in the lidding film was the limiting factor for O_2 absorption when retail trays were placed in a bag.

Due to significant ($p<0.05$) variation in O_2 absorption rates of commercial O_2 scavengers, their appropriate selection is of importance in situations where high O_2 absorption is initially required, as in prevention of transient discoloration of ground beef. Extreme care should also be exercised when selecting O_2 scavengers, since little information about their O_2 absorption rates is provided by the manufacturer, which can lead to misuse. Therefore, O_2 absorption rates of O_2 scavengers must be examined thoroughly in reference to specific requirements. Ageless® FX-100 or FreshPax® R-2000 scavengers had the highest O_2 absorption rates among the commercial scavengers used in the present study and may be used in situations where rapid removal of residual O_2 is required. However, due to significant positioning effects, contact with O_2 may be restricted. In the configuration of the system studied here, it was found that scavengers should be placed either inside the retail trays containing O_2 sensitive products or inside the retail trays as well as in the gas impermeable bags. Multiple O_2 scavengers should

also be placed in the package to obtain a consistent and reproducible O_2 absorption rate. Further, calculation of an appropriate number is based upon O_2 scavenger type, initial amount of O_2 present, storage temperature, and the desired O_2 absorption rate. The present study should serve as a guide for possible application of O_2 scavengers in situations where the rate of O_2 absorption is of primary importance.

Table 3.1 Manufacturers' specifications for O_2 scavengers*.

Name	Scavenging reaction	Capacity (mL O_2)	Features & suggested applications	Atmosphere (CO_2/Air/N_2)	Activating agent
Bioka® S-100	Enzyme mediated oxidation	100	-	Air/N_2	Self-activated
Bioka® S-75	Enzyme mediated oxidation	75	-	Air/N_2	Self-activated
Ageless® FX-100	Iron oxidation	100	For moist food; stable in air before use; excellent water resistance	Air/N_2	Moisture
FreshPax® M-100	Iron oxidation	100	For refrigerated applications; designed for modified atmosphere packaging of moist product	CO_2	Moisture
FreshPax® R-300	Iron oxidation	300	For refrigerated and frozen application; recommended for cases where rapid removal of O_2 is required	Air/N_2	Self-activated
FreshPax® R-2000	Iron oxidation	2000	For refrigerated and frozen application; recommended for cases where rapid removal of O_2 is required	Air/N_2	Self-activated

* All of the scavengers are designed for products with a water activity ≥ 0.85.
- Not given.

Table 3.2 Variability in O_2 half-life among single vs four O_2 scavengers of the same type in air at 25°C.

Scavenger-type	Half-life of O_2 (h)	
	Single O_2 scavenger	Four O_2 scavengers
Ageless® FX-100	1.8-2.5[++]	0.7[+] (0.05)[*]
Bioka® S-100	2.8-4.6	1.0 (0.03)
FreshPax® R-300	2.0-2.8	0.9 (0.04)
FreshPax® R-2000	0.9-1.6	0.7 (0.02)

[+] Average of three replicates.
[*] Standard deviation.
[++] Range of O_2 half-life.

Table 3.3 Half-life of O_2 in bags containing four scavengers and air, N_2, or CO_2 atmosphere.

Scavenger-type	Atmosphere	O_2 half-life (h)			
		25°C	12°C	2°C	-1.5°C
Ageless® FX-100	Air	0.7[+] (0.08)[*]	0.8 (0.07)	1.2 (0.06)	2.5 (0.02)
	N_2 + air	1.3 (0.08)	1.6 (0.03)	2.2 (0.03)	2.3 (0.02)
Bioka® S-100	Air	1.0 (0.08)	1.7 (0.03)	4.1 (0.04)	7.1 (0.03)
	N_2 + air	3.3 (0.04)	7.2 (0.05)	12.1 (0.05)	8.5 (0.05)
FreshPax® R-300	Air	0.9 (0.09)	0.9 (0.04)	0.9 (0.03)	1.2 (0.03)
	N_2 + air	2.6 (0.03)	3.1 (0.04)	4.4 (0.03)	6.1 (0.04)
FreshPax® M-100	Air	7.5 (0.8)	12.1 (0.7)	38.8 (0.8)	40.0 (0.8)
	N_2 + air	6.1 (0.6)	12.8 (0.8)	29.5 (0.9)	37.3 (0.9)
	CO_2 + air	5.0 (0.08)	12.0 (0.1)	18.0 (0.2)	21.8 (0.9)

[+]Average of three replicates.
[*] Standard deviation.

Table 3.4 Constants of first order kinetics equation for different scavengers.

Scavenger-type	Temp. (°C)	Atmosphere	Initial O_2 volume (mL)	Initial O_2 concentration (ppm)	Constants of first order kinetics equation[a]		Calculated O_2 half-life[b] (h)	Observed O_2 half-life (h)	Correlation coefficient (r^2)
					k (h^{-1})	A_0			
Ageless® FX-100	25	Air	50	200 000	2.46	3.94	0.3	0.7	0.72
	25	N_2 + air	2.25	500	0.35	0.51	1.8	1.3	0.92
	12	Air	50	200 000	1.82	3.96	0.4	0.8	0.96
	12	N_2 + air	2.25	500	0.36	0.61	1.9	1.6	0.98
	2	Air	50	200 000	0.69	3.61	1.0	1.2	0.99
	2	N_2 + air	2.25	500	0.25	0.79	2.7	2.2	0.99
	-1.5	Air	50	200 000	0.31	3.54	2.3	2.5	0.92
	-1.5	N_2 + air	2.25	500	0.26	0.76	2.7	2.3	0.99
Bioka® S-100	25	Air	50	200 000	0.56	3.34	1.2	1.0	0.99
	25	N_2 + air	2.25	500	0.20	0.88	3.5	3.3	0.99
	12	Air	50	200 000	0.40	3.62	1.7	1.7	0.99
	12	N_2 + air	2.25	500	0.09	0.84	7.7	7.2	0.99
	2	Air	50	200 000	0.20	3.45	3.5	4.1	0.99

Scavenger-type	Temp. (°C)	Atmosphere	Initial O_2 volume (mL)	Initial O_2 concentration (ppm)	Constants of first order kinetics equation[a]		Calculated O_2 half-life[b] (h)	Observed O_2 half-life (h)	Correlation coefficient (r^2)
					k (h^{-1})	A_0			
	2	N_2 + air	2.25	500	0.06	0.80	11.5	12.1	0.96
	-1.5	Air	50	200 000	0.08	3.72	8.7	7.1	0.98
	-1.5	N_2 + air	2.25	500	0.08	0.84	8.7	8.5	0.99
FreshPax® R-300	25	Air	50	200 000	1.04	3.60	0.7	0.9	0.99
	25	N_2 + air	2.25	500	0.35	0.94	2.0	2.6	0.95
	12	Air	50	200 000	0.99	3.60	0.7	0.9	0.99
	12	N_2 + air	2.25	500	0.23	0.87	3.1	3.1	0.99
	2	Air	50	200 000	0.91	3.80	0.8	0.9	0.98
	2	N_2 + air	2.25	500	0.18	0.82	3.9	4.4	0.99
	-1.5	Air	50	200 000	0.74	3.60	1.0	1.2	0.99
	-1.5	N_2 + air	2.25	500	0.15	0.86	4.7	6.1	0.99
FreshPax® M-100	25	Air	50	200 000	0.09	3.88	7.7	7.5	0.88
	25	N_2 + air	2.25	500	0.15	1.10	4.6	6.1	0.82

Scavenger-type	Temp. (°C)	Atmosphere	Initial O_2 volume (mL)	Initial O_2 concentration (ppm)	Constants of first order kinetics equation[a]		Calculated O_2 half-life[b] (h)	Observed O_2 half-life (h)	Correlation coefficient (r^2)
					k (h^{-1})	A_0			
	25	CO_2 + air	1.8	500	0.18	0.73	3.9	5.0	0.82
	12	Air	50	200 000	0.08	3.87	8.7	12.1	0.88
	12	N_2 + air	2.25	500	0.05	0.90	13.9	12.8	0.92
	12	CO_2 + air	1.8	500	0.08	0.68	8.7	12.0	0.88
	2	Air	50	200 000	0.02	3.68	33.7	38.8	0.91
	2	N_2 + air	2.25	500	0.02	0.87	34.5	29.5	0.88
	2	CO_2 + air	1.8	500	0.05	0.72	14.0	18.0	0.82
	-1.5	Air	50	200 000	0.02	3.70	35.9	40.0	0.89
	-1.5	N_2 + air	2.25	500	0.01	0.90	47.5	37.3	0.94
	-1.5	CO_2 + air	1.8	500	0.03	0.71	23.1	21.8	0.98

[a] $\ln[O_2]_t = -kt + A_0 = -kt + \ln[O_2]_0$; $[O_2]_t$ is volume (mL) of O_2 in the pack atmosphere at time t (hour) and $[O_2]_0$ is volume (mL) of O_2 in the pack atmosphere at t =0 h.

[b] Calculated half-life (h)=0.693/k.

Table 3.5 Constants of Arrhenius equation for different O_2 scavengers.

Scavenger-type	Atmosphere	Frequency factor, *A*	Activation energy, E_a (kJ/mol)
Ageless®FX-100	Air	484077.4	49.9
	N_2 + air	0.005	9.3
Bioka® S-100	Air	13082.1	44.7
	N_2 + air	2.04	26.35
FreshPax® R-300	Air	0.006	7.3
	N_2 + air	0.41	20.7
FreshPax® M-100	Air	1636	44.1
	N_2 + air	7404511.2	64.1
	CO_2 + air	1480.3	42.6

4. DEVELOPMENT OF A RETAIL PACKAGING SYSTEM FOR CENTRALIZED MASTER PACKAGING OF OXYGEN-SENSITIVE FRESH MEAT DISPLAY

4.1 Summary

A series of three experiments was conducted to develop a retail packaging system suitable for use in centralized meat processing and packaging operations using controlled atmosphere master packaging of display ready meat cuts. Results from the first experiment clearly demonstrated the need to have O_2 scavengers inside the retail trays. Experiment II demonstrated either lidded or over-wrapped trays could be used with equal success and showed that a grid inside the retail tray was not required. Experiment III established the requirement in each retail tray for a minimum of eight O_2 scavenger sachets with an O_2 absorption rate high enough to deliver a O_2 half-life of 0.6-0.7 h in pack atmospheres, where the O_2 concentration remained $\leq$500 ppm at any time of storage. Overall results from the three experiments clearly demonstrated that the highest efficacy was associated with a retail packaging system where hard plastic retail trays containing eight O_2 scavenger sachets with high O_2 absorption rate (placed underneath an absorbent pad), were over-wrapped with an O_2 permeable film with holes in two corners to permit free exchange of atmospheres within the master packs.

Key-words: O_2 scavengers, centralized meat operations, retail packaging systems, fresh meat color, shelf-life.

4.2 Introduction

Master packaging of meat in retail trays, by over-wrapping them with high oxygen (O_2) permeable film, placing them in groups inside gas-impermeable bags back-flushed with carbon dioxide (CO_2) or nitrogen (N_2), has potential for providing sufficient storage life to facilitate centralized meat cutting and packaging operations (Tewari et al. 1999). However, limited color stability may result in transient discoloration, if residual O_2 content is ≥400 ppm with LD (*longissimus dorsi*) or ≥100 ppm with PM (*psoas major*), or ground beef when stored at -1.5°C (Gill and Jones 1994a, b; Gill and McGinnis 1995a) or permanent discoloration if residual O_2 is high enough to prevent sufficient action by the metmyoglobin reducing activity of muscle (O'keeffe and Hood 1980-81a, b, 1982). Therefore, master packaging has found limited use in commercial centralized meat operations. Residual O_2 may be present inside the package due to entrapment of O_2 during controlled atmosphere packaging (CAP) because of insufficient evacuation or flushing times during CAP machine operation, use of an improper ratio of meat-mass to package atmosphere resulting in dead space in the master bag, or develop because of O_2 entrapment in retail-trays themselves, in absorbent pads, under the meat cut, or by O_2 ingress through the master pack film seams or at film defect sites. Some of these factors are inevitable in commercial meat packaging operations. In Chapter 3, O_2 scavengers were shown to have potential for reducing the O_2 concentration to 0 ppm within a few hours of master packaging, provided an appropriate selection of O_2 scavengers was combined with appropriate placement in the package. Previous studies (Rousset and Renerre 1990; Sorheim et al. 1995a, b; Allen et al. 1996; Doherty and Allen 1998; Isdell

et al. 1999) were conducted using O_2 scavengers without considering their O_2 absorption kinetics, and these have yielded differing results. No concerted effort has been made to identify a suitable packaging system for commercial applications that addresses problems associated with development of transient or permanent meat discoloration due to residual O_2. The objective of this study was to design an improved retail packaging system for commercial retail-ready meat cuts.

4.3 Materials and methods

4.3.1 Oxygen (O_2) scavengers

Ageless® FX-100 O_2 scavengers, based on iron-chemical systems, were used (Mitsubishi Gas Chemical Co. Inc., Tokyo, Japan). These scavengers require moisture (>70% relative humidity) for activation and operate in air or N_2 atmospheres but not in CO_2 atmospheres. Detailed information regarding these scavengers has been given in Table 3.1.

4.3.2 Measurement of O_2 concentration

An O_2 analyzer (Mocon MS-750, Modern Controls Inc., Minneapolis, MN), based on a solid state O_2 ion conduction material (zirconium oxide), was used to determine the O_2 concentrations of headspace atmospheres. The appendices A-1 and A-2 give specifications, working principle, and calibration procedure for the O_2 analyzer.

4.3.3 Master-packaging and storage of steaks and chops

4.3.3.1 Experiment#1

Fresh beef tenderloins (*psoas major*, PM) and fresh pork loins (*longissimus dorsi*, LD) from animals slaughtered 24 h previously, at local commercial beef and pork

abattoirs were used. All primal cuts were vacuum-packaged and stored at 2°C for 14 to 21 days. A total of 39 steaks and 39 pork chops were prepared from the beef tenderloins and pork loins, respectively. Each steak or pork chop was placed on a solid polystyrene tray (clear plastic tray # 2D, Western Paper & Food Distributors (Int') Ltd., Calgary, AB) with dimensions of 216x133x25 mm (L x W x H) containing eight Ageless® FX-100 O_2 scavengers and a single absorbent pad (MP-30620, Paper Pak® Corp., La Verne, CA). Each retail tray was lidded with a shrinkable film with an O_2 transmission rate (OTR) of 8000 mL/(m^2 24 h) at 1 atm, 23°C, and 70% RH. (Vitafilm 'Choice Wrap', Goodyear Canada Ltd., Calgary, AB) using commercial glue (INSTA-CURE+™, H&D Hobby Distributing Ltd., Calgary, AB, Canada) (Fig. I1 in Appendix-I). Two 3 mm holes were burned through the film in two corners of each tray using a soldering iron to allow free exchange of atmospheres during gas flushing. Three retail trays were placed on a plastic cafeteria tray, which was then placed in a 595x447 mm (L x W) bi-metalized, plastic laminate bag (SecureFresh Pacific Ltd., Auckland, New Zealand) with an OTR of 0.55 mL/(m^2 24 h) at 1 atm, 23°C, and 70% RH. The bag was then evacuated, filled with 2.5 L of N_2, and heat-sealed using a controlled atmosphere packaging machine, CAP (CAPTRON® SecureFresh Pacific Ltd., Auckland, New Zealand). Twelve master packs each containing three steaks or three pork chops, were prepared and randomly allocated by species to different treatments (Table 4.1). The O_2 concentration was measured in every fifth pack immediately after initial packaging using the Mocon O_2 analyzer to make sure that initial O_2 concentration did not exceed 200 ppm.

Master-packaged steaks and pork chops were stored at 2°C for one week. The O_2 concentration in each master pack was then measured. The retail trays were then placed on retail display and evaluated for visual characteristics by a four member well-trained sensory panel.

4.3.3.2 Experiment#2

Beef rib-eyes (*longissimus thoracis*, LT) from animals slaughtered 24 h previously, were obtained from a local commercial abattoir and were vacuum-packaged and stored at 2°C. Following storage at 2°C under vacuum for 3 weeks, 96 steaks (each 2 cm thick) were prepared and placed in solid polyethylene trays with dimensions of 216x133x25 mm containing eight Ageless® FX-100 O_2 scavengers underneath an absorbent pad. Retail trays were lidded with a shrinkable permeable film and were prepared as in experiment #1. Four retail trays were placed on a cafeteria tray, which in turn was placed into a master pack. The master packs were evacuated, filled with 3.25 L of N_2 and heat-sealed using the CAP machine. Six such packs were prepared containing one of four treatment combinations: G and H Table (4.1), plus G2 and H2, which were the same, but over-wrapped instead of lidded (Fig. I1 in Appendix-I). The master packs were stored and evaluated using procedures similar to those used in experiment#1.

4.3.3.3 Experiment#3

Beef tenderloins (*psoas major*, PM) from animals slaughtered within 24 h, were obtained from a local commercial abattoir. Steaks (2 cm thick) were placed in 216x133x25 mm solid polyethylene trays containing two (S2), four (S4), six (S6), or eight (S8) Ageless® FX-100 O_2 scavengers underneath an absorbent pad. Each retail tray

was over-wrapped with the O_2 permeable and shrinkable film as previously described. Four retail trays containing the same treatment combination (S2, S4, S6, or S8), were placed in a master pack, evacuated, filled with 4.5 L of N_2, and heat-sealed using the CAP machine. Three retail trays served as un-stored controls, which did not undergo any storage and were placed directly on retail display for analysis.

Following one week of storage at -1.5°C in a liquid-N_2 refrigerated container (Jeyamkondan 1999), all master bags were removed, and the O_2 concentration in each master pack was measured using the Mocon O_2 analyzer. The retail trays were placed on retail display and evaluated for visual characteristics daily for four days.

4.3.4 Display and evaluation of retail trays

All retail trays were placed at the center of the display shelf in a horizontal, fan-assisted display case (model LPM12T, Hill Refrigeration, Barrie, ON). The case was illuminated with incandescent and fluorescent lights giving a light intensity of 1080 lux at the meat surface (Gill and Jones 1994a).

Displayed steaks (PM or LT) and pork chops (LD) were evaluated for color, extent of discoloration, and retail appearance 30-45 min after master pack opening by a 4-5 member trained sensory panel. The color of beef was evaluated using an eight-point descriptive scale (0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red); and color of pork was evaluated using a six-point descriptive scale (0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark). Discoloration of both beef and pork was evaluated using a seven-point descriptive scale

(1=0%, 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100%), and retail appearance of both beef and pork was estimated using a seven-point hedonic scale (1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable) (Jeremiah and Gibson 1997b).

4.3.5 Estimation of the oxidative states of myoglobin

Each retail tray containing a steak or a chop was evaluated by reflectance spectrophotometry at three anatomical locations on each cut. A reflectance spectrophotometer (Macbeth Color Eye 1500/Plus, Kollmorgen Corp., Newburg, NY) was used. Proportions of the different chemical states of myoglobin (deoxy, met, and oxy) were estimated using procedures outlined by AMSA (1991), by converting the readings (R) to K/S values [K is the absorption coefficient and S is the scattering coefficient, determined at selected wavelengths using the formula: $K/S=(1-R)^2/2R$]. Ratios of wavelengths used for calculations are: K/S 474÷K/S 525 for % deoxymyoglobin, K/S 572 ÷ K/S 525 for % metmyoglobin, and K/S 610 ÷ K/S 525 for oxymyoglobin (AMSA 1991). Reflectance spectra from the meat surfaces were obtained to estimate the proportions of metmyoglobin, deoxymyoglobin, and oxymyoglobin after evaluation for visual characteristics.

4.3.6 Statistical analysis

The influences of different treatments on factors influencing meat color were compared statistically for significant differences ($p<0.05$) using Analysis of Variance (proc ANOVA) in SAS (SAS Institute Inc., Cary, NC).

4.4 Results

4.4.1 Experiment#1

4.4.1.1 Oxygen concentration

The O_2 concentration in every fifth bag during initial packaging was 150-200 ppm. After being stored for one week at 2°C, the O_2 concentration in most bags with O_2 scavengers was 0 ppm, except for bags with beef treatments H, E, and G which might have been be leakers (Table 4.2). Bags without O_2 scavengers contained O_2 concentrations up to 1150 ppm.

4.4.1.2 Visual properties

Pork color scores in all treatments ranged from 2.36 to 3.25, and would be considered normal (Table 4.3). Chops in all treatments could be considered to be without discoloration, except in treatments A and B, where the chops were slightly discolored. Chops in all treatments were rated desirable to extremely desirable except in treatments A, B, and D1. Chops in treatment A were rated slightly undesirable and chops in treatments B and D1 were rated slightly desirable.

Beef steaks in all treatments were perceived to be bright cherry red to moderately dark red. Steaks in all treatments without O_2 scavengers either inside the retail tray or in the master pack were moderately discolored. Steaks in treatments H and G1were also moderately discolored, undoubtedly as a result of O_2 ingress through the pack. Steaks in all treatments with O_2 scavengers inside the retail tray were perceived to be at least slightly desirable, except in treatments H and G, due to extensive discoloration as a result of the presence of O_2. Comparison of retail appearance scores for beef steaks stored with

and without O_2 scavengers indicates the necessity of including O_2 scavengers in master packaged, display ready meat cuts, stored in controlled atmospheres. Comparison of treatments D and F with D1 and F1 for beef clearly demonstrates the O_2 scavengers should be positioned inside the retail tray.

4.4.1.3 Chemical states of myoglobin

Pork chops in all treatments with O_2 scavengers had 62.0% or more oxymyoglobin and essentially 0.0% metmyoglobin, except in treatments G and H1 (Table 4.4). Chops in treatment G had 2.1% and chops in treatment H1 had 6.8% metmyoglobin. Beef steaks in treatments containing O_2 scavengers had >90.0% oxymyoglobin, and <2.5% metmyoglobin, except in treatment H and G1. Steaks in treatment H had 78.5% oxymyoglobin and 7.8% metmyoglobin; and steaks in treatment G1 had 58.9% oxymyoglobin and 37.29% metmyoglobin, presumably as a result of O_2 ingress into the package. These data confirm the conclusions based on the visual data that O_2 scavengers should be placed inside the retail tray, when master packing display ready meat cuts in controlled atmospheres.

4.4.2 Experiment#2

4.4.2.1 Oxygen concentration

The initial O_2 concentration in every fifth bag was ~120 ppm. After one week of storage, the O_2 concentration in all bags was 0 ppm, except for one bag (Bag#2, treatment H) which contained 2650 ppm O_2 and had a failed seal. Consequently it was eliminated from further evaluation.

4.4.2.2 Visual and reflectance properties

Although significant ($p<0.05$) differences existed between treatments in visual color ratings, all steaks were perceived to be bright cherry red and no differences of practical importance existed, i.e., consumer would not be able to examine the difference (Table 4.5). Retail trays containing grids resulted in steaks with greater amounts of surface discoloration. However, no differences in surface discoloration attributable to lidding or over-wrapping were detected. Consequently, steaks in retail trays containing grids were rated less desirable in retail appearance ($p<0.05$). However, the magnitudes of these differences in retail appearance were approximately 0.8 of a panel unit making them of only marginal practical importance, i.e, unnoticeable by the consumer. Steaks in over-wrapped trays containing a grid had the highest proportions of oxymyoglobin and the lowest proportions of metmyoglobin ($p<0.05$). Despite this finding, the visual data clearly indicate inclusion of a grid in the tray is counter productive, and the composite data clearly demonstrate a lack of advantage for either lidding or over-wrapping the trays. Consequently, the most feasible retail packaging system for use with controlled atmosphere master packaging, is use of over-wrapped trays containing O_2 scavengers underneath an absorbent pad.

4.4.3 Experiment#3

4.4.3.1 Oxygen concentration

The O_2 concentration during initial packaging was approximately 80 ppm. After 7 days of storage at -1.5°C, the O_2 concentration in all bags was 0 ppm.

4.4.3.2 Visual and reflectance properties

Steaks in retail trays containing up to four O_2 scavengers became darker in color during the first 3 days of display, and then discolored. Steaks in retail trays containing more than four O_2 scavengers remained stable in color for two or more days until they discolored (data not shown). Steaks in retail trays containing ≤six O_2 scavengers were more discolored than the un-stored controls at all display intervals ($p<0.05$), but discolored essentially at the same rate as the un-stored controls (Fig. 4.1). Steaks in retail trays containing eight O_2 scavengers also discolored at essentially the same rate as the un-stored controls, but did not discolor as extensively. Un-stored controls deteriorated rapidly in retail appearance and had a retail case-life of 2.5 days (Fig. 4.2). Steaks stored with up to six O_2 scavengers also deteriorated rapidly in retail appearance and had shorter retail case-lives than un-stored controls. Steaks stored with eight O_2 scavengers deteriorated more slowly in retail appearance and did not reach the point of unacceptability, ≤3.5 (Personal Communication: Dr. L. E. Jeremiah, Research Scientist, Agriculture and Agri-food Canada, Lacombe, AB), during four days of retail display. Consequently, stored with eight O_2 scavengers had retail case-lives in excess of four days. The rate of change of metmyoglobin and oxymyoglobin formation during retail display (Fig. 4.3) clearly demonstrates the advantage of using O_2 scavengers and indicates a minimum of eight O_2 scavengers, resulting in O_2 half-life of 0.6-0.7 h in the pack atmosphere whose initial O_2 concentration is ≤500 ppm (Chapter 3), should be used in controlled atmosphere packaging of display ready meat cuts. Appendices B and C give data for visual scores and reflectance, respectively.

4.5 Discussion

At low temperatures pork color is stable at several hundred ppm of O_2 (Sorheim et al. 1995a). The present study confirmed this finding. However beef, especially PM, discolors even at very low O_2 concentrations, which is also evident from the results of the current study. The present results clearly demonstrated that O_2 scavengers are essential to prevent and/or reduce discoloration in master-packaged meats. The use of O_2 scavengers in master-packing of pork will provide protection to complement the intrinsic ability of pork muscle tissue to resist oxidative discoloration and will further increase display life.

Oxygen scavengers in multiple numbers reduced O_2 concentrations to 0 ppm in most treatments in the present study. The appropriate number of O_2 scavengers to be used appears to be eight based upon results presented here, however, the appropriate number of other types of O_2 scavengers can be deduced from previous research (Chapter 3) based upon: storage temperature, initial O_2 concentration, desired O_2 absorption rate, package atmosphere (CO_2/air/N_2), placement of O_2 scavengers (inside the retail tray or in the master-package atmosphere), and scavenger operating principles. Steaks placed in master-packs with O_2 scavengers outside the retail trays generally had higher metmyoglobin content and were less desirable in appearance than steaks packaged with O_2 scavengers inside the retail trays.

Steaks and chops used in the present study were vacuum-packaged and stored for two to three weeks at 2°C before master packaging, which lowered their metmyoglobin-reducing capacity, and therefore presented a worst-case scenario for centralized packaging operations. Therefore, greater storage ability should be expected with fresh, un-stored

beef or pork. Although pork can probably be master-packaged without O_2 scavengers or using any treatment combination with O_2 scavengers, the presence of O_2 scavengers inside the retail tray appears to be imperative when master packaging beef. Treatments G, G2, H, and H2 were selected as retail packaging systems which may be commercially adaptable. Additional replicates of each of these treatments were evaluated in subsequent experiment II of the present study to determine the importance of a grid inside the retail tray and to obtain a comparison of lidded and over-wrapped retail trays. Results clearly indicated a grid was not required and there was little difference between lidded and over-wrapped trays.

High-O_2 permeable film over-wrap has been shown to act as an O_2 barrier at low O_2 concentration (Chapter 3). Consequently, two isolated systems affect the O_2 concentration in the overall package atmosphere of master packs. The probability of having O_2 entrapped inside the retail tray is high due to the absorbent pad and space between over-wrap and edges of the tray. Gill and McGinnis (1995b) placed 20 O_2 scavengers into the master packs outside the retail trays to prevent transient discoloration of ground beef even when the O_2 concentrations during packaging were very low, and this became negligible after a day in master packs without O_2 scavengers (i.e., from 40 ppm to 10 ppm). However, placing O_2 scavengers inside the retail trays should reduce the number of O_2 scavengers required to prevent transient discoloration. This fact was confirmed in a separate study (Chapter 5) where O_2 concentration rose from 78 to 477 ppm in master packs without O_2 scavengers after a day of storage, and transient discoloration of beef steaks (PM) was prevented by placing eight O_2 scavengers with low

capacity (100 mL) or two O_2 scavengers with high capacity (2000 mL) inside each of the four retail trays in the master pack. Isdell et al. (1999) reported O_2 concentrations of 500 ppm after storing master-packaged steaks at 0°C for several weeks. However, only one O_2 scavenger was placed in each retail tray. Due to significant variation in the O_2 absorption rates among individual O_2 scavengers of the same type (Chapter 3), multiple O_2 scavengers should be placed in the retail tray. Since, O_2 concentration in the atmosphere surrounding the meat is the prime concern, and because even high O_2-permeable films can be a barrier to diffusion of low concentrations of O_2, the O_2 scavengers should be placed inside retail trays.

The amount of O_2 absorbing capacity in each retail tray will also dictate the retail display life of meat cuts. Steaks packaged with greater absorbing capacity, i.e., with larger numbers of O_2 scavengers, tended to have more retail display life than those with fewer O_2 scavengers. The retail display life for steaks packaged with 8 O_2 scavengers was longer by 1.5 days than with ≤ 6 O_2 scavengers. With prevention of transient discoloration, the limited metmyoglobin-reducing capacity of the muscle is preserved. This activity further delays development of discoloration during retail display and yields acceptable retail appearance even after four days of retail display.

The retail packaging system with the most potential for CAP systems in commercial centralized meat operations utilizing a saturated 100% N_2 atmosphere in the master pack includes the use of hard plastic retail trays containing only an absorbent pad and eight O_2 scavengers with high O_2 absorption rates. Such absorbing capacity should result in O_2 half-lives of 0.6-0.7 h in the pack atmosphere where O_2 concentration remains

$\leq$500 ppm at any time of storage. Trays should be over-wrapped with a film of high O_2 permeability having two holes to permit free exchange of atmospheres between the master packs and the retail trays.

Table 4.1 Description of treatments for beef steaks and pork chops for experiment #1.

Treatment	N[a]	Description
A	3	Lidded control tray with meat
B	3	Lidded tray containing meat and grid*
C	3	Lidded tray with meat and absorbent pad
D	3	Lidded tray containing meat and O_2 scavengers (inside retail tray)
E	3	Lidded tray containing meat, grid, and absorbent pad
F	3	Lidded tray containing meat, grid, and O_2 scavengers (inside retail tray)
G	3	Lidded tray containing meat, absorbent pad, and O_2 scavengers (inside retail tray)
H	3	Lidded tray with meat, grid, absorbent pad, and O_2 scavengers (inside retail tray)
D1	3	Treatment D with O_2 scavengers outside the retail tray
F1	3	Treatment F with O_2 scavengers outside the retail tray
G1	3	Treatment G with O_2 scavengers outside the retail tray
H1	3	Treatment H with O_2 scavengers outside the retail tray

[a] Number of retail trays in a master pack.
* 165x105 mm (L x W) of thickness 1.5 mm with 4 mm^2 openings; grid was placed underneath the absorbent pad.

Table 4.2 Oxygen (O_2) concentration in master packs containing beef and pork stored at 2°C in 100% nitrogen (N_2) atmosphere for 7 days.

Treatment*	**O_2 Concentration (ppm)**	
	Beef	**Pork**
A	214	853
B	334	1150
C	890	862
D	0	0
E	201	377
F	0	0
G	30	0
H	1560	0
D1	0	0
F1	0	0
G1	102	0
H1	0	0

* Description of treatments is given in Table 4.1.

Table 4.3 Mean color, surface discoloration, and retail appearance scores and standard errors for pork chops and beef steaks after various treatments.

	Beef						Pork					
Treat.*	**Color†,+**	**SE++**	**Discol.††,+**	**SE**	**Appear.‡,+**	**SE**	**Color†,+**	**SE++**	**Discol.††,+**	**SE**	**Appear‡,+**	**SE**
A	6.8^{A}	0.2	5.6^{A}	1.0	2^{E}	0.4	2.8^{D}	0.2	3.8^{A}	0.7	3.7^{E}	0.8
B	$5.5^{B,C}$	0.3	$5.5^{A,B}$	0.4	1.9^{E}	0.5	2.8^{D}	0.2	$3.3^{A,B}$	0.7	4.6^{D}	0.7
C	$5.0^{D,C}$	0.0	$5.2^{A,B}$	0.2	2.3^{E}	0.4	$3.0^{B,C}$	0.0	1.3^{C}	0.2	$6.8^{A,B}$	0.2
D	$5.2^{D,C}$	0.2	1.0^{F}	0.0	6.3^{A}	0.2	$3.0^{B,C}$	0.0	1.0^{C}	0.0	$6.8^{A,B}$	0.2
E	5.8^{B}	0.3	4.7^{B}	0.4	1.9^{E}	0.3	3.3^{A}	0.2	1.0^{C}	0.0	$6.5^{A,B}$	0.3
F	$5.0^{D,C}$	0.1	$1.7^{D,E}$	0.4	6.3^{A}	0.4	$3.1^{A,B}$	0.2	1.2^{C}	0.2	$6.6^{A,B}$	0.3
G	$5.0^{D,C}$	0.3	$1.8^{D,E}$	0.6	4.7^{C}	0.6	$2.8^{D,C}$	0.2	1.4^{C}	0.3	6.3^{B}	0.3
H	$6.0^{A,B}$	0.1	3.5^{H}	0.5	3.3^{D}	0.4	$3.0^{B,C}$	0.0	1.2^{C}	0.2	$6.8^{A,B}$	0.2
D1	$5.6^{A,B}$	0.1	$1.8^{D,E}$	0.6	$5.0^{B,A,C}$	0.6	2.4^{A}	0.3	2.5^{B}	0.9	5.2^{C}	0.3
F1	$5.7^{B,C}$	0.3	1.9^{D}	0.9	$5.1^{B,C}$	0.6	$3.0^{B,C}$	0.0	1.0^{C}	0.0	7.0^{A}	0.0
G1	5.6^{D}	0.3	5.8^{A}	0.5	1.8^{E}	0.4	$3.0^{B,C}$	0.0	1.1^{C}	0.2	6.9^{A}	0.2
H1	$5.7^{B,C}$	0.3	$1.6^{D,E}$	0.3	$5.8^{A,B}$	0.4	$3.0^{B,C}$	0.0	1.1^{C}	0.2	6.9^{A}	0.2

* Description of treatments is given in Table 4.1.
† Color scale (pork chop): 0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark; Color scale (beef steak): 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale (pork chop or beef steak): 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
‡ Retail appearance scale (pork chop or beef steak): 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.
+ Means in the same column bearing a common letter do not differ significantly ($p>0.05$).
++ Standard error.

Table 4.4 Mean values of the chemical states of myoglobin (% met-, % deoxy-, and % oxy-myoglobin) and standard errors for pork chops and beef steaks after various treatments.

Treatment*	Pork chops						Beef steaks					
	% of chemical states of myoglobin						% of chemical states of myoglobin					
	% met-[+]	SE[++]	% deoxy-[+]	SE	% oxy-[†,+]	SE	% met	SE	% deoxy	SE	% oxy	SE
A	26.8[A]	5.8	24.2[D,C]	5.1	49.0[F,E]	0.7	57.4[A]	6.1	0.0[B]	0.0	42.6[D,C]	6.1
B	20.4[A]	8.8	24.6[D,C]	4.1	55.0[F,D,E,C]	4.8	55.2[A]	24.2	4.1[A,B]	1.8	40.6[D]	23.4
C	5.2[B]	0.9	42.1[A,B]	3.0	52.7[F,D,E]	2.2	23.2[B,A,C]	16.4	1.4[B]	0.7	75.4[B,D,A,C]	16.9
D	0.0[B]	0.0	37.8[B,A,C]	3.8	62.2[B,D,E,C]	3.9	0.6[C]	0.1	3.0[A,B]	1.4	96.4[A,B]	1.0
E	5.4[B]	2.4	47.9[A]	3.0	46.7[F]	1.7	17.7[B,C]	15.4	2.1[B]	1.6	80.2[B,A,C]	14.5
F	0.1[B]	0.1	35.3[B,D,A,C]	4.4	64.5[B,D,A,C]	4.5	0.0[C]	0.0	1.2[B]	1.1	98.8[A]	1.1
G	2.1[B]	1.8	21.8[D]	7.5	76.1[A,B]	8.2	2.1[B,C]	1.8	5.7[A,B]	2.9	92.2[A,B]	1.6
H	0.0[B]	0.0	31.9[B,D,A,C]	3.4	68.1[B,A,C]	3.4	7.8[B,C]	4.5	13.7[A]	8.8	78.5[B,A,C]	8.0
D1	0.0[B]	0.0	21.1[D]	2.4	78.9[A]	2.4	2.4[B,C]	1.1	7.1[A,B]	1.0	90.5[A,B]	0.2
F1	0.0[B]	0.0	28.7[B,D,C]	4.7	71.3[A,B]	4.2	2.2[B,C]	1.8	5.2[A,B]	4.5	92.6[A,B]	3.8
G1	0.0[B]	0.0	25.6[D,C]	3.3	74.4[A,B]	3.3	37.3[A,B]	16.2	3.8[A,B]	1.5	58.9[B,D,C]	17.7
H1	6.8[B]	5.9	27.8[B,D,C]	7.3	65.4[B,D,A,C]	3.8	0.0[C]	0.0	8.5[A,B]	4.2	91.5[A,B]	4.2

* Description of treatments is given in Table 4.1.

† % oxy-=100-[(% met-) + (% deoxy-)]

+ Means in the same column bearing a common letter do not differ significantly ($p>0.05$).

++ Standard error.

Table 4.5 Means and standard errors for visual and reflectance properties of beef (*longissimus thoracis*, LT) steaks stored in different packaging treatments.

Trait	Treatment**							
	G (n*=24)		H (n=20)		G2 (n=24)		H2 (n=24)	
	Mean+	SE++	Mean	SE	Mean	SE	Mean	SE
Color	4.9[c]	0.1	5.3[b]	0.1	5.6[a]	0.1	5.2[b,c]	0.2
Discoloration	1.9[b]	0.4	2.3[a]	0.5	1.1[c]	0.2	2.3[a]	0.2
Retail appearance	6.1[a,b]	0.4	5.4[b]	0.4	6.4[a]	0.1	5.6[b]	0.2
% metmyoglobin	8.2[b]	2.9	6.9[b,c]	4.5	9.5[a]	0.7	1.7[c]	0.6
% deoxymyoglobin	9.1[a]	2.0	5.2[a]	2.1	5.0[a]	1.3	1.4[b]	0.7
% oxymyoglobin	82.7[b]	3.2	87.9[b]	3.7	85.5[b]	1.0	97.1[a]	0.7

** Description of the treatments is given in Table 4.1.
* Number of replicates.
+ Means in the same row bearing a common letter do not differ significantly ($p>0.05$).
++ Standard errors.

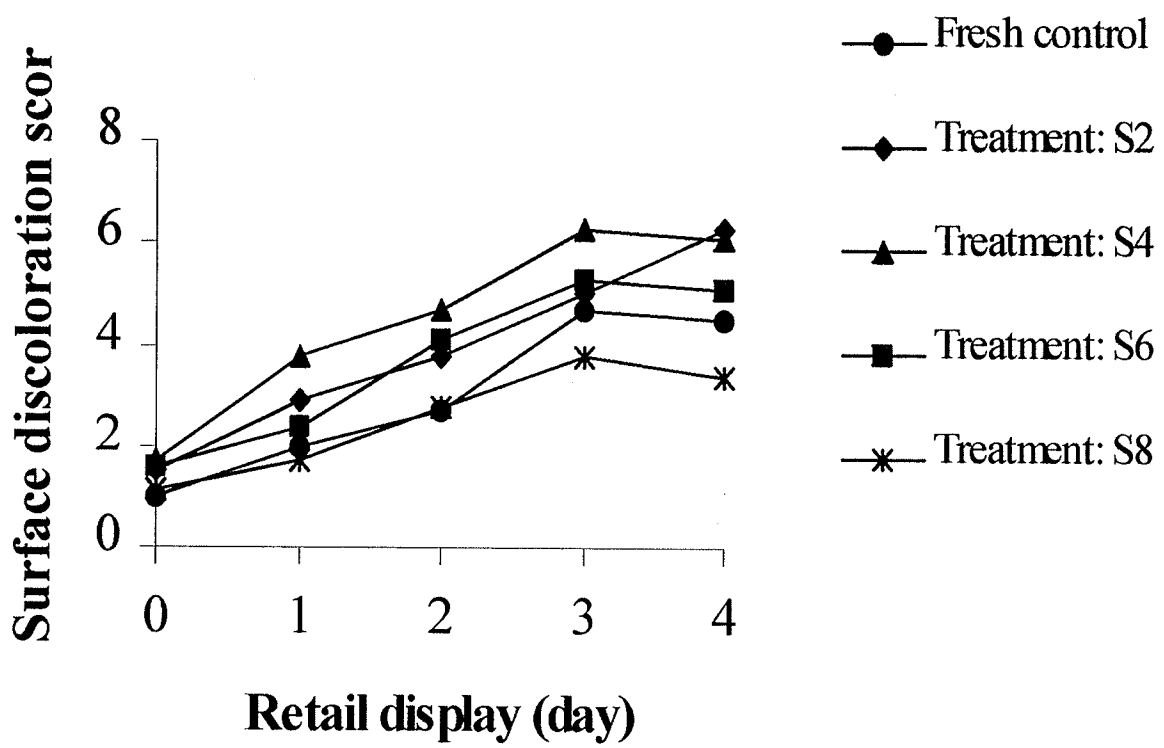

Fig. 4.1 Mean discoloration scores for steaks stored with different numbers of O_2 scavengers indicated by numbers on treatments.

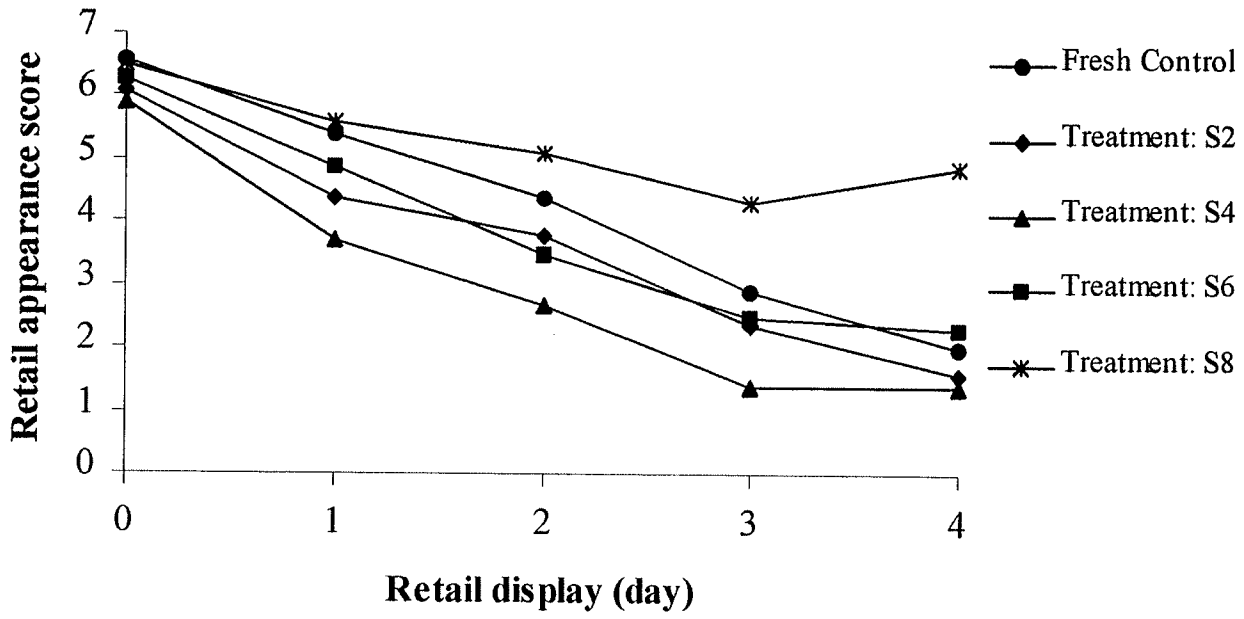

Fig. 4.2 Retail appearance scores of steaks stored with different numbers of O_2 scavengers indicated by numbers on treatments.

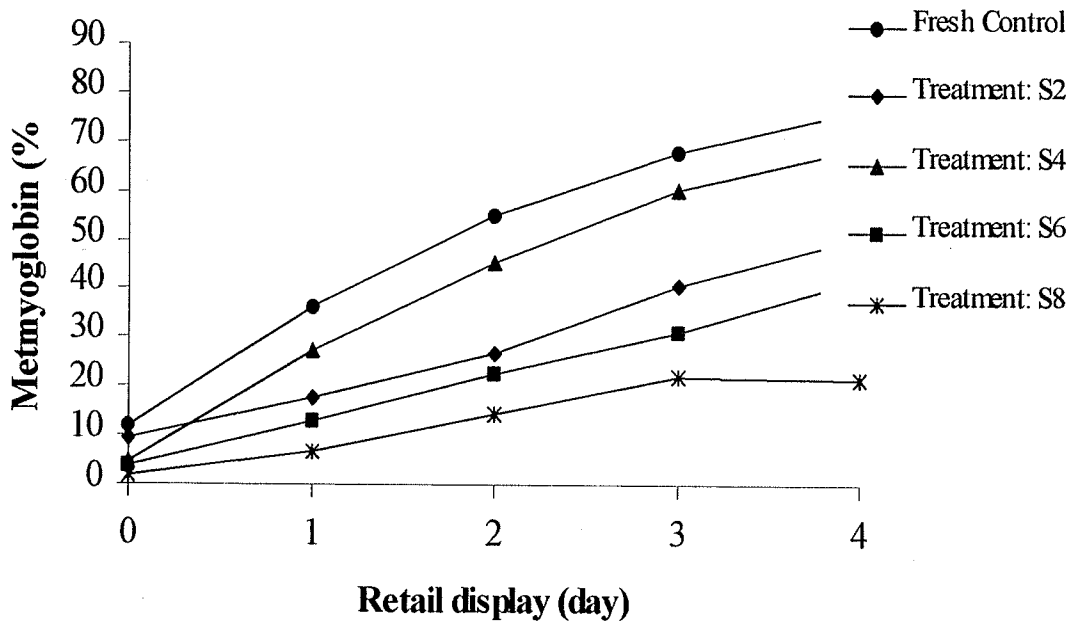

Fig. 4.3 Mean percentages of metmyoglobin on the surfaces of steaks stored with different numbers of O_2 scavengers indicated by numbers on treatment.

5. PREVENTION OF TRANSIENT DISCOLORATION OF BEEF

5.1 Summary

Oxygen absorbent technology in conjunction with controlled atmosphere packaging (CAP) were used to prevent transient discoloration in centrally prepared beef steaks. Two types of commercial O_2 scavengers were used in the study. Beef tenderloins (psoas major) were each cut into four steaks, placed on retail trays with or without O_2 scavengers, over-wrapped with high O_2 permeable film and placed into master packs. Each master pack contained four such retail trays, and were back flushed and heat sealed to provide a saturated 100% atmosphere of N_2. The master packs were stored at 1±0.5°C. Three master packs, one untreated control and the other two containing two types of commercial scavengers, were opened daily for eight days. Each pack was only opened once. The steaks were presented in a display case for visual evaluation. Reflectance spectra from each steak surface were obtained to estimate metmyoglobin content.

Steaks packaged without O_2 scavengers showed more discoloration, received lower retail appearance scores, and had significantly higher proportions of metmyoglobin when compared to steaks with O_2 scavengers, after most storage intervals ($p<0.05$). Prevention of metmyoglobin formation was not significantly influenced by the type of O_2 scavenger used ($p>0.05$). At 1±0.5°C, the transient discoloration of beef cuts in an atmosphere initially containing 78 ppm O_2 which rose up to 477 ppm after a day of master pack storage, was prevented by the presence of 7 and 2 scavengers with capacity of 100 and 2000 mL, respectively, per L of atmosphere. To prevent transient

discoloration of beef steaks the O_2 concentration should be reduced to 0 ppm at 1±0.5°C, within 3 h of pack closure.

Key-words: Oxygen scavengers, centralized meat operations, transient discoloration, controlled atmosphere packaging, residual oxygen, fresh beef packaging.

5.2 Introduction

Centralized packaging of retail meat cuts is becoming of increasingly greater interest to the retail sector and the fresh meat industry because of its economic advantages, ability to maintain quality, and safety, and potential to extend shelf life (Farris et al. 1991). Although substantial research has been completed on the microbiological and sensory aspects of meat during centralized packaging under various modified atmospheres (Gill and Jones 1994a, 1994b, 1996; Jeremiah and Gibson 1997b, 1997c, 1997d; Tewari et al. 1999), problems regarding color stability of centrally prepared retail meat cuts, particularly beef, remain to be resolved. Color deterioration of fresh meat is the most important factor limiting its storage life since consumers rely on the red color of meat as an indicator of freshness (Shay and Egan 1986, 1990). The color of fresh meat is dependent on the oxidation state of the muscle pigment myoglobin (Penney and Bell 1993). Myoglobin can exist in three forms, deoxymyoglobin (purple red color- reduced myoglobin formed in the absence of O_2), oxymyoglobin (bright red color-oxygenated myoglobin formed in the presence of O_2), and metmyoglobin (brown in color-oxidized myoglobin formed under atmospheric or reduced O_2 concentrations). Metmyoglobin is the major pigment responsible for discoloration of meat. Centrally prepared retail beef cuts stored in controlled atmospheres containing nearly 100%

carbon dioxide (CO_2) or nitrogen (N_2) which may have small amounts of O_2 are susceptible to the formation of metmyoglobin, due to the presence of residual O_2 (Ledward 1970; Gill 1989; Gill and Jones 1994a). If the O_2 concentration is not excessive, the meat will absorb the residual O_2 and any metmyoglobin formed will be reduced to deoxymyoglobin as a result of metmyoglobin reducing activity (MRA) within the muscle tissue (O'keeffe and Hood 1980-81a, b, 1982). Gill and Jones (1994a) reported that in packaged fresh beef 2-4 days are required for reduction of metmyoglobin to deoxymyoglobin. When stored meat is removed from the controlled atmosphere, it blooms to the desirable, bright, red color associated with freshly cut meat, but this will not occur if a substantial amount of metmyoglobin is present (Gill 1990). The MRA of muscle tissue is limited and once exhausted metmyoglobin cannot be converted back to myoglobin (Gill 1991).

Transient discoloration of meat is not a major concern when the product is in storage, transit, or both for long periods (Gill and McGinnis 1995a). However, such discoloration is highly undesirable when commercial conditions require periodic rapid distribution and display of centrally packaged meat. Consequently, premature temporary discoloration limits the advantages of centrally packaged retail ready meat cuts using O_2-depleted master packaging technology. Such discoloration is also dependent upon the specific muscle packaged since tissues vary in their capacity to withstand "low" O_2 concentrations (<500 ppm). Centrally prepared beef steaks and ground beef packaged under controlled atmospheres, were shown to be susceptible to very low O_2 concentrations (Gill and Jones 1994a, 1994b). Gill and McGinnis (1995a) examined the

factors affecting transient discoloration of beef and reported that longissimus dorsi (LD) samples stored at -1.5°C for 48 h (O_2 concentrations < 400 ppm) showed lower metmyoglobin formation than when stored at other storage temperatures. In contrast, myoglobin in beef of low color stability (psoas major, PM) oxidized even at lower O_2 concentrations (< 100 ppm), irrespective of storage temperatures. The authors concluded that beef with high color stability (LD) was least susceptible to metmyoglobin formation if atmospheres contained < 600 ppm of O_2 at temperatures < 0°C; however, beef with poor color stability (PM) (O'keeffe and Hood 1980-81a, b, 1982) was highly susceptible to metmyoglobin formation even at very low O_2 concentrations and sub-zero temperatures.

Transient discoloration may be prevented if O_2 absorbent technology is used in conjunction with controlled atmosphere packaging (CAP). Next to PM, ground beef is most sensitive to discoloration. To understand temporary degradation of ground beef color, Gill and McGinnis (1995b) performed an O_2 absorption kinetics study with a commercial O_2 scavenger and reported transient discoloration could be prevented by O_2 scavengers, if large (>20) numbers were used in each pack. This strategy worked if residual O_2 were brought to <10 ppm within 2 h at a storage temperature of -1.5°C and O_2 concentration in the package never exceeded 40 ppm. However, use of a large number of scavengers may not be commercially feasible. They did not compare different methods of O_2 scavenger placement (e.g., placing O_2 scavengers inside the retail tray vs. placing them in the master pack atmosphere or a combination of both) nor did they examine the O_2 absorption kinetics at low initial O_2 concentration. They also

did not study O_2 absorption kinetics of more than one type of commercial O_2 scavenger. In addition, controversy exists in the literature regarding usefulness of O_2 scavengers in different meat packaging systems (Rousset and Renerre 1990; Sorheim et al. 1995a, 1995b; Allen et al. 1996; Doherty and Allen 1998). Therefore, studies on O_2 absorption kinetics of commercial O_2 scavengers at low initial O_2 concentrations (Chapter 3) and their use in retail-packaging systems (Chapter 4) were performed. Incorporating results from these studies (Chapters 3 and 4), the present work was done to determine O_2 scavenging capacity required to prevent transient discoloration of PM steaks. The objective of this study was to test the hypothesis that O_2 scavengers have the capacity to prevent transient discoloration of retail ready beef cuts.

5.3 Materials and Methods

5.3.1 Oxygen scavengers

Ageless® FX-100 (Mitsubishi Gas Chemical Co. Inc., Tokyo, Japan) and FreshPax® R-2000 (Multiform Desiccants Inc., Buffalo, NY) O_2 scavengers were used in the study. Both O_2 scavengers have iron-based chemical reactions. Ageless® FX-100 needs moisture (>70% relative humidity, R.H.) for activation, which prevents O_2 absorption during handling in air, whereas FreshPax® R-2000 is self-activating as soon as it is exposed to air.

5.3.2 Master-packaging, storage, and sampling of steaks

Fresh beef tenderloins (*psoas major*, PM) from animals slaughtered within 24 h, were obtained from a local beef packing plant. Four 2 cm thick steaks were prepared from each tenderloin. Each steak was placed on an absorbent pad of dimensions 152 x

114 mm (MP-30620, Paper Pak® Corp., La Verne, CA) in a 216x133x25 mm solid polystyrene tray (clear plastic tray # 2D, Western Paper & Food Distributors Ltd., Calgary, AB). Eight Ageless® FX-100 O_2 scavengers were placed underneath the absorbent pad. Each retail tray was over-wrapped with a shrinkable film having an O_2 transmission rate of 8000 mL/(m^2 24 h) at 1 atm, 23°C, and 70% RH (Vitafilm 'Choice Wrap', Goodyear Canada Ltd., Calgary, AB). After sealing, the film was shrunk to the tray using a hot air gun. Two 3 mm holes were made in the film at the corners of the tray to allow free exchange of atmospheres during gas flushing. Four such retail trays were placed in a 595x447 mm bimetalized, plastic laminate pouch (SEC 201, SecureFresh® Pacific Ltd., Auckland, New Zealand). The master packs were evacuated, filled with 4.5 L of N_2, and sealed using a CAP machine (CAPTRON, Model ZR897, SecureFresh Pacific Ltd., Auckland, New Zealand). Eight such master packs were prepared. Similarly, eight master packs, each having four retail trays containing two FreshPax® R-2000 O_2 scavengers underneath the absorbent pads, and an additional eight master packs, each containing four retail trays with no O_2 scavengers (controls), were prepared. Each pack was labeled accordingly. During initial packaging, the O_2 concentration was measured in every fifth master pack using an O_2 analyzer (Mocon MS-450, Modern Controls Inc., Minneapolis, MN). The appendices A1 and A2 give specifications, working principle, and calibration procedure of the O_2 analyzer.

The master-packaged steaks were stored at 1±0.5°C. On day 0, four retail trays served as fresh controls and were kept for visual evaluation in the retail display case and to obtain reflectance spectra of the steak surfaces. Three master packs (one having

Ageless® FX-100, one having FreshPax® R-2000 O_2 scavengers, and one having no O_2 scavenger), were opened at 1 day intervals for 8 days and placed in a display case (Model LPM12T, Hill Refrigeration, Barrie, ON). The O_2 concentration in each pack was measured immediately before being opened.

5.3.3 Display and sampling of retail trays

All retail trays were placed in the center of the display shelf of a horizontal, fan-assisted display case (Model LPM12T, Hill Refrigeration, Barrie, ON). The case was illuminated for 12 h/day with incandescent lamps giving a light intensity of 750 lux at the display shelf surface. Detailed information about the display case has been previously presented (Gill and Jones, 1994a). A temperature data logger (Tru-Test, Auckland, New Zealand) was placed at the center of the display case to record air temperatures surrounding the product.

The PM steaks on display were examined for color, discoloration, and retail appearance 30-45 min after opening of the master-packs, and reflectance spectra of the steak surfaces were obtained to estimate metmyoglobin, deoxymyoglobin, and oxymyoglobin content.

5.3.4 Visual assessment of master-packaged steaks

A five member well-trained panel was used for the subjective evaluation of the steaks. Color scores were assessed using a eight-point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven-point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%,

4=26-50%, 5=51-75%, 6=76-99%, 7= 100%. Retail appearance was assessed using a seven-point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable (Jeremiah and Gibson 1997b).

5.3.5 Estimation of myoglobin states

The average reflectance spectrum was obtained from three locations of the steak covered with a shrinkable film using a reflectance spectrophotometer (Macbeth Color Eye 1500/Plus, Kollmorgen Corp., Newburg, NY). Reflectance values (R) of the different myoglobin oxidation states were estimated at specified wavelengths, and converted to K/S values (K is the absorption coefficient and S is the scattering coefficient). The K/S values were used for quantifying the proportion of deoxy-, met-, and oxy-myoglobin, and were calculated using selected wavelengths (474, 525, 575, and 610 nm) for fresh meat color (AMSA 1991). The ratios and wavelengths used for the calculations were: K/S 474÷K/S 525 for percent deoxymyoglobin, K/S 572 ÷ K/S 525 for percent metmyoglobin, and K/S 610 ÷ K/S 525 for percent oxymyoglobin. Further information concerning calculation of deoxy-, met-, and oxy-myoglobin is given elsewhere (AMSA 1991).

5.3.6 Statistical analysis

The effects of treatment differences (control, Ageless® FX-100, and FreshPax® R-2000 O_2 scavengers) were examined statistically using analysis of variance (Proc ANOVA, SAS Institute Inc., Cary, NC) at an α level of 0.05.

5.4 Results

5.4.1 Oxygen concentration

Oxygen concentration increased from 78 to 477 ppm on the first day of storage in the master pack without O_2 scavengers which may be expected due to release of O_2 from oxymyoglobin under reduced O_2 conditions, whereas in packs containing Ageless® FX-100 or FreshPax® R-2000 O_2 scavengers, O_2 decreased to 31 and 0 ppm, respectively (Table 5.1). Oxygen concentration decreased continuously until day 6 in master packs with no O_2 scavengers, and reached 0 ppm in master packs containing FreshPax® R-2000 and Ageless® FX-100 O_2 scavengers after 1 and 2 days of storage, respectively. An increase in O_2 concentration was observed in master packs containing controls on day 7, and 8 of storage, which may have been due to a package-leak.

5.4.2 Visual assessment of steaks

Color: On day 0, steaks serving as fresh controls were given color scores of 6 (slightly dark red). After subsequent daily storage intervals, steaks packaged with no O_2 scavengers received color scores of 5 (bright cherry red) or 6 (slightly dark red) and steaks packaged with Ageless® FX-100 and FreshPax® R-2000 O_2 scavengers received color scores of 6 and 5 or 6, respectively (Table 5.2). Steaks packaged with FreshPax® R-2000 were a little less dark than the steaks packaged with Ageless® FX-100 O_2 scavengers.

Discoloration: On day 0, all steaks received discoloration scores of 1 (0%: discoloration). After subsequent daily storage intervals, steaks packaged with no O_2 scavengers had discoloration scores of either 2 (1-10% discoloration), 3 (11-25%

discoloration) or 4 (26-50% discoloration) (Table 5.2). Steaks packaged with Ageless® FX-100 O_2 scavengers received a discoloration score of 1 (0% discoloration) after 2, 4, 6, and 7 days, and 2 (1-10% discoloration) after 1, 3, 5, and 8 days. Steaks packaged with FreshPax® R-2000 O_2 scavengers received discoloration scores of 1 (0% discoloration) at storage intervals of 1, 2, 4 and 6 days , and discoloration scores of 2 (1-10% discoloration) at storage intervals of 3, 5, 7, and 8 days (Table 5.2).

Retail Appearance (RA): On day 0, control steaks received retail appearance scores of 7 (extremely desirable). After subsequent daily storage intervals, steaks packaged with no O_2 scavengers received RA scores of 5 (slightly desirable) or 6 (desirable) after 1, 2, 5, and 7 days. However, these scores were down to 3 (slightly undesirable) or 4 (neither desirable nor undesirable) after 3, 4, 6, and 8 days of storage. Steaks packaged with Ageless® FX-100 O_2 scavengers received RA scores of 6 (desirable) or 7 (extremely desirable) for all storage intervals, and steaks packaged with FreshPax® R-2000 O_2 scavengers received RA scores of 6 or 7 for all storage intervals, except after 7 days when they received RA scores of 5 (slightly desirable) (Table 5.2). Visual scores of the trained panel are given in Appendix D.

5.4.3 Percentage of metmyoglobin on the steak surface

Metmyoglobin content was not significantly different for control steaks (with no O_2 scavengers) after most storage intervals when compared with steaks packaged with O_2 scavengers ($p>0.05$), except after 3 and 7 days. Metmyoglobin content increased from 3.5 on day 0 to 22.8 % on day 3, then decreased to 4.7% on day 4, and again increased to 16.1% on day 7 but decreased to 5.2% on day 8 (Table 5.3). Discoloration

was visible at the edges of these steaks for all storage intervals. However, these areas were not exposed during reflectance spectrophotometry, and thus, the reflectance spectra did not report this discoloration, which would have undoubtedly increased the proportion of metmyoglobin. Detailed reflectance data are given in Appendix E.

Metmyoglobin content of steaks packaged with Ageless® FX-100 O_2 scavengers was not significantly different when compared to control steaks (steaks packaged with no O_2 scavengers), for all storage intervals ($p>0.05$), except after 3 and 7 days of storage. Also, the metmyoglobin content was comparable with that of the fresh control for all storage intervals ($p>0.05$) (Table 5.3).

The metmyoglobin content of steaks packaged with FreshPax® R-2000 O_2 scavengers was not significantly different when compared with fresh controls and steaks packaged with Ageless® FX-100 O_2 scavengers, for all storage intervals ($p>0.05$). In contrast, steaks packaged with no O_2 scavengers had significantly higher metmyoglobin content than the steaks packaged with FreshPax® R-2000 O_2 scavengers after 3, and 7 days of storage ($p<0.05$). Differences were most noticeable at 2, 3, 6, and 7 days of storage, where the metmyoglobin content of steaks packaged with FreshPax® R-2000 O_2 scavengers was reduced to zero (Table 5.3).

5.5 Discussion

On day 0, the O_2 concentration was 78 ppm and this rose to 477 ppm in master packs without O_2 scavengers after 1 day of storage. Master packs containing O_2 scavengers had no measurable O_2 at most storage times, except after 1 and 2 days in the case of Ageless® FX-100 O_2 scavengers. As a consequence, steaks with O_2 scavengers

had low metmyoglobin content and almost no discoloration, which resulted in significantly higher RA scores. Steaks packaged without O_2 scavengers had an increase in metmyoglobin content from day 0 to day 3 of storage. After 4 days of storage metmyoglobin content decreased, but then gradually increased until after 7 days of storage, when it decreased again. This indicates these steaks underwent two cycles of transient discoloration, regaining color due to MRA or other reducing factors. Steaks packaged with O_2 scavengers did not undergo such transient discoloration. Moreover, steaks packaged with FreshPax® R-2000 O_2 scavengers had lower metmyoglobin content than the fresh control after all storage intervals, and metmyoglobin content was reduced to zero in some cases. These results are supported by the observation that at no or low partial pressure of O_2, metmyoglobin present in the muscle was reduced to deoxymyoglobin due to MRA (O'keeffe and Hood 1982). Higher metmyoglobin contents (25 or 23%) were observed after 2 and 4 days of CAP storage on LD steak surfaces, which resulted in transient discoloration which pose a challenge for centralized preparation of retail ready meat cuts (Gill and Jones 1994a). In the present study, PM steaks expected to have poor color stability were used, but very low metmyoglobin contents and high RA scores were observed in samples packaged with O_2 scavengers. Thus, our hypothesis of combining O_2 absorbent technology with CAP to prevent transient discoloration was confirmed.

The O_2 concentration during initial packaging was 78 ppm, and it went up to 477 ppm after one day of storage. Therefore the amount of time required to reduce the O_2 concentration from 477 to 0 ppm would be almost four times the half-life of O_2 in the

package atmosphere. For Ageless® FX-100 and FreshPax® R-2000 O_2 scavengers, by incorporating 32 or 8 scavengers used in the study (Chapter 3), the O_2 half-lives were 0.6 and 0.7 h, respectively (Steaks will also contribute to the total O_2 absorbing capacity to some extent (<10%) (Gill and McGinnis 1995b)). Thus, at 1±0.5°C, transient discoloration of PM steaks can be prevented if residual O_2 is reduced to 0 ppm within 3 h of pack closure.

Selection of a suitable retail packaging system is another critical aspect of master packaging technology using CAP. It is evident from the results of the present study that the O_2 concentration in the master pack may initially increase drastically after packaging. Such an increase may be attributed to O_2 entrapment either in the absorbent pad or under the over-wrap film during evacuation. In addition, meat tissue itself initially releases dissolved, unreacted O_2 causing reduction of oxymyoglobin to deoxymyoglobin in the presence of low partial pressures of O_2 in the headspace during CAP storage. This increase is inevitable. Therefore, O_2 entrapment must be minimized to prevent O_2 concentrations increasing in the pack to the point where transient discoloration may occur.

It has been found that over-wrap film with high O_2 permeability acts as an O_2-barrier at low initial O_2 concentrations (Chapter 3), and the barrier property increases at low storage temperatures. It is also evident that O_2 concentration may increase due to entrapment of O_2 in either the soaker pad or the over-wrap. It is recommended that each retail tray within the master pack contain O_2 scavengers to absorb any O_2 trapped inside tray which may affect meat color. This conclusion was reached during concurrent work

(Chapter 4), which indicated less discoloration occurred on steak surfaces in a system where O_2 scavengers were placed inside the retail tray as compared to a system where O_2 scavengers were placed in the master pack. Perhaps this is the reason Gill and McGinnis (1995b) used 20 scavengers in each master pack stored at -1.5°C to prevent transient discoloration even when the initial O_2 concentration in the package was 40 ppm. Placing O_2 scavengers directly inside the retail tray should reduce the number of O_2 scavengers required.

The present study was designed to examine meat samples with the highest pigment instability stored under conditions conducive to discoloration during centralized distribution. For that purpose PM beef steaks were used in experiments. Although a storage temperature of 1±0.5°C is not recommended for optimized storage life of fresh meat cuts in centralized systems, it is closer to the optimum (-1.5°C) than the commercial norm of 4°C. Rates of myoglobin oxidation and metmyoglobin reducing activity increase and decrease, respectively, at temperatures above 0°C (Gill and McGinnis 1995a). Thus, better results can be expected at -1.5°C. Nevertheless, under worst-case conditions, the use of O_2 scavengers in conjunction with CAP prevented transient discoloration of PM beef steaks. It is probable that the system used in the present study will easily prevent transient discoloration in beef steaks with higher color stability, such as LD, especially if stored below 0°C. Oxygen scavengers have the potential of preventing transient discoloration of all centrally prepared beef cuts, but, factors such as selection of packaging systems, O_2 scavenger type, and package atmospheres (N_2/CO_2) may affect results. Similar studies on other cuts of retail-ready

and ground beef are warranted.

Table 5.1 The oxygen (O_2) concentration in master packs* containing beef steaks stored under a nitrogen atmosphere for up to eight days at 1±0.5°C.

Day	Oxygen Concentration (ppm)		
	Control[a]	FX-100[b]	R-2000[c]
0	78	78	78
1	477	31	0
2	340	7	0
3	328	0	0
4	110	0	0
5	56	0	0
6	37	0	0
7	50	0	0
8	243	0	0

* Four over-wrapped trays, each containing a PM steak, were placed in a master pack.
[a] Master pack with four retail trays, without O_2 scavengers.
[b] Master pack with four retail trays, each containing eight Ageless® FX-100 O_2 scavengers underneath the absorbent pad.
[c] Master pack with four retail trays, each containing two FreshPax® R-2000 O_2 scavengers underneath the absorbent pad.

Table 5.2 Sensory panel scores (average scores of five panelists±standard deviation) for beef (PM) steaks stored in master packs* under a nitrogen atmosphere for up to eight days at 1±0.5°C.

	Color†, **			Discoloration††, **			Retail Appearance‡, **		
Day	Control[a]	FX-100[b]	R-2000[c]	Control	FX-100	R-2000	Control	FX-100	R-2000
0	5.6±0.5[***,E,F,D,G]			1.0±0.0[K]			6.8±0.4[A]		
1	5.3±0.5[I,H,G]	5.8±0.7[E,F,D,C]	5.7±0.9[E,F,D,G]	2.5±1.1[E,F,D]	1.8±1.1[H,I,J,G]	1.4±0.6[H,I,J,K]	4.9±1.9[J,I]	6.0±1.1[E,B,D,C,F]	6.2±1.0[E,B,D,A,C,F]
2	5.9±0.5[E,D,C]	5.8±0.8[E,F,D,C]	5.2±0.5[I,H]	2.7±1.6[E,C,D]	1.2±0.8[H,I,J,K]	1.4±0.5[H,I,J,K]	4.6±2.0[J]	6.5±0.8[B,A,C]	6.4±0.6[B,D,A,C]
3	5.6±0.5[E,F,D,G]	5.9±0.6[E,D,C]	5.6±0.7[E,F,H,G]	3.6±1.3[B]	1.9±1.5[H,F,G,I]	1.9±0.8[H,F,G]	3.6±1.2[K]	5.7±1.1[E,H,G,I,F]	5.7±0.8[E,H,D,G,F]
4	5.6±0.5[E,F,G,H]	5.5±0.5[E,F,G,H]	6.2±0.4[B,A,C]	3.6±0.8[A,B]	1.4±0.6[H,I,J,K]	1.4±0.5[H,I,J,K]	3.2±0.8[K]	6.4±0.8[E,B,D,A,C]	5.6±0.9[E,D,G,C,F]
5	5.1±0.3[I]	5.6±0.6[E,F,G,H]	5.4±0.5[I,F,H,G]	1.8±0.9[H,I,G]	1.9±1.0[H,F,G,I]	1.6±0.8[H,I,J,K]	5.7±0.9[E,H,D,G,F]	5.6±1.2[H,G,I,F]	6.1±0.7[E,B,D,A,C,F]
6	5.5±1.5[E,D,C]	6.5±0.5[A]	5.3±0.8[I,H,G]	4.3±1.5[A]	1.6±0.5[H,I,J,K]	1.1±0.3[J,K]	2.9±1.6[K]	5.8±1.1[E,D,C,F]	6.6±0.5[A,B]
7	6.3±0.5[A,B]	6.0±0.4[B,D,C]	4.4±0.5[J]	3.2±2.1[B,C,D]	1.0±0.0[K]	2.4±0.7[E,F,G]	5.0±1.8[H,J,G,I]	6.7±0.5[A,B]	4.9±1.4[H,J,I]
8	5.7±0.7[E,F,D,G]	6.0±0.4[B,D,C]	5.7±0.7[E,F,D,G]	3.3±1.0[B,C]	1.3±0.5[H,I,J,K]	1.3±0.6[I,J,K]	3.3±1.2[K]	6.1±0.7[E,B,D,A,C,F]	6.4±0.7[B,D,A,C]

* Four over-wrapped trays, each containing a PM steak, were placed in a master pack.
[a] Master pack with four retail trays, with no O_2 scavengers.
[b] Master pack with four retail trays, each containing eight Ageless® FX-100 O_2 scavengers underneath the absorbent pad.
[c] Master pack with four retail trays, each containing two FreshPax® R-2000 O_2 scavengers underneath the absorbent pad.
† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red,

8=Extremely dark red.

[††] Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).

[‡] Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

[**] Means within the same category (color, discoloration, appearance) having the same superscript letter are not significantly different ($p>0.05$).

[***] Standard deviation.

Table 5.3 Mean values (±standard deviation) for the oxidation states of myoglobin obtained from the surfaces of beef (PM) steaks, stored in master packs* under a nitrogen atmosphere for eight days at 1±0.5°C. Steaks were prepared from beef tenderloins within 24 h of slaughter.

Day	% Metmyoglobin**			% Deoxymyoglobin**			% Oxymyoglobin**		
	Control[a]	FX-100[b]	R-2000[c]	Control	FX-100	R-2000	Control	FX-100	R-2000
0	3.5±3.2***,D,C			0.0±0.0D			96.5±3.2A,B		
1	10.9±21.9B,D,A,C	6.7±2.5B,D,C	2.7±4.5D,C	2.5±1.7D,C	6.7±13.5B,D,C	7.3±14.6B,D,C	86.6±10.2B,D,A,c	86.5±14.1B,D,A,C	90.0±19.1B,D,A,C
2	10.2±19.5B,D,C	10.5±7.7B,D,C	0.0±0.0D	19.5±14.3A	1.4±2.9D,C	0.0±0.0D	70.3±8.4E	88.1±5.2B,D,A,C	100.0±0.0A
3	22.8±15.9A	6.3±4.3B,D,C	0.0±0.0D	7.8±7.5B,D,A,C	3.6±4.3D,C	6.2±6.3D,C	69.5±10.5E	90.1±2.1B,D,A,C	93.9±6.3B,A,C
4	4.7±4.9B,D,C	3.1±2.9D,C	1.8±2.1D,C	13.1±9.6B,A,C	18.5±19.9A,B	8.2±5.2B,D,A	82.1±5.9B,D,E,C	78.4±22.1D,E	89.9±7.3B,D,A,C
5	6.4±1.9B,D,C	6.1±7.1B,D,C	2.2±2.9D,C	4.9±9.9D,C	0.3±0.5D	2.7±4.4D,C	88.±9.1B7,D,A,C	93.6±7.3B,A,C	95.1±7.2B,A,C
6	12.4±15.2B,A,C	8.9±5.7B,D,C	0.0±0.0D	0.3±0.5D	10.3±12.6B,D,A,C	0.0±0.0D	87.4±14.9B,D,A,C	80.8±17.8D,E,C	100.0±0.0A
7	16.1±15.9A,B	3.2±3.8D,C	0.0±0.0D	6.7±8.1D,C	3.2±3.0D,C	1.5±2.3D,C	77.2±8.6D,E	93.7±1.5B,A,C	98.6±2.3A
8	5.2±4.3B,D,C	4.4±5.1B,D,C	2.5±2.3D,C	6.7±8.7D,C	0.6±1.3D	3.3±4.4D,C	88.1±9.3B,D,A,C	94.9±5.4B,A,C	94.2±2.4B,A,C

* Four over-wrapped trays, each containing a PM steak, were placed in a master pack.
[a] Master pack with four retail trays, without O_2 scavengers.
[b] Master pack with four retail trays, each containing eight Ageless® FX-100 O_2 scavengers underneath the absorbent pad.
[c] Master pack with four retail trays, each containing two FreshPax® R-2000 O_2 scavengers underneath the absorbent pad.
** Means within the same category (metmyoglobin, deoxymyoglobin, oxymyoglobin) having same superscript letter are not significantly different ($p>0.05$).
*** Standard deviation.

6. DISPLAY LIFE OF RETAIL-READY MASTER-PACKAGED BEEF STEAKS USING O_2 ABSORBENT TECHNOLOGY AFTER STORAGE IN A LIQUID-N_2 REFRIGERATED CONTAINER

6.1 Summary

Beef tenderloins (*psoas major*, PM), cut into steaks, were master-packaged under 100% N_2 atmosphere, and stored at -1.5°±0.5°C in a liquid-N_2 refrigerated container for 10 weeks. At weekly intervals, 2 master packs were removed from storage, and steaks were analyzed for visual, odor, flavor, and microbiological characteristics. Also, reflectance spectra were obtained from the steak surface to estimate metmyoglobin content. The steaks were placed on retail display for 4 days, and daily analyses of visual characteristics using both a panel and a reflectance spectrophotometer were conducted. On days 0 and 4 of retail display, odor, flavor, and microbial analysis were also performed along with visual examination.

Steaks had acceptable visual, odor, and flavor characteristics on day 0 of retail display for any prior storage interval in master packs. Also, metmyoglobin content (<10%) and microbial count ($<10^2$ cfu/cm^2) were comparable with controls. All steaks were acceptable until day 3 of retail display. Storage time under N_2 had a significant effect (<0.05) on visual characteristics, however, this effect was only of marginal practical importance. However, the retail display period significantly ($p<0.05$) affected visual, odor, flavor, and microbial characteristics. Retail appearance was the limiting factor for the retail display life of the steaks. The developed system can deliver a storage life of at least 10 weeks with a subsequent retail display life of 3 days for master-

packaged PM steaks.

Key-words: Controlled atmosphere packaging, O_2 absorbent technology, master packaging, retail-ready fresh beef, meat shelf life.

6.2 Introduction

Centralized packaging of retail meat cuts is gaining the attraction of the meat industry because of its economies and potential to maintain quality, safety, and extend the shelf life of fresh meat (Farris et al. 1991). There are two basic requirements for a centralized system, strict temperature control (-1.5±0.5°C) and master-packaging technology using controlled atmosphere packaging (CAP). Such a strict temperature control is desired because shelf life of fresh meat can be optimized by storing meat at a temperature just above its freezing point and within a narrow range as the growth of spoilage bacteria is proportional to storage temperature (Gill and Jones 1992). In addition, color stability is maximized at sub-zero temperatures because a decrease in temperature increases the distance from the meat surface at which the maximum metmyoglobin is formed due to increased solubility of O_2 in the water of the meat tissue. This has the effect of decreasing the maximal O_2 concentration required for maximum metmyoglobin formation, but also makes it less visible (O'keeffe and Hood 1982). Recently, a liquid-N_2 refrigerated container has been developed using a jacketed design (Jeyamkondan 1999), which can control temperature within the required narrow range. Thus, the primary requirement for maintaining temperature in a narrow range during storage and transportation of fresh meat has been achieved (Jeyamkondan 1999).

The secondary requirement was use of an appropriate master packaging system, which would minimize both color instability and microbial spoilage. Although research has been done on microbiological and sensory aspects of meat during centralized meat packaging under various modified atmospheres (Gill and Jones 1994a, 1994b, 1996; Jeremiah and Gibson 1997a, 1997b, 1997c; Tewari et al. 1999), meat discoloration due to residual O_2 in controlled atmospheres remains a challenge as the rate of metmyoglobin formation increases at low partial pressures of O_2 (Faustman and Cassens 1990). Beef steaks made from muscles of poor color stability such as *psoas major*, PM, discolor rapidly even at O_2 concentrations of <100 ppm and sub-zero temperatures, and this results in short storage life under CAP and short subsequent display life (Gill and McGinnis 1995a). Consequently, techniques for reducing O_2 concentrations in package during CAP storage (O_2 absorbent technology) became an attractive option. However, there is little information about the O_2 absorption kinetics of commercial O_2 scavengers available, and there is some discrepancy in the literature about their efficacy (Sorheim et al. 1995a, b; Allen et al. 1996; Rousset and Renerre 1990; Doherty and Allen 1998; Isdell et al. 1999). In addition, a suitable retail packaging system is required to reduce residual O_2 in the controlled atmospheres by reducing opportunity for O_2 entrapment within retail trays. To resolve these issues, studies related to the O_2 absorption kinetics of commercial O_2 scavengers (Chapter 3) and retail packaging system design (Chapter 4) were performed. Knowing the disadvantages and advantages of residual O_2 in the packs and sub-zero storage temperatures, respectively, the present study was designed to examine the efficacies of CAP storage, O_2 absorbent technology, and liquid-N_2

refrigeration to minimize the deterioration of centrally prepared beef steaks, and to enhance product shelf life.

6.3 Materials and Methods

6.3.1 Oxygen scavengers

Ageless® FX-100 (Mitsubishi Gas Chemical Co. Inc., Tokyo, Japan) O_2 scavengers were used in the study. These O_2 scavengers are based on iron-chemical systems, and need moisture (>70% relative humidity) for activation. Detailed information about these scavengers has been reported elsewhere (Table 3.1).

6.3.2 Master-packaging, storage, and sampling of steaks

Fresh beef tenderloins (*psoas major*, PM) from animals slaughtered 24 h previously, were obtained from a local beef abattoir. Eighty steaks of 2 cm thickness, were prepared from these tenderloins. Each steak was placed on a 152 x 114 mm absorbent pad (MP-30620, Paper Pak® Corp., La Verne, CA) in a 216 x 133 x 25 mm (L x W x H) solid polystyrene tray (clear plastic tray # 2D, Western Paper & Food Distributors Ltd., Calgary, AB), with 8 Ageless® FX-100 O_2 scavengers placed underneath the absorbent pad. Each retail tray was over-wrapped with a shrinkable O_2 permeable film (Vitafilm 'Choice Wrap', Goodyear Canada Ltd., Calgary, AB) with an O_2 transmission rate of 8000 mL/(m^2 24 h) at 1 atm, 23°C, and 70% RH. After sealing, the film was shrunk to the tray using a hot air gun. Then, two 3 mm holes were made at the corners of the tray to allow free exchange of atmospheres during gas flushing. Four such retail trays were placed in an EVA co-extruded master pack (WINPAK ESOPAEV2E 121575 R, Winnipeg, MB) with O_2 transmission rate of 0.55 mL/(m^2 24

h) at 1 atm, 23°C, and 70% RH. The bags were evacuated, filled with 4.5 L of N_2, and sealed using a CAP machine (CAPTRON®, SecureFresh Pacific Ltd., Auckland, New Zealand). Twenty such bags were prepared. Additionally, 8 retail trays were prepared and treated as un-stored (fresh) controls. During initial packaging, the O_2 concentration was measured in every fifth bag using an O_2 analyzer (Mocon MS-750, Modern Controls Inc., Minneapolis, MN), which is based on a solid state O_2 ion conduction material, zirconium oxide. The appendices A1 and A2 give specifications, working principle, and calibration procedure of the O_2 analyzer.

The master packs were stored at -1.5±0.5°C in the liquid-N_2 refrigerated container (Fig. I2 in Appendix-I). On week 0 and day 0 of retail display, four steaks in retail trays, which served as fresh, un-stored controls, were analyzed for visual, odor, taste, and microbial characteristics. Also, reflectance spectra were obtained from the surface of these steaks. The visual analysis was done daily for four days, and reflectance spectra were also obtained daily. On day 4 of retail display, odor, taste, and microbial analysis were done in addition to visual examination and obtaining reflectance spectra. Two master packs were opened at subsequent 1 week storage intervals for 10 weeks. The O_2 concentration in each bag was measured immediately before opening the bag.

6.3.3 Display and sampling of retail trays

After storage for 1 week, and on day 0 of retail display, all of the eight retail trays from two master packs were placed in the center of the display shelf of a horizontal, fan-assisted display case (model LPM12T, Hill Refrigeration, Barrie, ON). The case was illuminated for 12 h/day with incandescent light giving a light intensity of

750 lux at the display-shelf surface. Detailed information about the display case has been described previously (Gill and Jones 1994a). A temperature data logger (Tru-Test, Auckland, New Zealand) was placed at the center of the display case to record the air temperatures surrounding the product.

The displayed PM steaks were examined for color, discoloration, retail-acceptability, off odor intensity, odor acceptability, and odor profile 45 min after opening of the master-packages. Also, reflectance spectra from the steak surfaces were obtained to estimate the proportions of metmyoglobin, deoxymyoglobin, and oxymyoglobin. After visual scores and reflectance spectra were obtained, two steaks (one from each master bag) were removed from the display case, and samples were taken for microbial analysis. Then the steaks were cooked and analyzed for flavor acceptability and off-flavor intensity. The remaining six steaks were left in the display case and were examined for visual characteristics at subsequent intervals of 24 h over a 96 h period. In addition, reflectance spectra were also obtained at 12 h intervals for 96 h. After 96 h of retail display, the steaks were analyzed in the same fashion as on the day 0 of retail display. Similar procedures were repeated for all storage intervals.

6.3.4 Visual assessment of master-packaged steaks

A five member well-trained panel was used for the subjective evaluation of the steaks. Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%,

4=26-50%, 5=51-75%, 6=76-99%, 7= 100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable (Jeremiah and Gibson 1997b).

6.3.5 Odor assessments of master-packaged steaks

A five member panel was used for odor assessment. Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable. Odor description scores were assessed using a six point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other (Jeremiah and Gibson 1997b).

6.3.6 Flavor assessment of master-packaged steaks

The steaks were cooked according to a standard procedure (Jeremiah et al. 1998). The steaks had thermocouples inserted horizontally into them, making sure that the tip was in the center of the steak. They were then placed on a grill (Type G01, Hamilton Beach, Proctor-Silex Inc., Washington, NC) preheated to 210°C. As steaks reached an internal temperature of 40°C, they were flipped and grilled to a final temperature of 72°C. The steaks were allowed to cool for 5 min. The cooked steaks were trimmed of outside surfaces and were then cut into 1.5 cm cubes avoiding all fat and large areas of connective tissue. Each sample had a color coded pin inserted into it for identification and all were placed into glass jars in a circulating water bath at 70°C for 7 min to

equilibrate sample temperatures. Then they were served to three or four well-trained panelists for rating. All panel sessions were conducted in well ventilated, temperature-controlled, partitioned booths under 1076 lx of fluorescent and incandescent lighting. Room temperature distilled water and unsalted soda crackers were provided to panelists for the removal of residual flavor notes between sample evaluations. The flavor was assessed using a six point descriptive scale: 6=Desirable, 5=Moderately desirable, 4=Slightly desirable, 3=Slightly undesirable, 2=Moderately undesirable, 1=Undesirable. Off flavor intensity was assessed using a four point descriptive scale: 4=Prevalent off flavor, 3=Moderate off flavor, 2=Slight off flavor, 1=No off flavor; and additional comments on overall palatability were also noted.

6.3.7 Estimation of myoglobin forms

The average reflectance spectrum was obtained from 3 locations of the steak covered with a shrinkable film using a reflectance spectrophotometer (Macbeth Color Eye 1500/Plus, Kollmorgen Corp., Newburg, NY). Reflectance values (R) of the different myoglobin oxidation states were estimated at specified wavelengths, and converted to K/S values (K is the absorption coefficient and S is the scattering coefficient). The K/S values are used for quantifying the proportion of deoxy-, met-, and oxy-myoglobin, and are calculated using selected wavelengths (474, 525, 575, and 610 nm) for fresh meat color (AMSA 1991). The ratios and wavelengths used for the calculations were: K/S 474÷K/S 525 for percent deoxymyoglobin, K/S 572 ÷ K/S 525 for percent metmyoglobin, and K/S 610 ÷ K/S 525 for percent oxymyoglobin. Further information concerning calculation of deoxy-, met-, and oxy-myoglobin is available

(AMSA 1991).

6.3.8 Microbial analysis

A 10 cm^2 sample was obtained at each sampling time (on days 0 and 4 of each storage interval) from each of the two steaks using a sterile cork borer. Then, the sample was placed into a stomacher bag with 10 mL of 0.1% peptone solution and was stomached for 120 s using a commercial stomacher (Stomacher 400, Seward Medical, London, UK), yielding a dilution of 10^0 cfu/cm^2. The homogenate was further diluted to 10-, 100-, 1000-, 10000-, and 100000-, after which 0.1 mL volumes of undiluted homogenate and of each dilution prepared, were spread on duplicate plates of APT (All Purpose Tween, DIFCO Laboratories, Detroit, MI). The plates were incubated for 3 days at 25°C. Total microbial populations were determined by counting colonies on plates bearing 20-200 colonies. A detailed explanation of microbial analysis is given in Appendix G.

6.3.9 Statistical analysis

The main effects of storage interval and retail display period were examined statistically using analysis of variance (proc ANOVA, SAS Institute Inc., Cary, NC) at an α level of 0.05.

6.4 Results

6.4.1 Measurement of O_2 concentration

The O_2 concentration was < 100 ppm during initial packaging, and after any storage interval was reduced to an undetectable level until week 8 when 24 ppm of O_2 was measured in one bag.

6.4.2 Storage and retail display temperature

The temperature in the liquid-N_2 refrigerated container was maintained at -1.5±0.5°C for all storage intervals, and the retail display temperature was maintained between 6.5-8.2°C throughout the display period.

6.4.3 Evaluation of steaks

Although significant ($p<0.05$) differences existed between storage intervals in visual color rating on day 0 of retail display, i.e., when steaks were removed from storage, all steaks were perceived to be bright cherry red or slightly dark red and no differences of practical importance existed. Generally, steaks remained stable in color until they became moderately dark (Fig. 6.1) or completely discolored (data not shown) on the 4th day of retail display for any storage interval. Steaks were completely discolored on day 1 of retail display after 1 week of storage. Data obtained on these steaks were not analyzed further.

On day 0 of retail display for any storage interval, no significant ($p>0.05$) surface discoloration was noticed on the steaks. The retail display period significantly ($p<0.05$) increased the amount of surface discoloration on the steaks for any storage interval. However, the steaks discolored at a faster rate than the controls for all storage intervals, and were relatively extensively discolored ($p<0.05$) (Fig 6.2). Steaks were extremely desirable in retail appearance on day 0 of retail display for any storage interval ($p>0.05$). However, steaks' retail appearances were significantly affected by the retail display period ($p<0.05$). Despite the fact they darkened more rapidly in retail appearance than un-stored (fresh) controls, they were in the acceptable range (~3.5) on the 3rd day of

retail display (Fig. 6.3).

From practical perspective, it was significant that with stored steaks no off-odors were perceived on day 0 of retail display for any storage interval, however, significant differences existed between storage intervals with respect to off odor intensity ratings ($p<0.05$) (Fig. 6.4). The maximum difference in ratings was 0.3 of a panel unit, which is of marginal practical importance. Generally, odor was acceptable on steaks on day 0 of retail display (Fig. 6.5). Maximum differences of 0.3 of a panel unit were noticed after 7 and 8 weeks of storage, which have little practical significance. Despite significant ($p<0.05$) differences between storage intervals on odor acceptability ratings on day 4 of retail display, majority of steaks were perceived to be slightly acceptable (Fig. 6.5). The predominant odor was either sour-lactic acid or other (stale).

Significant ($p<0.05$) differences existed between storage intervals in flavor acceptability ratings on day 0 of retail display. All steaks were perceived to be desirable, and differences were of only marginal practical importance. The lowest score of 3.2 (slightly undesirable) was obtained after 10 weeks of storage (Fig. 6.6). However, on day 4 of retail display, steaks had significantly ($p<0.05$) lower flavor acceptability scores than controls, and had undesirable scores after 7 weeks of storage and onwards (Fig. 6.6). Obviously, storage intervals had a significant ($p<0.05$) effect on off-flavor intensity scores (Fig. 6.7), and after 8 weeks of storage and onwards, slight off-flavors were perceived on day 0 of retail display (Fig. 6.7). On day 4 of retail display, steaks perceived to have moderate off-flavors in most cases, when compared with non-stored controls (Fig. 6.7).

Despite significant ($p<0.05$) differences between storage intervals on microbial numbers on day 0 of retail display, steaks had $<10^2$ cfu/cm^2 of total aerobic microbial population, and no differences of practical importance existed because such numbers do not normally cause off-odors. Microbial populations at day 0 of retail display were comparable with those of non-stored controls (Fig. 6.8). On day 4 of retail display, microbial populations were $\geq 10^4$ cfu/cm^2 in most cases (Fig. 6.8).

Steaks had <10% of metmyoglobin and >90% oxymyoglobin on day 0 of retail display for any storage interval (Fig. 6.9). Deoxymyoglobin content was down to 0% at any storage interval or retail display time. Retail display period significantly ($p<0.05$) increased the metmyoglobin content of steaks for any storage interval. Rates of metmyoglobin formation were essentially the same during retail display when compared with un-stored (fresh) controls, and in some cases, steaks had significantly ($p<0.05$) lower metmyoglobin content than un-stored (fresh) controls (Fig. 6.9). Although significant ($p<0.05$) differences existed between some storage intervals on metmyoglobin content, such as after three and five weeks of storage, steaks had ≤ 70 % metmyoglobin content on the 3rd day of retail display and received satisfactory retail appearance scores. This makes these differences of only marginal practical importance from consumers perspective. Steaks did not reach the point of unacceptability (≤ 3.5) in appearance on the 3rd day of retail display. Thus a retail display life of three days for the steaks was obtained in the present study at which point the metmyoglobin content was ≤ 70%. Appendices F, G, and H contain panel, microbial, and reflectance data, respectively.

6.5 Discussion

Centrally prepared retail beef cuts stored in controlled atmospheres containing nearly 100% carbon dioxide (CO_2) or nitrogen (N_2) which may have small amounts of O_2, are susceptible to the formation of metmyoglobin, due to the presence of residual O_2 (Ledward 1970; Gill 1989; Gill and Jones 1994a). If the O_2 concentration is not excessive, the meat will absorb the residual O_2 and any metmyoglobin formed will be reduced to deoxymyoglobin as a result of metmyoglobin reducing activity (MRA) within the muscle tissue (O'keeffe and Hood, 1980-81a, b, 1982). Gill and Jones (1994a) reported that in packaged fresh beef 2-4 days are required for reduction of metmyoglobin to deoxymyoglobin. When stored meat is removed from the controlled atmosphere, it blooms to the desirable, bright, red color associated with freshly cut meat, but this will not occur if a substantial amount of metmyoglobin is present (Gill 1990). The metmyoglobin reducing activity of muscle tissue is limited and once exhausted metmyoglobin cannot be converted back to myoglobin (Gill 1991). The tenderloins are expected to have very poor color stability and discolor rapidly even at very low O_2 concentrations and at a storage temperature of -1.5±0.5°C. Thus, the tests conducted rigorously evaluated discoloration by using these muscle tissues. The effect of inter-muscular differences on color stability is an important parameter regarding discoloration of meat (Hood 1980; Renerre 1984). Biochemical factors, such as oxygen consumption rate (OCR) and MRA, have been reported to be different for different muscles (O'keeffe and Hood 1982). Therefore, the overall system was evaluated using beef muscles which have poor color stability and it represents a worst-case situation for centralized meat

operations. Efficacy of O_2 absorbent technology was also put to the test during this study to prevent transient discoloration by reducing O_2 concentration to zero ppm rapidly, and thereby conserving the limited MRA of muscle. Once conserved, MRA may further serve to enhance the retail display life of steaks. It was shown that the steaks packaged with an optimum of added O_2 absorbing capacity had more retail display life when compared with steaks packaged without such capacity (Figs. 4.1-4.3). Thus, the system used in the present study had the capability to provide remedies to major problems related to residual O_2 concentrations and temperature control.

For all storage intervals, the steaks had acceptable visual, odor, and flavor scores on day 0 of retail display. Additionally, metmyoglobin content and microbial growth was minimal, and in some cases even lower than fresh controls on the day packs were opened and displayed. Along with a low storage temperature of -1.5±0.5°C, an important factor influencing microbial growth was the low initial microbial load. Beef tenderloins were used in the study, and since they are internals cuts, they do not undergo much handling by meat cutters as compared to other cuts. This factor reduced cross-contamination, and yielded low level of initial microbial contamination. Also, in the present study, meat was obtained from a Federally inspected beef packing plant which had a recognized Hazard Analysis Critical Control Point (HACCP) program in place to monitor meat hygiene practices. Results showed that the meat cuts used in the present study had a very low level of microbial contamination, which would have delayed premature development of off-odors. Therefore, microbial growth and odor were not among the limiting factors which influenced available storage and retail display lives of

steaks.

Due to the increased solubility of O_2 and the decreased maximum O_2 partial pressure requirement for maximal metmyoglobin formation at sub-zero temperatures, maximum discoloration occurred several millimeters below the meat surface. Since meat is translucent, such discoloration is normally visible. The deeper the maximum discoloration, the lower the visibility, and this resulted in low discoloration and higher retail appearance scores during retail display. Also, use of O_2 scavengers which provided an optimum O_2 absorbing capacity in each retail tray prevented transient discoloration of beef steaks, in turn conserved MRA and delayed discoloration further. Prevention of such transient discoloration has been reported (Tables 5.1-5.3). The combination of these strategies resulted in reduced discoloration even on day three of the retail display period. Since the bright-red color of meat was restored, the steaks received acceptable retail appearance scores on day 3 of retail display for all storage intervals, after which the meat was in an unacceptable range. Thus, visual characteristics seemed to be the limiting factor for evaluation of steaks but this is not the complete profile. Steaks had a slight off-flavor on day 0 of retail display after 8 weeks of storage and onwards. Considering the intrinsic variability in meat cuts, and the low number of samples which were evaluated (two), such slight off-flavors may be of no practical importance.

In a similar study by Isdell et al. (1999), a shelf life of 6 weeks with a subsequent retail display life of 2 days was reported for PM steaks at 0°C. It is surprising that such a shelf life was obtained for PM steaks since the packages had a residual O_2 of 500 ppm

after 6 weeks of storage. These results are difficult to understand since it has been established that PM is highly susceptible to discoloration even under 100 ppm of O_2. In another study by Gill and Jones (1994a), a shelf-life of 4 weeks with a subsequent retail display life of 2 days was reported for strip loin steaks. O'keeffe and Hood (1982) reported 1.5 days of retail display life for PM, whereas the present system delivered a retail display life of 3 days. The relative success of the system used in the present study is noteworthy considering the poor color stability of PM muscle. The system may further deliver longer CAP storage and subsequently longer retail display life when beef muscles with higher color stability are used. The present system not only had strict temperature control but also had a means of preventing transient discoloration of meat due to the use of O_2 absorbent technology along with CAP, which resulted in enhanced refrigerated storage and subsequent retail display life. Thus, it can be safely concluded that the present system has the capability of providing a 10 week CAP storage life with a subsequent 3 day retail display life for centrally prepared PM steaks. Similar studies with other beef muscles are warranted.

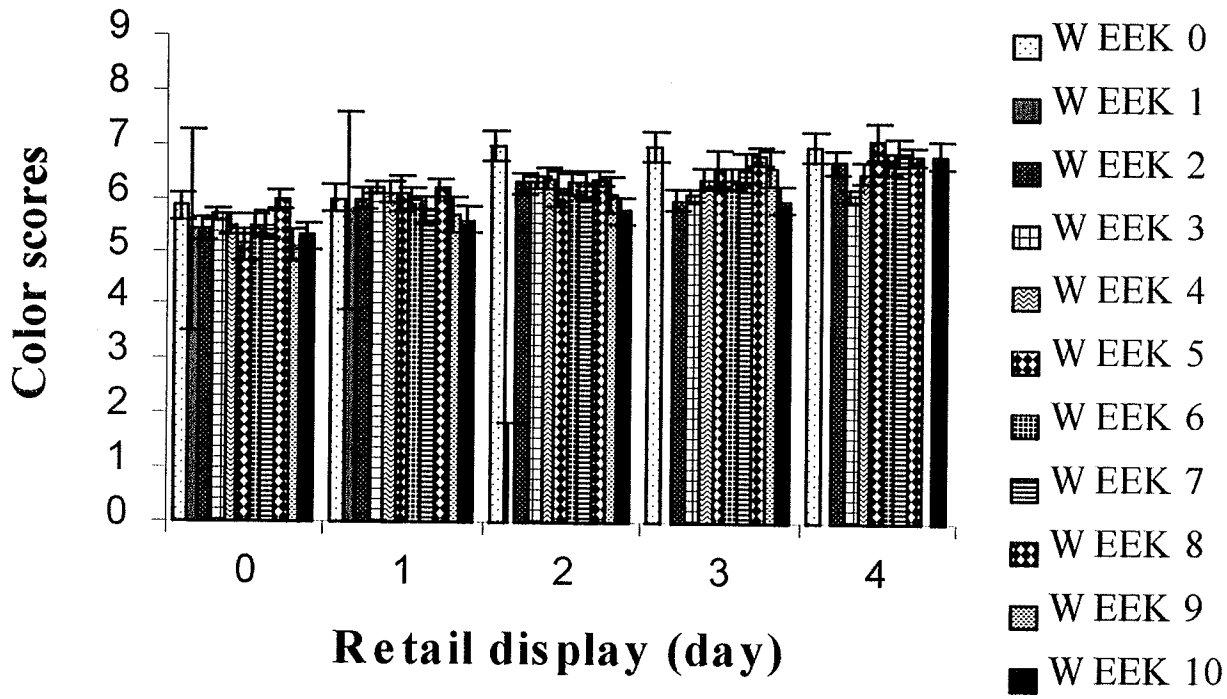

Fig. 6.1 Mean color scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

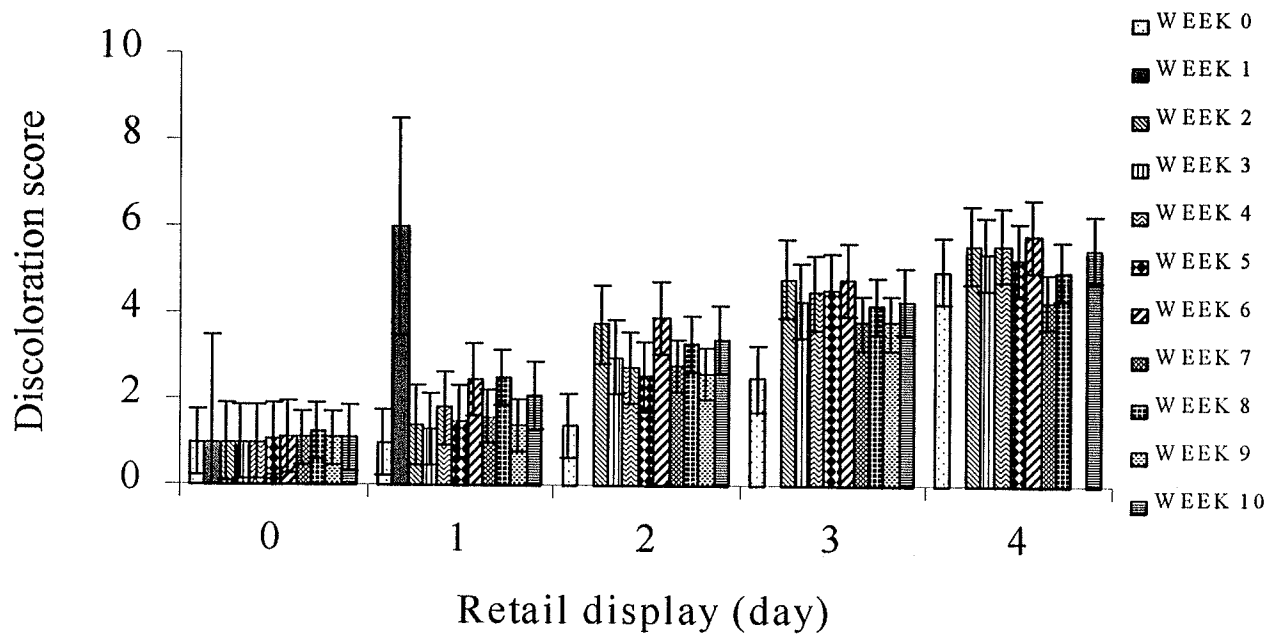

Fig. 6.2 Mean discoloration scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

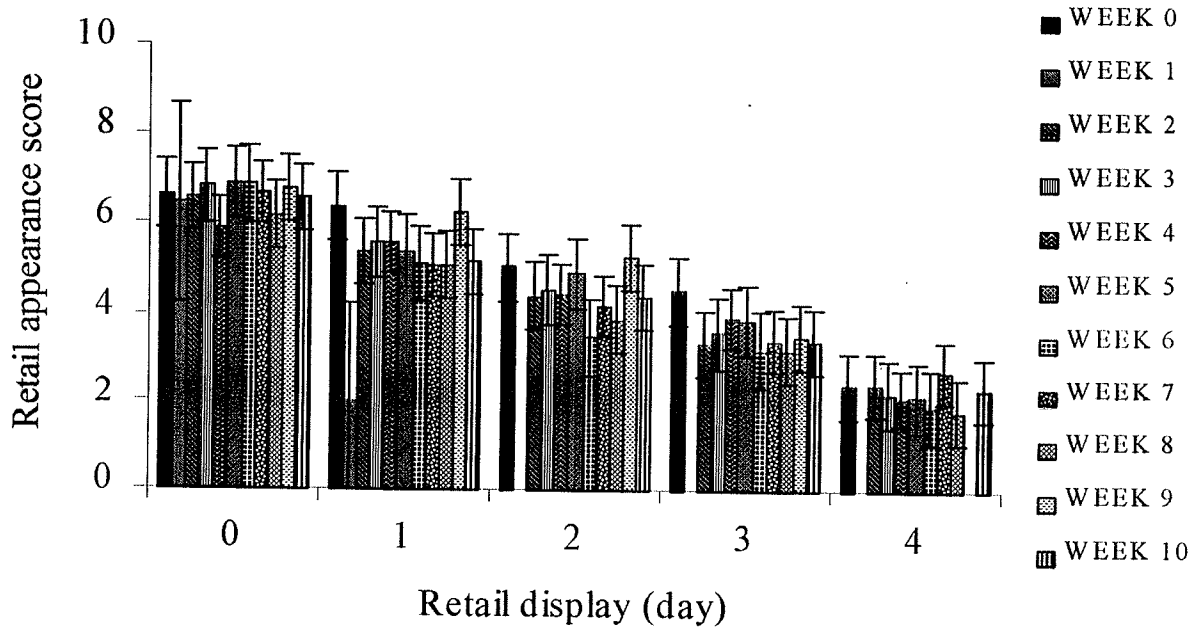

Fig. 6.3 Mean retail appearance scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

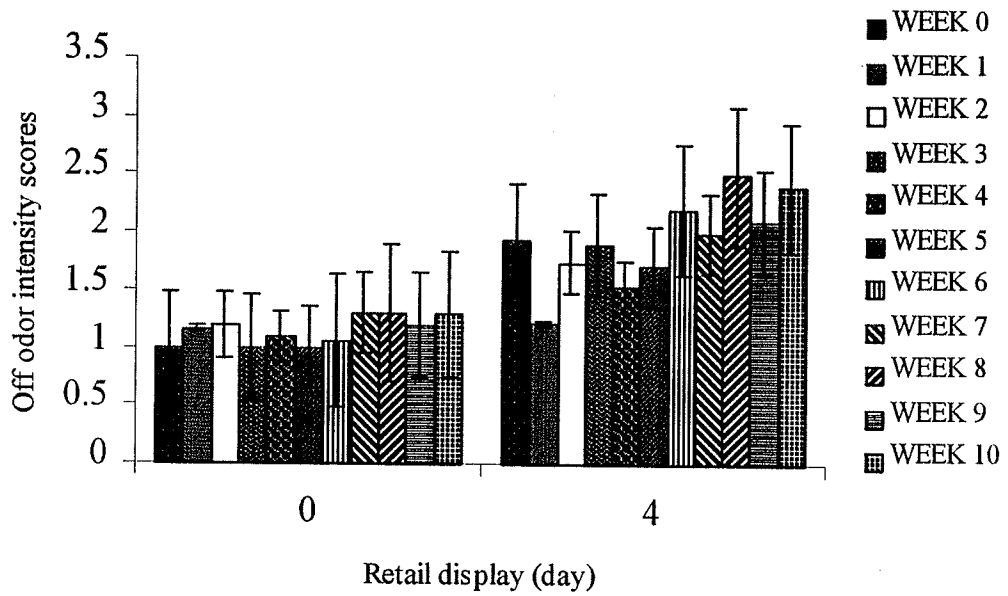

Fig. 6.4 Mean off-odor intensity scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

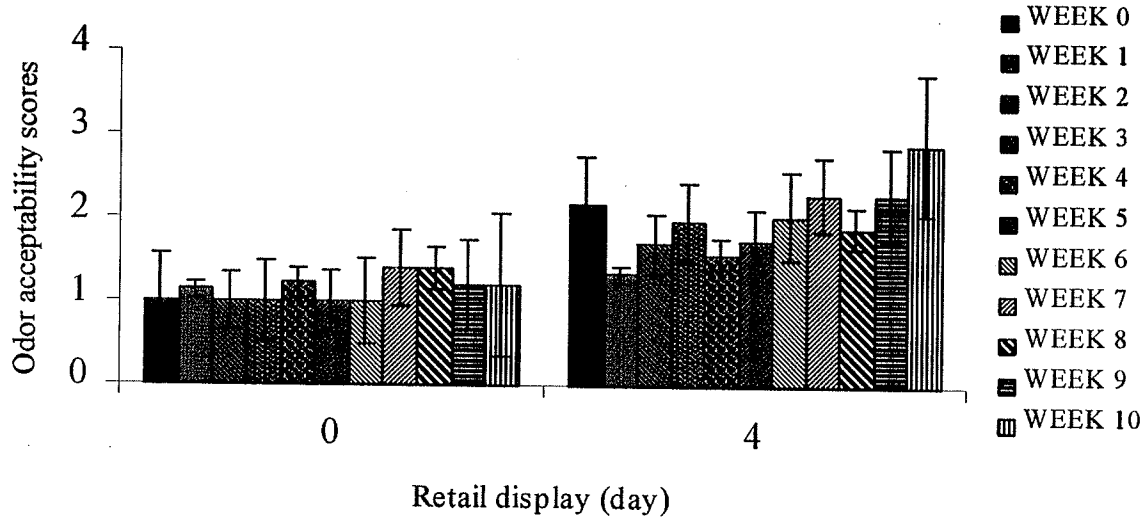

Fig. 6.5 Mean odor acceptability scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

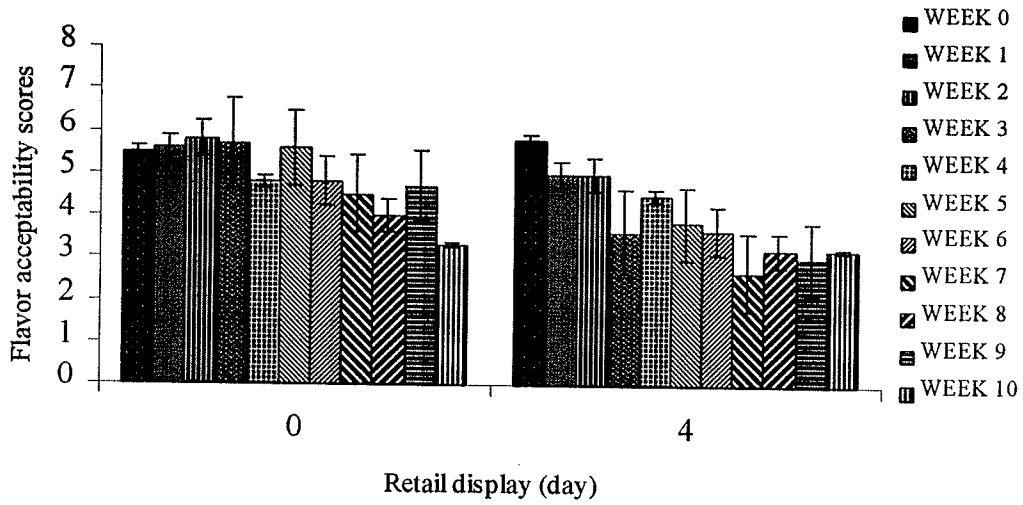

Fig. 6.6 Mean flavor acceptability scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

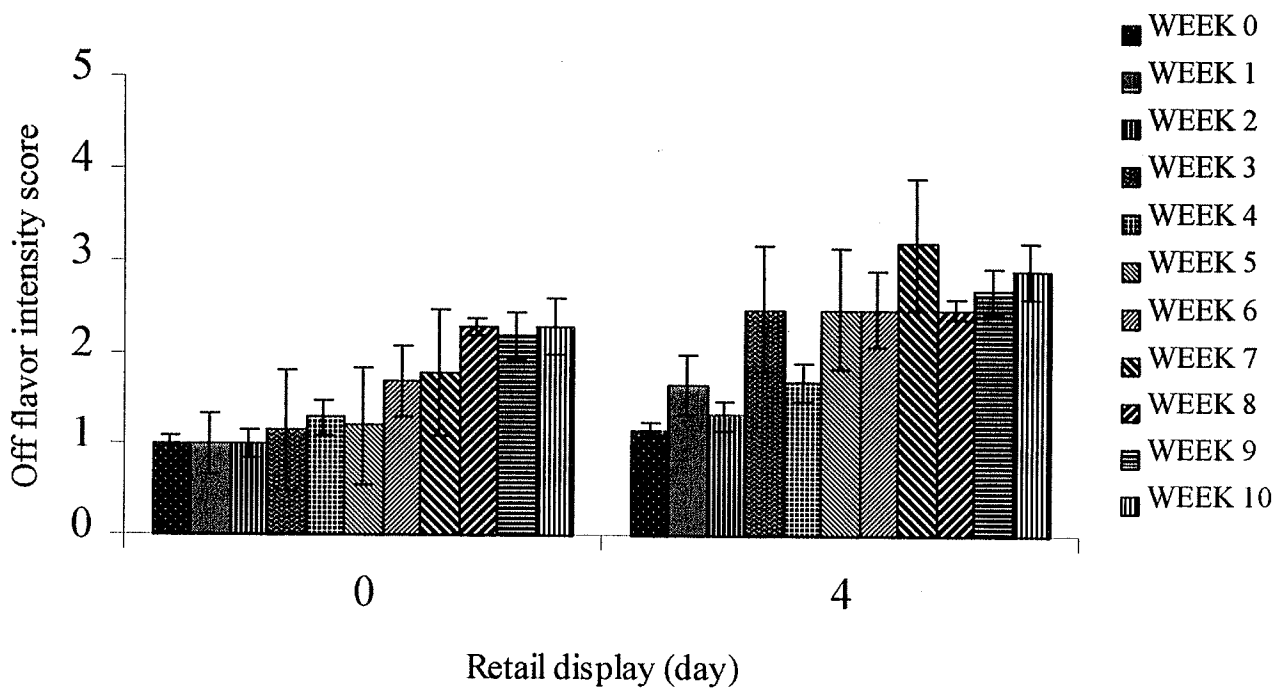

Fig. 6.7 Mean off-flavor intensity scores (with standard deviation) for steaks stored in the liquid-N_2 refrigerated container.

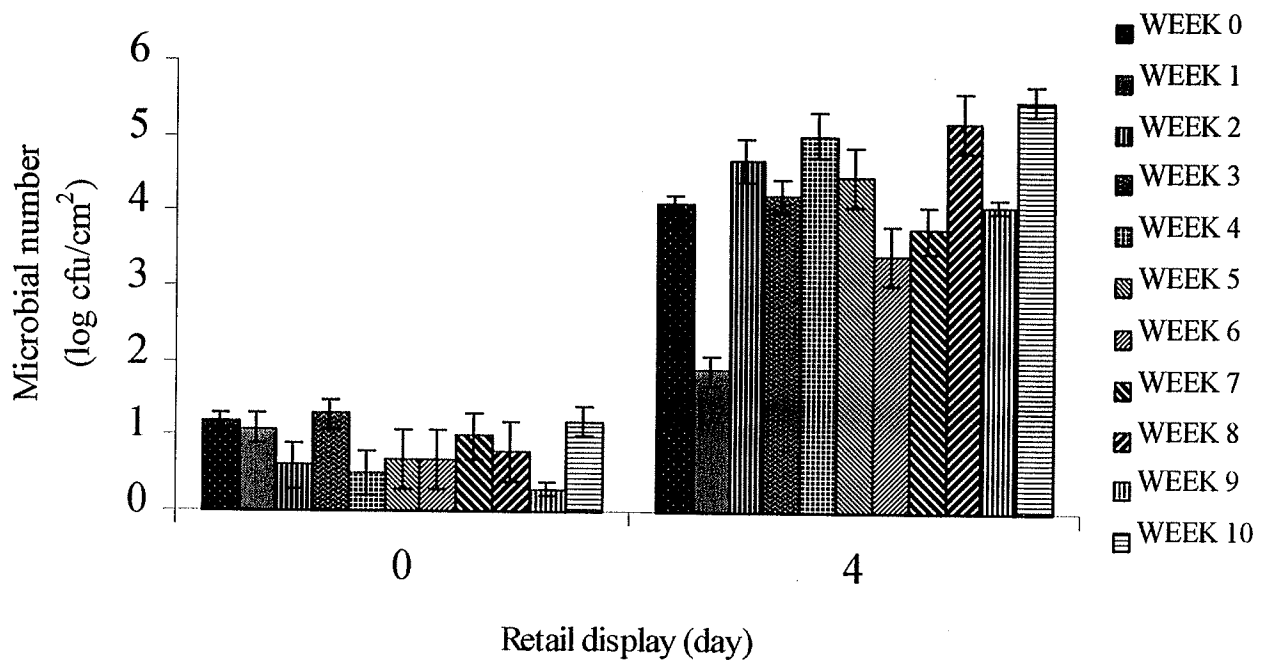

Fig. 6.8 Mean microbial numbers (with standard deviation) on steaks stored in the liquid-N_2 refrigerated container.

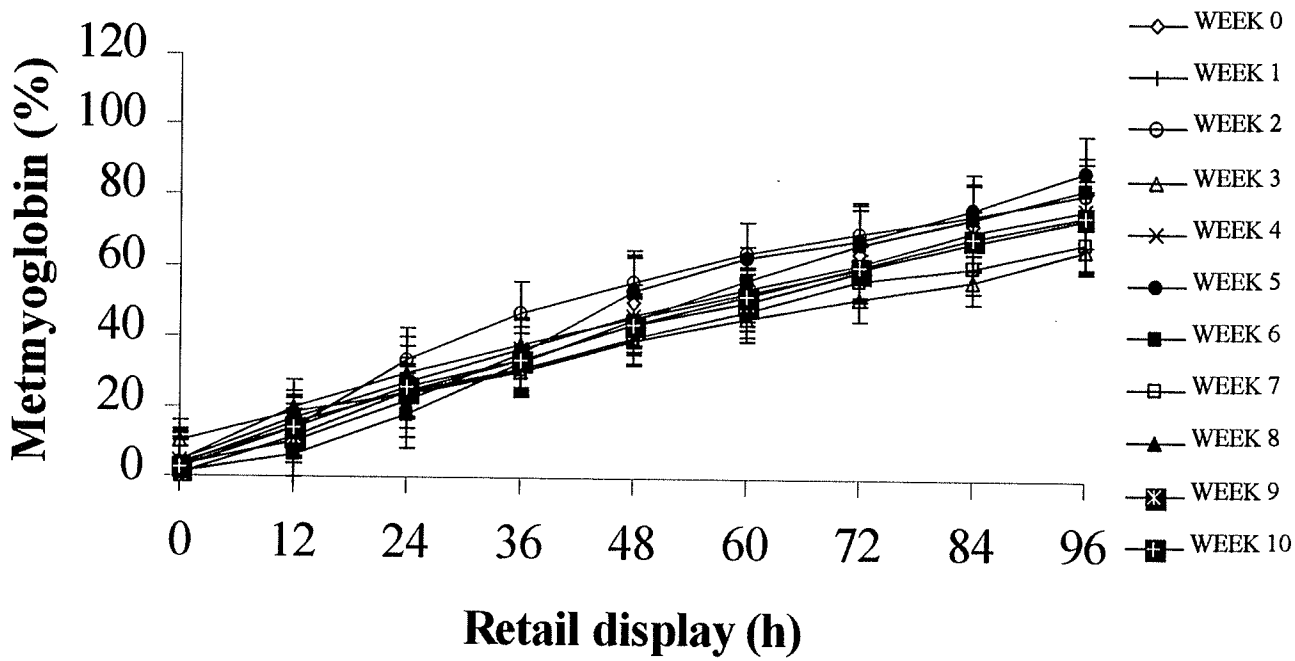

Fig. 6.9 Mean percentages of metmyoglobin (with standard deviation) on the surfaces of steaks stored in the liquid-N_2 refrigerated container.

7. CONCLUSIONS

The following conclusions were drawn from the present study:

1. Ageless® FX-100 and FreshPax® R-2000 O_2 scavengers have the highest O_2 absorption rates, and can be adapted with success in centralized meat operations. However, they should be used in multiple numbers to obtain consistent and reproducible results, and this number will be based upon scavenger type, pack atmosphere, initial O_2 concentration in the pack, storage temperature, and the desired O_2 absorption rate.
2. Oxygen permeable films in master pack systems, in which retail trays are placed in another bag, acted as an O_2 barrier, hence, there is a high probability of O_2 entrapment inside the retail tray and O_2 scavengers should be placed in the retail tray so that they are closer to O_2 sensitive products in such systems.
3. The retail packaging system with the most potential for CAP systems in commercial centralized meat operations utilizing a controlled 100% N_2 atmosphere in the master pack consists of hard plastic retail trays containing only an absorbent pad and 8 O_2 scavengers. This should result in O_2 half-lives of 0.6-0.7 h in the pack atmosphere where the O_2 concentration remains $\leq$500 ppm at any time of storage. Fresh meat must be over-wrapped with a film of high O_2 permeability with two holes to permit free exchange of atmospheres between the master packs and the retail trays.
4. To prevent transient discoloration of beef steaks, the O_2 concentration should be reduced to 0 ppm at 1±0.5°C, within 3 h of pack closure.

5. The developed system can provide a 10 week CAP storage life with a subsequent 3 day retail display life of centrally prepared PM steaks.

8. REFERENCES

Allen P., A. M. Doherty, D. J. Buckley, J. Kerry, M. N. O'Grady, and F. J. Monahan. 1996. Effect of oxygen scavengers and vitamin E supplementation on color stability of MAP beef. In *42nd International Conference on Meat Science and Technology (ICoMST)*, 88-89. The Hague, Netherlands.

AMSA. 1991. Guidelines for meat color evaluation. American Meat Science Association and National Live Stock Meat Board, Chicago, IL, p 3-17.

Anonymous. 1995. PacCheck® 450 Operator's Manual. Mocon/Modern Controls Inc., Minneapolis, MN. 40 p.

Anonymous. 1998. Ageless® Technical Literature: Mitsubishi Gas Chemical America Inc., New York, NY. 11 p.

Ayres, J. C. 1955. Microbiological implications in handling, slaughtering and dressing meat animals. *Advances in Food Research* 6:109-161.

Ayres, J. C. 1960. Temperature relationships and some other characteristics of the microbial flora developing on refrigerated beef. *Food Research* 25:1-18.

Bailey, C. G., D. S. Jayas, R. A. Holley, L. E. Jeremiah, and C. O. Gill. 1997. Design, fabrication, and testing of a returnable insulated, nitrogen-refrigerated shipping container for distribution of fresh red meat under controlled CO_2 atmosphere. *Food Research International* 30:743-753.

Benedict, R. C., E. D. Strange, S. Palumbo, and C. E. Swift. 1975. Use of in-package controlled atmospheres for extending the shelf life of meat products. *Journal of Agriculture and Food Chemistry* 23:1208-1212.

Blickstad, E. and G. Molin. 1983. Carbon dioxide as a controller of the spoilage flora of pork, with special reference to temperature and sodium chloride. *Journal of Food Protection* 46:756-763.

Borch, E., M. L. Kant-Muermans, and Y. Blixt. 1996. Bacterial spoilage of meat and cured meat products. *International Journal of Food Microbiology* 33:103-120.

Brody, A. L. 1996. Integrating aseptic and modified atmosphere packaging to fulfil a vision of tomorrow. *Food Technology* 50(4): 56-66.

Brown T. L., H. E. Lemay Jr., and B. E Busten. 1994. Chemical kinetics. In *Chemistry: the central science*, 6th ed., eds. Brown T. L., H. E. Lemay Jr., and B. E Busten, 487-532. Englewood Cliffs, N.J.:Prentice Hall.

Brown, W. 1922. On the germination and growth of fungi at various temperatures and in various concentrations of oxygen and carbon dioxide. *Ann. Bot* 36:375-383.

Buys, E. M., G. L. Nortje, and P. L. Steyn. 1993a. The effect of wholesale vacuum and 100% CO_2 storage on the subsequent microbiological, color and acceptability attributes of PVC-overwrapped pork loin chops. *Food Research International* 26:421-429.

Buys, E. M., J. Kruger, and G. L. Nortje. 1993b. The effect of centralised pre-packaging on the microbial, odor, color, and acceptability attributes of PVC-overwrapped pork loin chops. In *Proceedings of 39th International Conference of Meat Science & Technology meeting*, Calgary, AB.

Callow, E. H. 1932. Gas storage of pork and bacon 1: Preliminary experiments. *Journal of the Society of Chemistry and Industry* 51: 116T-119T.

Coulate, T. P. 1990. *Food: the Chemistry of Its Components*, 2nd ed. Cambridge, London: Royal Society of Chemistry. 486 p.

Coyne, F. P. 1933. The effect of carbon dioxide on bacterial growth. *Proceedings of Royal Society Series B 113*:196-217.

Day, B. P. F. 1990. A perspective of modified atmosphere packaging of fresh produce in Western Europe. *Food Science & Technology Today* 4:215-221.

Doherty, A. M. and P. Allen. 1998. The effect of oxygen scavengers on the color stability and shelf life of CO_2 packaged pork. *Journal of Muscle Foods* 9:351-363.

Eskin, N. A. M. 1990. *Biochemistry of foods*. 2nd ed. San Diego, CA: Academic Press Inc. 352 p.

Farris, D. E., R. A. Dietrich, and J. B. Ward. 1991. Reducing the cost of marketing beef. *Meat Processing* 30:60, 62.

Faustman, C. and R. G. Cassens. 1990. The biochemical basis for discoloration in fresh meat: a review. *Journal of Muscle Foods* 1:217-243.

Gill, C. O. 1985. The control of microbial spoilage in fresh meats. In *Advances in Meat Research, Meat and Poultry Microbiology, vol. 2*, eds. A. M. Pearson and T. R. Dutson, 49-88. Westport, CT: AVI publishing Co. Inc.

Gill, C. O. 1986. Temperature function integration for hygiene evaluation of food processing procedures. *Food Technology Australia* 38: 203-204.

Gill, C. O. 1988a. Packaging meat under CO_2: The Captech System. In *Proceedings of Industry Day, 34th International Congress of Meat Science and Technology,*

Livestock and Meat Authority of Queensland, 76-77. Brisbane, Australia.

Gill, C. O. 1988b. CO_2 packaging-the technical background. In *Proceedings of 25th Meat Industry Research Conference, Meat Industry Institute*, 181-185. Hamilton, New Zealand.

Gill, C. O. 1989. Packaging meat for prolonged chilled storage: The CAPTECH Process. *British Food Journal* 91:11-15.

Gill, C. O. 1990. Controlled atmosphere packaging of chilled meat. *Food Control* 1:74-78.

Gill, C. O. 1991. Meat and modified atmosphere packaging. In *Encyclopedia of Food Science and Technology*, ed. Y. H. Hui, 1678-1683. New York, NY: John Wiley & Sons.

Gill, C. O. 1995. MAP and CAP of Fresh, Red Meats, Poultry and Offals. In *Principles of Modified Atmosphere and Sous-Vide Product Packaging*, eds. J. M. Farber and K. L. Dodds, 105-136. Lancaster, PA: Technomic Publishing Co. Inc.

Gill, C. O. and J. C. L. Harrison. 1989. The storage life of chilled pork packaged under carbon dioxide. *Meat Science* 26:313-324.

Gill, C. O. and S. D. M. Jones. 1992. Efficiency of a commercial process for the storage and distribution of vacuum-packaged beef. *Journal of Food Protection* 55:880-887.

Gill, C. O. and T. Jones. 1994a. The display life of retail-packaged beef steaks after their storage in master packs under various atmospheres. *Meat Science* 38:385-396.

Gill, C.O. and T. Jones. 1994b. The display life of retail packs of ground beef after their storage in master packages under various atmospheres. *Meat Science* 37:281-295.

Gill, C. O. and T. Jones. 1996. The display life of retail packaged pork chops after their storage in master packs under atmospheres of N_2, CO_2, or O_2+ CO_2. *Meat Science* 42:203-213.

Gill, C. O. and J. C. McGinnis. 1993. Changes in the microflora on commercial beef trimmings during their collection, distribution, and preparation for retail sale as ground beef. *International Journal of Food Microbiology* 18:321-332.

Gill, C. O. and J. C. McGinnis. 1995a. The effects of residual oxygen concentration and temperature on the degradation of the color of beef packaged under oxygen-depleted atmospheres. *Meat Science* 39:387-394.

Gill, C. O. and J. C. McGinnis. 1995b. The use of oxygen scavengers to prevent the transient discoloration of ground beef packaged under controlled, oxygen-depleted atmospheres. *Meat Science* 41:19-27.

Gill, C. O. and N. Penney. 1988. The effect of initial gas volume to meat weight ratio on the storage life of chilled beef packaged under CO_2. *Meat Science* 22:53-63.

Gill, C. O. and K. H. Tan. 1980. Effect of carbon dioxide on growth of meat spoilage bacteria. *Applied Environmental Microbiology* 39:317-319.

Gill, C. O., C. McGinnis, and A. K. W. Tong. 1994. Consumer acceptance of display packs of beef stored under N_2 or CO_2 in master packs. *Meat Science* 38:397-406.

Gill, C. O., D. M. Phillips, and J. C. L. Harrison. 1988. A computer program for assessing the remaining storage life of chilled red meats from product temperature histories. In *Refrigeration for Food and People*, 35-39. Paris, France: International Institute of Refrigeration.

Grau, F. H. 1981. Role of pH, lactate, and anaerobiosis in controlling the growth of some fermentative Gram-negative bacteria on beef. *Applied Environmental Microbiology* 42:1043-1050.

Grau, F. H. 1983. Microbial growth on fat and lean surfaces of vacuum-packaged chilled beef. *Journal of Food Science* 48:326-328.

Greer, G. G., B. D. Dilts, and L. E. Jeremiah. 1993. Bacteriology and retail case life of pork after storage in carbon dioxide. *Journal of Food Protection* 56:689-693.

Habok, M. N. N. 1999. Modification and testing of a nitrogen refrigerated, controlled atmosphere container for the distribution of fresh red meat. Unpublished MSc thesis. Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB.

Haines, R. B. 1933. The influence of carbon dioxide preservation on the rate of multiplication of certain bacteria as judged by viable counts. *Journal of Society Chemistry and Industry* 52: 13T-17T.

Hintlian, C. B. and J. H. Hotchkiss. 1986. The safety of modified atmosphere packaging: a review. *Food Technology* 40(12):70-76.

Holley, R. A., P. Delaquis, J. Gagnon, G. Doyon, and C. Gariepy. 1993. Modified atmosphere packaging of fresh pork. *Alimentech* 6(3):16-17.

Holley, R. A., P. Delaquis, N. Rodrigue, G. Doyon, J. Gagnon, and C. Gariepy. 1994a. Controlled-atmosphere storage of pork under carbon dioxide. *Journal of Food Protection* 57:1088-1093.

Holley, R. A., C. Gariepy, P. Delaquis, G. Doyon, and J. Gagnon. 1994b. Static, controlled (CO_2) atmosphere packaging of retail ready pork. *Journal of Food Science* 59:1296-1301.

Hood, D. E. 1980. Factors affecting the rate of metmyoglobin accumulation in pre-packaged beef. *Meat Science* 4:247-265.

ICMSF. 1980. Microbial Ecology of Foods — Factors Affecting Life and Death of Microorganisms. vol. 1. International Commission on Microbiological Specifications for Foods, Academic Press, London.

Igbinedion, J. E., V. R. Cahill, H. W. Ockerman, N. E. Parrett, and B. D. Vanstavern. 1983. Effects of packaging method, display light, and storage time on the microbial growth and rancidity of fresh pork. *Journal of Food Science* 48:848-852.

Isdell, E., P. Allen, A. M. Doherty, and F. Butler. 1999. Color stability of six beef muscles stored in modified atmosphere mother pack system with oxygen scavengers. *International Journal of Food Science and Technology* 34:71-80.

Jeremiah, L. E., C. O. Gill, and N. Penney. 1992a. The effects on pork storage life of oxygen contamination in nominally anoxic packaging. *Journal of Muscle Foods* 3:263-281.

Jeremiah, L. E., N. Penney, and C. O. Gill. 1992b. The effects of prolonged storage under vacuum or CO_2 on the flavor and texture profiles of chilled pork. *Food Research International* 25:9-19.

Jeremiah, L. E. and L. L. Gibson. 1997a. The influence of controlled atmosphere storage on the flavor and texture profiles of display-ready pork cuts. *Food Research International* 30:117-129.

Jeremiah, L. E. and L. L. Gibson. 1997b. The influence of storage and display conditions on the color stability of display-ready pork loin roasts. *Meat Science* 47:1-16.

Jeremiah, L. E. and L. L. Gibson. 1997c. The influence of storage and display conditions on the retail properties and case-life of display-ready pork loin roasts. *Meat Science* 47:17-27.

Jeremiah, L. E. and L. L. Gibson. 1997d. The influence of controlled atmosphere storage on the flavor and texture profiles of display-ready pork cuts. *Food Research International* 30:117-129.

Jeremiah, L. E., K. A. Beauchemin, S. D. M. Jones, L. L. Gibson, and L. M. Rode. 1998. The influence of dietary cereal grain source and feed enzymes on the cooking properties and palatability attributes of beef. *Canadian Journal of Animal Science* 78:271-275.

Jeyamkondan, S. 1999. Design and evaluation of a portable, nitrogen refrigerated, chilled meat jacketed container for storage and distribution of chilled meat. Unpublished MSc thesis. Department of Biosystems Engineering, University of

Manitoba, Winnipeg, MB.

Johnson, B. Y. 1974. Chilled vacuum-packaged beef. *Commonwealth Scientific and Industrial Research Organization (Australia) Res. Q.* 34: 14-20.

Kidd, F. and C. West. 1927. Gas storage of fruit. Food Investigation Special Report No. 30. Department of Science and Industrial Research, London, United Kingdom.

Killefer, D. H. 1930. Carbon dioxide preservation of meat and fish. *Industrial Engineering Chemistry* 22:140-143.

Kraft, A. A. 1986. Meat Microbiology. In *Muscle as Food*, ed. R. J. Betchel, 239-278. London, UK: Academic Press Inc.

Labuza, T. P. 1996. An introduction to active packaging of foods. *Food Technology* 50(4):68-71.

Ledward, D. A. 1970. Metmyoglobin formation in beef stored in carbon dioxide enriched and oxygen-depleted atmosphere. *Journal of Food Science* 35:33-37.

Moran, T., E. C. Smith, and R. G. Tomkins. 1932. The inhibition of mould growth on meat by CO_2. *Journal of Society Chemistry and Industry* 51:114T-116T.

Offer, G. I. and P. Knight. 1988. The structural basis of water-holding in meat. Part 1: general principles and water uptake in meat processing. In *Developments in Meat Science*, vol. 4., ed. R. Lawrie, 63-171. Essex, England: Elsevier Applied Science.

Ogilvy, W. S. and J. S. Ayres. 1951. Post mortem changes in stored meats II. The effect of atmospheres containing CO_2 in prolonging the storage life of cut-up

chicken. *Food Technology* 5:97-102.

O'keeffe, M. and D. E. Hood. 1980-81a. Anoxic storage of fresh beef 1: Nitrogen and carbon dioxide storage temperatures. *Meat Science* 5:27-39.

O'keeffe, M. and D. E. Hood. 1980-81b. Anoxic storage of fresh beef 2: Color stability and weight loss. *Meat Science* 5:267-281.

O'keeffe, M. and D. E. Hood. 1982. Biochemical factors influencing metmyoglobin formation on beef from muscles of differing color stability. *Meat Science* 7:209-228.

Oraikul, B. and M. E. Stiles. 1991. *Modified Atmosphere Packaging of Foods*. West Sussex, England: Ellis Harwood Limited. 752 p.

Parry, R. T. 1993. Introduction. In *Principles and Applications of Modified Atmosphere Packaging of Foods*, ed. R. T. Parry, 1-17. Glasgow, Scotland: Chapman & Hall.

Penney, N. and R. G. Bell. 1993. Effect of residual oxygen on the color, odor and taste of carbon dioxide-packaged beef, lamb and pork during short term storage at chill temperatures. *Meat Science* 33:245-252.

Renerre, M. 1984. Variability between muscles and between animals of the color stability of beef meats. *Sciences Des Aliments* 4: 567-584.

Roth, L. A. and D. S. Clark. 1972. Studies on the bacterial flora of vacuum-packaged fresh beef. *Canadian Journal of Microbiology* 18:1761-1766.

Rousset, S. and M. Renerre. 1990. Comparison of different packaging systems for the storage of fresh beef meat in carbon dioxide atmosphere with or without residual

oxygen. *Sciences des Aliments* 10: 737-747.

Savell, J. W. 1986. Packaging, transportation, and distribution of edible meat byproducts. In *Advances in Meat Research, vol. 5*, eds. A. M. Pearson and T. R. Dutson, 357-379. London, UK: Elsevier Applied Science.

Scholtz, E. M., E. Jordaan, J. Kruger, G. L. Nortje, and R. T. Naude. 1992. The influence of different centralised pre-packaging systems on the shelf life of fresh pork. *Meat Science* 32:11-29.

Scott, V. N. 1989. Interaction of factors to control microbial spoilage of refrigerated foods. *Journal of Food Protection* 52:431-435.

Scrine, G. R. 1985. Refrigerated vehicles-what next? In *Long Distance Refrigerated Transport: Land and Sea*, 17-22. International Institute of Refrigeration, Paris, France.

Shay, B. J. and A. F. Egan. 1986. The packaging of chilled red meats. *Food Technology Australia* 38:283-285.

Shay, B. J. and A. F. Egan. 1990. Extending retail storage life of beef and lamb by modified atmosphere packaging. *Food Technology Australia* 42:399-400, 404.

Smith, J.P., Y. Abe, and J. Hoshino. 1995. Modified atmosphere packaging-present and future uses of gas absorbents and generators. In *Principles of Modified Atmosphere and Sous-Vide Product Packaging*, eds. J. M. Farber and K.L. Dodds, 287-323. Lancaster, PA: Technomic Publishing Co. Inc.

Sorheim, O., J. A. Grini, H. Nissen, H. J. Anderson, and P. Lea. 1995a. Pork loins stored in carbon dioxide: color and microbiological shelf life. *Fleischwirtschaft*

75:679-681.

Sorheim, O., P. Lea, A. K. Arnesen, and J. Haugdal. 1995b. Color of beef loins stored in carbon dioxide with oxygen scavengers. In *Foods and Packaging Materials-Chemical Interactions*, eds. P. Ackermann, M. Jägerstad, and T. Ohlsson, 217-221. Lund, Sweden: The Royal Society of Chemistry.

Spahl, A., G. Reineccius, and S. Tatini. 1981. Storage life of pork chops in CO_2-containing atmospheres. *Journal of Food Protection* 44:670-673.

Stiles, M. E. 1991. Modified atmosphere packaging of meat, poultry, and their products. In *Modified Atmosphere Packaging of Foods*, eds. B. Oraikul and M. E. Stiles, 118-147. West Sussex, UK: Ellis Horwood Limited.

Taylor, A. A. 1990. Developments in fresh meat technology. In *Proceeding of 36th International Congress of Meat Science and Technology*, 346-365. Havana, Cuba.

Tomkins, R. G. 1932. The inhibition of the growth of meat attacking fungi by carbon dioxide. *Journal of Society Chemistry and Industry* 51:261T-264T.

Tewari, G., Jayas, D.S. and Holley, R.A. 1999. Centralized packaging of retail meat cuts: a review. *Journal of Food Protection* 62:418-425.

Vanderzant, C., J. W. Savell, M. O. Hanna, and V. Potluri. 1986. A comparison of growth of individual meat bacteria on the lean and fatty tissues of beef, pork and lamb. *Journal of Food Science* 51:5-8.

Woolfe, M. L. 1992. Temperature monitoring and measurement. In *Chilled Foods: a Comprehensive Guide*, eds. C. Dennis and M. Stringer, 77-109. West Sussex,

UK: Ellis Harwood Limited.

APPENDICES A-I

APPENDIX A

Appendix A-1

Table A1 Specifications of Oxygen Analyzer (Mocon, PAC CHECK® 450, Minneapolis, MN, USA).

Sample Size	8 cc minimum (automatic mode)
	2 cc minimum (manual mode)
Accuracy	±5 ppm O_2 from 0 to 1000 ppm
	±0.05% O_2 from 0.1 to 9.99%
	±1% O_2 from 10.0 to 100.0%
Range	0 ppm to 100.0%
Response	98% of final value within 10 s
Warm-up Time	30 min minimum
Resolution	1 ppm in range 1 to 999 ppm
	0.001% in range 0.100 to 0.9995%
	0.01% in range 1.00 to 9.99%
	0.1% in range 10.0 to 99.9%
Measurement Method	Solid State Zirconium Oxide
Sampling Method	Internal sampling pump with user-controlled on/off
	Optional injection with syringe
Operating Temperature	5 to 40°C
Operating Humidity	10 to 90% non-condensing

Calibration of Oxygen Analyzer (Mocon, PAC CHECK® 450, Minneapolis, MN, USA)- The gas calibration consists of two basic calibration steps that were performed in the following sequence:

Step 1 O_2 Air Calibration

The SETUP key was pressed to get to a display for an O_2 Air Calibration.

The fittings on the suction tube were connected securely at the injection filter assembly and the sampling probe.

The sample probe was laid on the bench beside the Oxygen Analyzer.

Test key was pressed to allow room air sample to enter the Oxygen Analyzer.

After the pump cycle was completed, it was recommended to wait for 10 s.

The scroll up-down keys were used to adjust the room air to a value between 20.1 to 21.1%.

The SETUP key was pressed to enter the new value into memory and then Step 2 was performed.

Step 2 O_2 Reference Gas Calibration

The reference gas supply (it is recommended to use reference gases of known O_2 concentrations in a balance of an inert gas, like N_2) was connected to the injection filter assembly, and the reference gas was turned on.

The flow of the reference gas was slowly increased until the light (on the Oxygen Analyzer display-panel) came on. Then the reference gas was left to flow for 8 s.

The scroll up-down keys were used to adjust the reference gas display to the value of reference gas. The SETUP key was pressed to enter the new setting into the memory and the calibration was completed.

Working Principle: Zirconium oxide has O_2 vacancies in its ceramic lattice structure permitting O_2 ions to move into the solid material. When two gases of different O_2 concentrations are on opposite sides of the zirconium oxide membrane, a DC voltage proportional to the difference in O_2 concentration is generated. The reference gas used was air, and the unknown gas sample to be measured was on the other side. Once the DC voltage generated was determined, the unknown gas composition was calculated using the Nernst equation (Anonymous 1995).

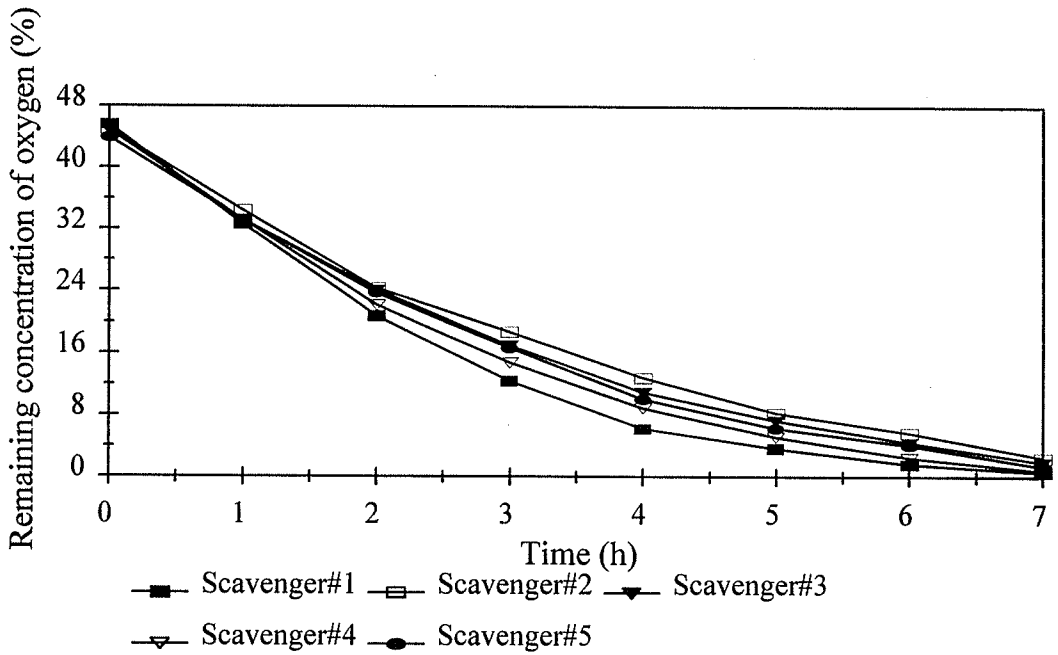

Fig. A1 Variability in the O_2 absorption rates among individual Ageless® FX-100 scavengers at 25°C and at an initial O_2 concentration of 20%.

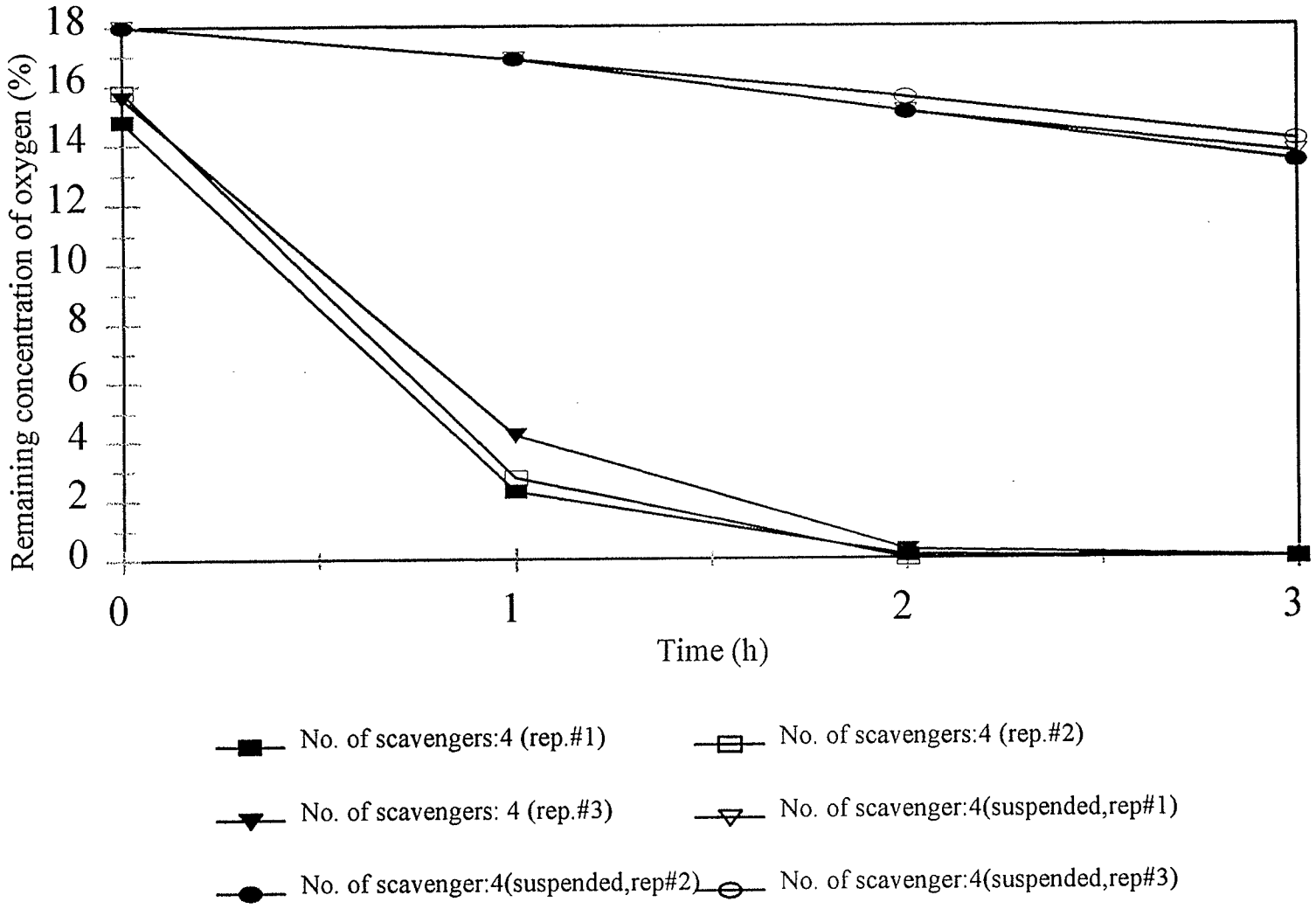

Fig. A2 Effect of suspension on the O_2 absorption rates of Ageless® FX-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

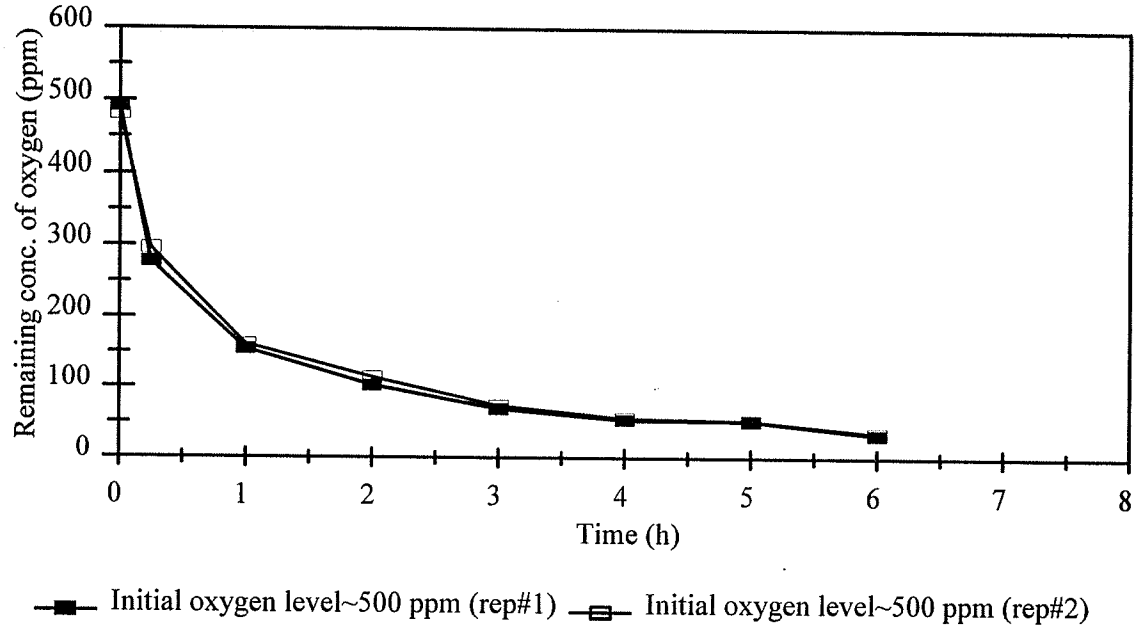

Fig. A3 Oxygen absorption rates of Ageless® FX-100 scavengers at 25°C and at an initial O_2 concentration of 500 ppm.

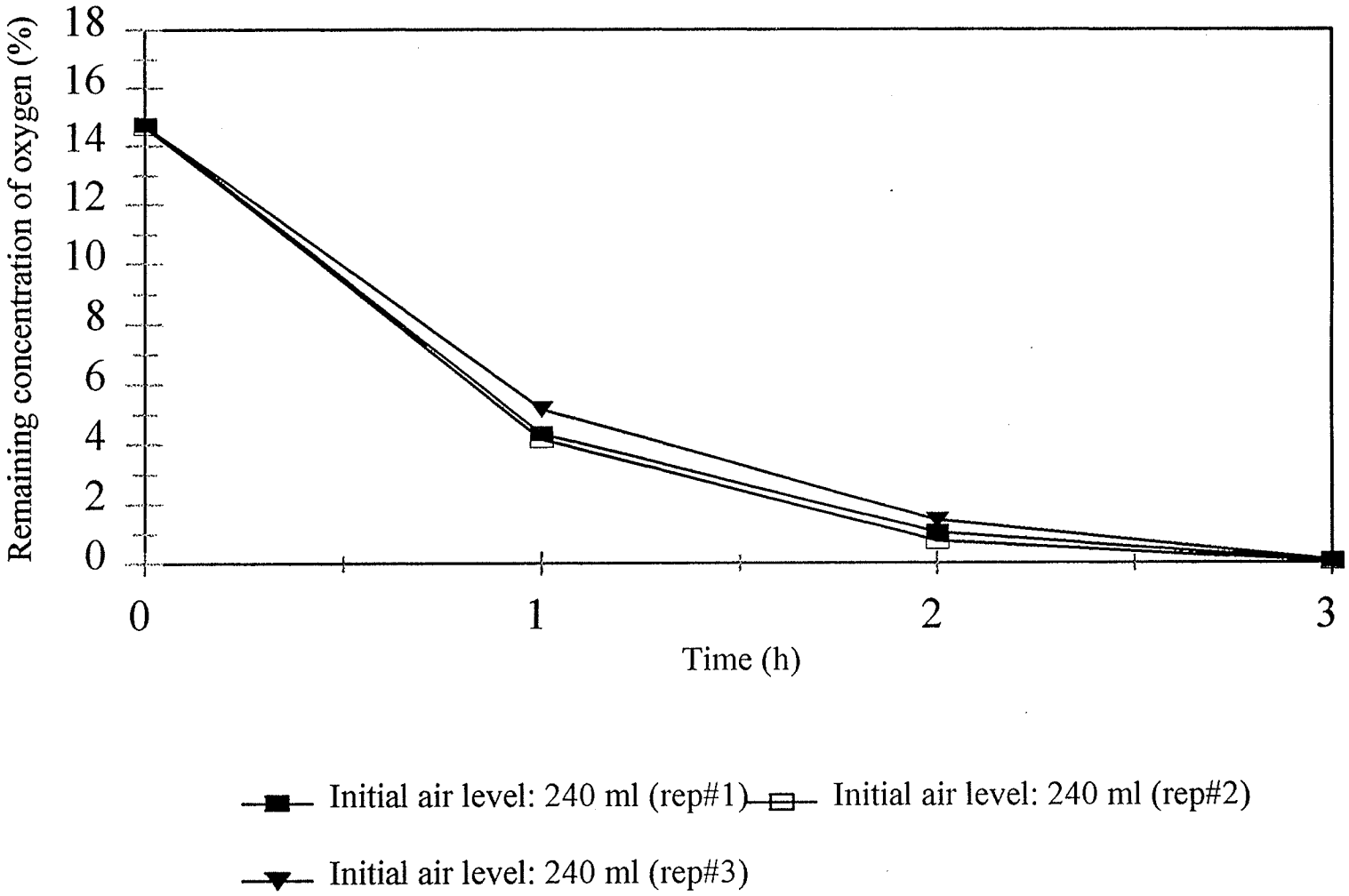

Fig. A4 Oxygen absorption rates of Ageless® FX-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 20%.

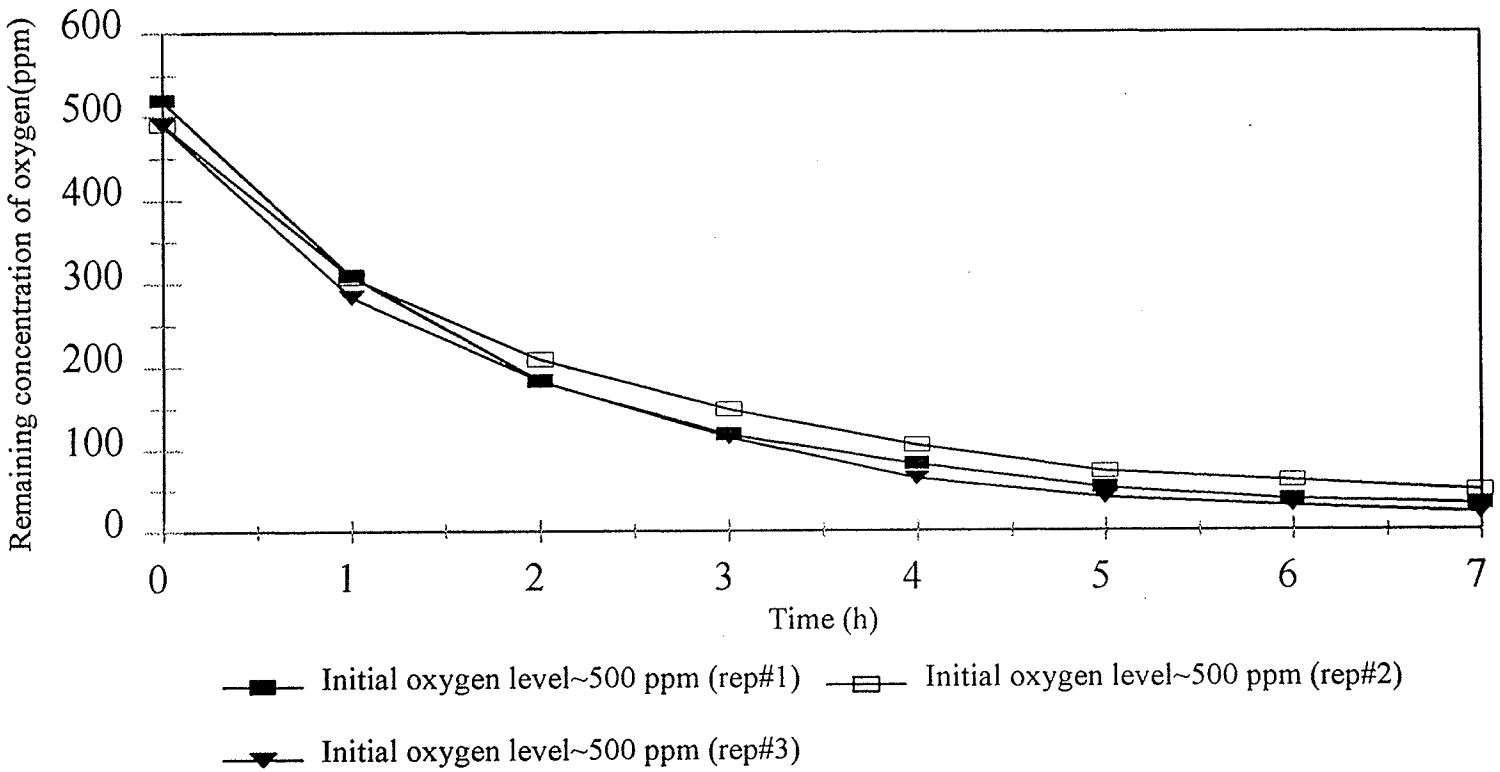

Fig. A5 Oxygen absorption rates of Ageless® FX-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 500 ppm.

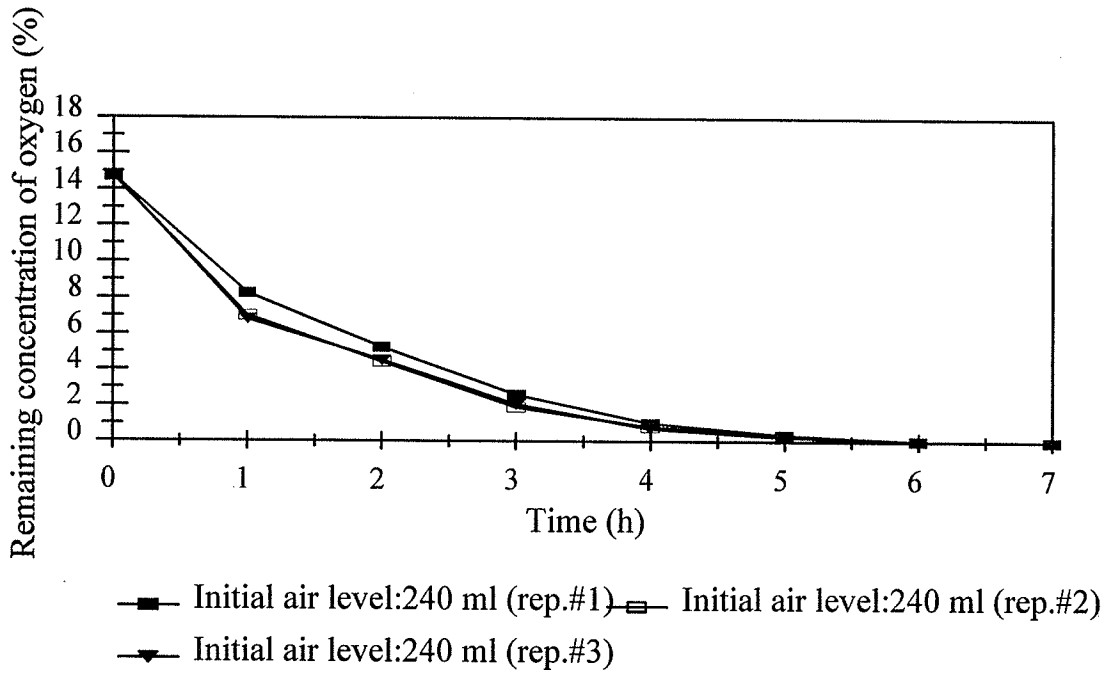

Fig. A6 Oxygen absorption rates of Ageless® FX-100 scavengers at 2°C and at an initial O_2 concentration of 20%.

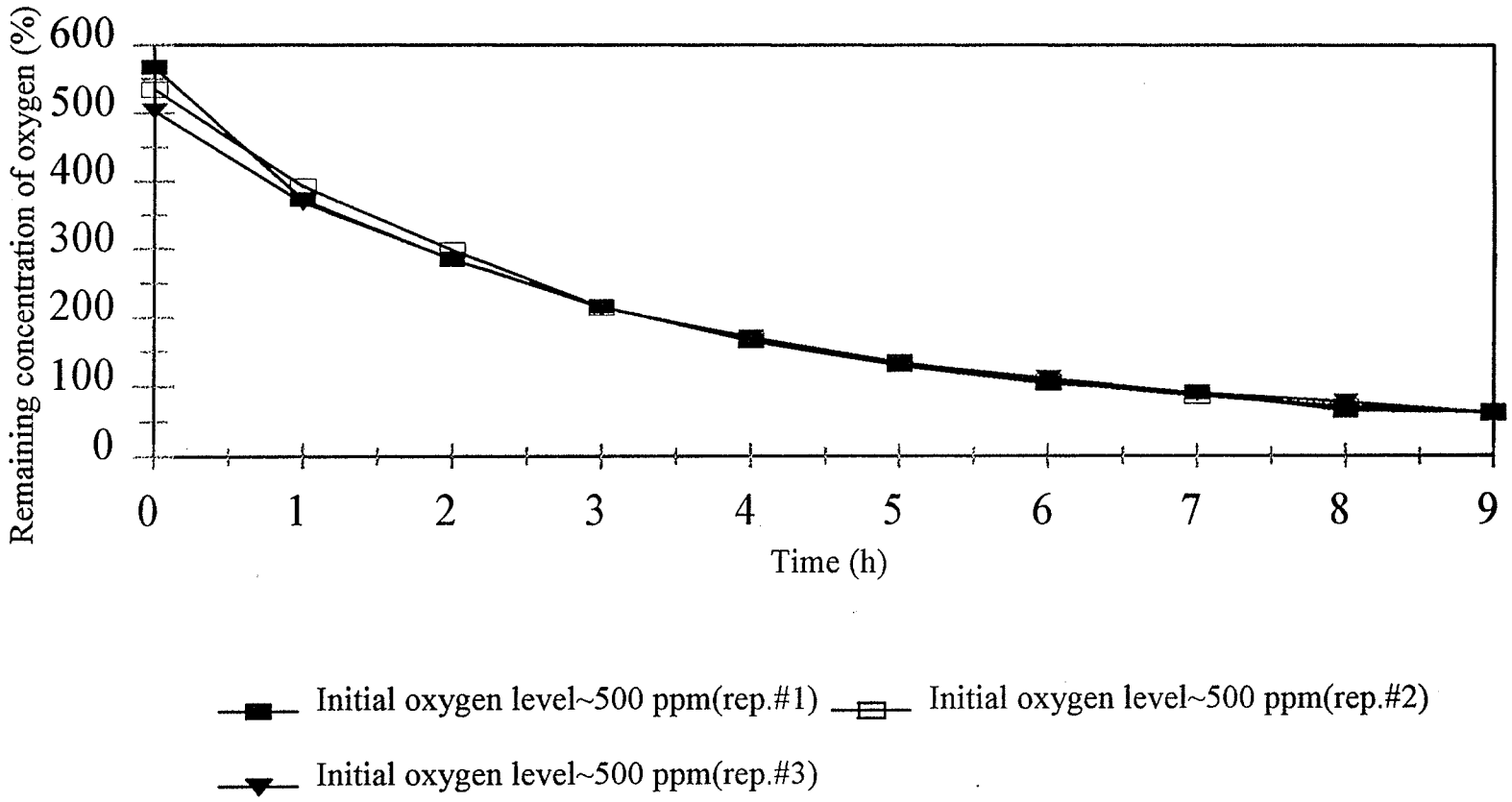

Fig. A7 Oxygen absorption rates of Ageless® FX-100 O_2 scavengers at 2°C and at an initial O_2 concentration of 500 ppm.

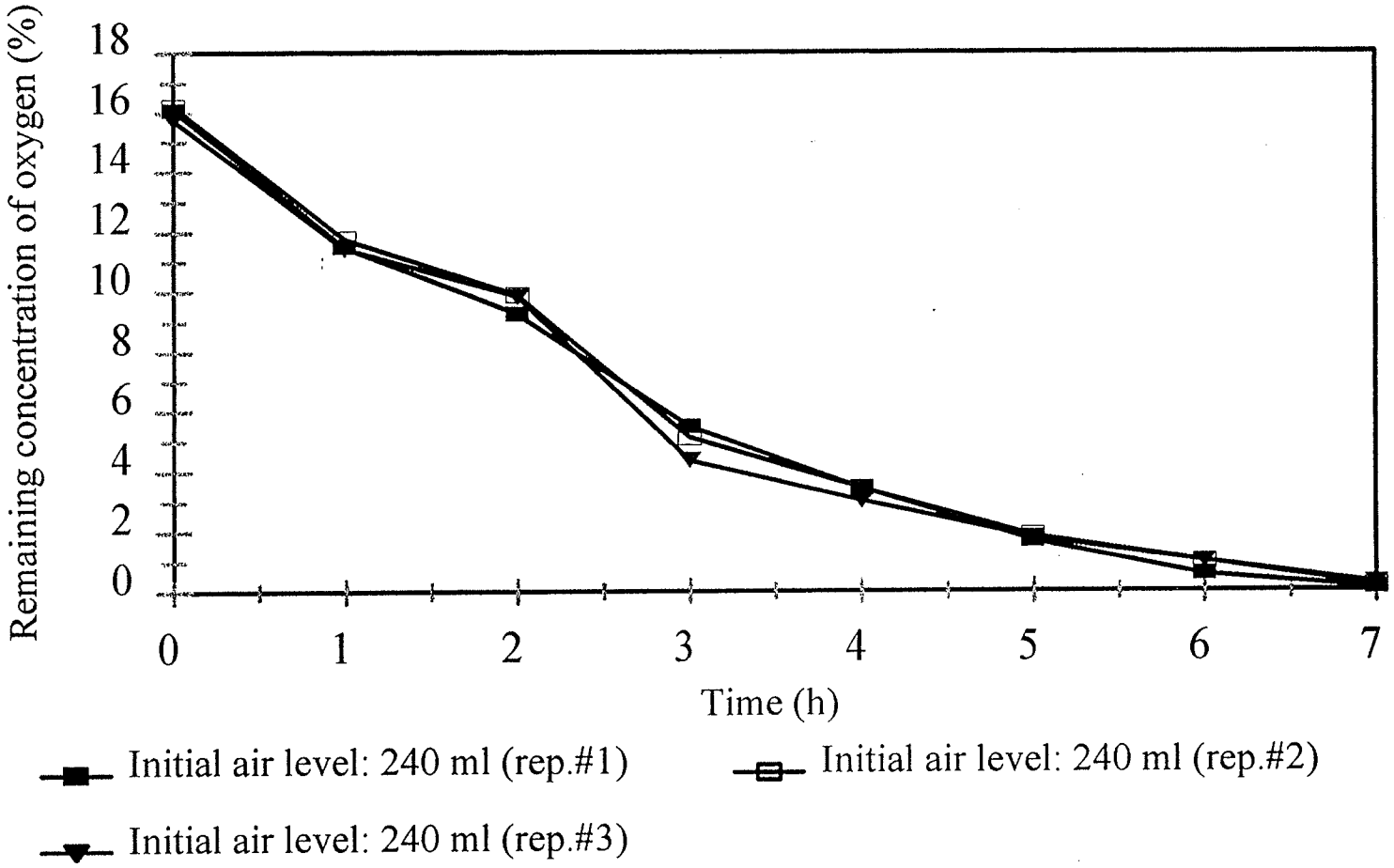

Fig. A8 Oxygen absorption rates of Ageless® FX-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 20%.

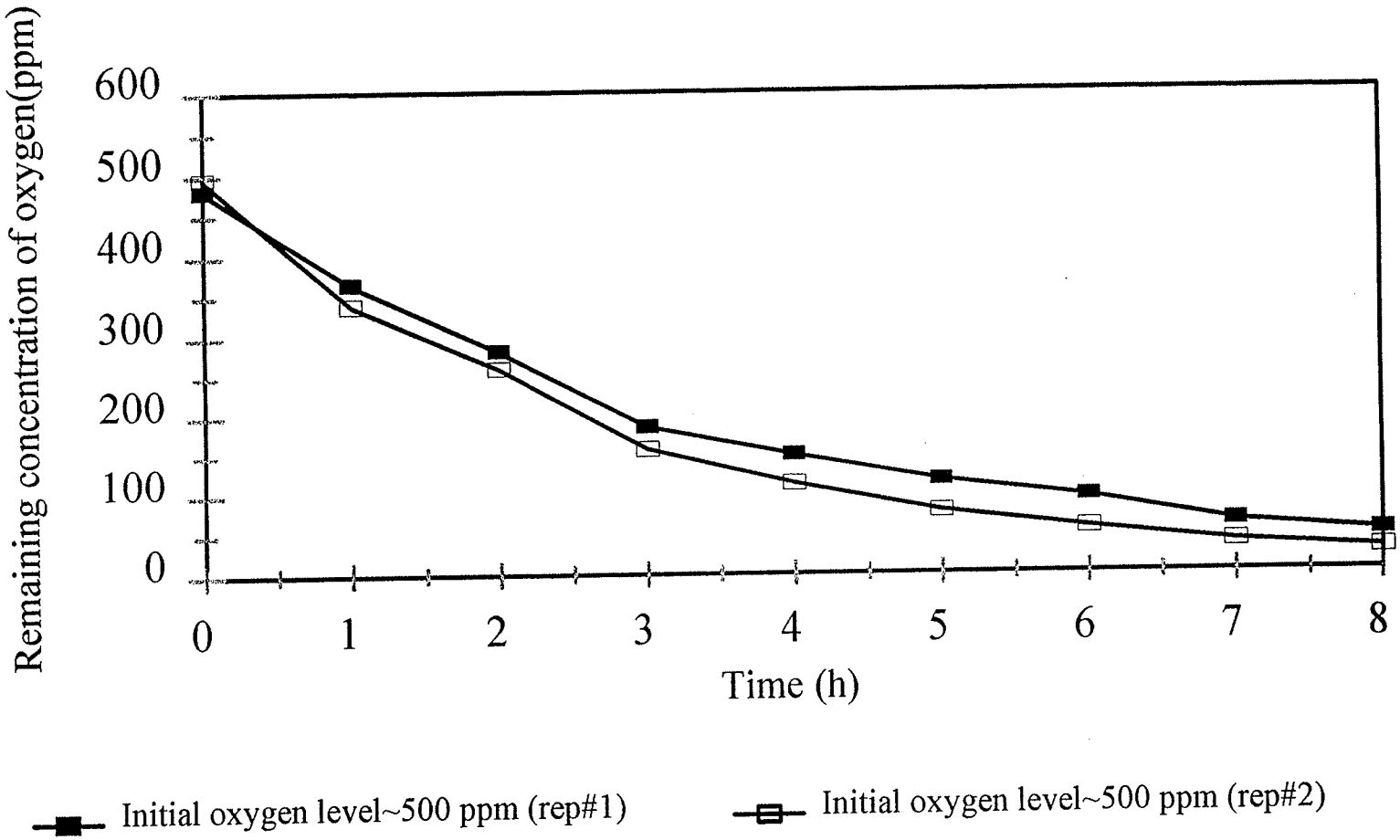

Fig. A9 Oxygen absorption rates of Ageless® FX-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 500 ppm.

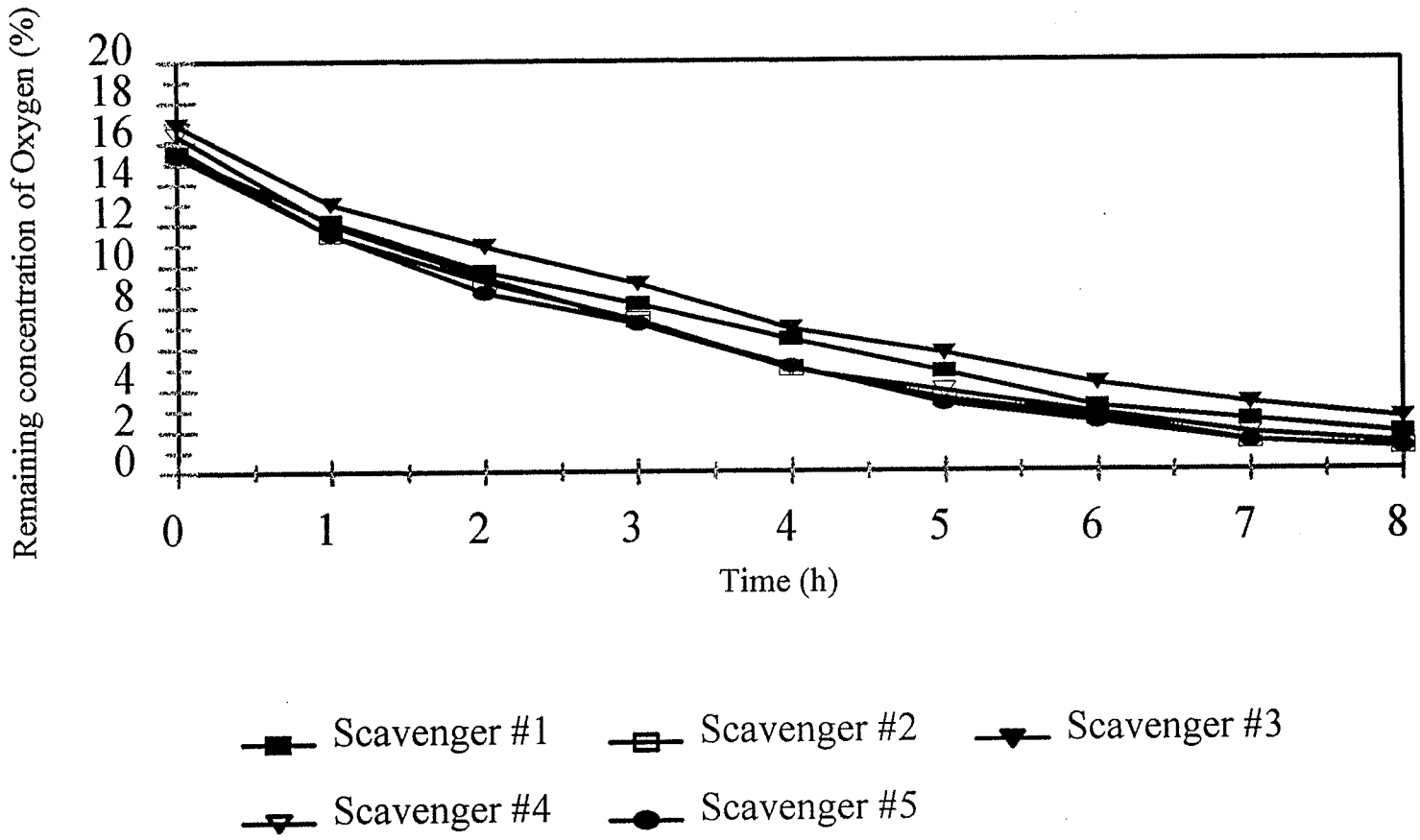

Fig. A10 Variability in the O_2 absorption rates among individual FreshPax® R-300 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

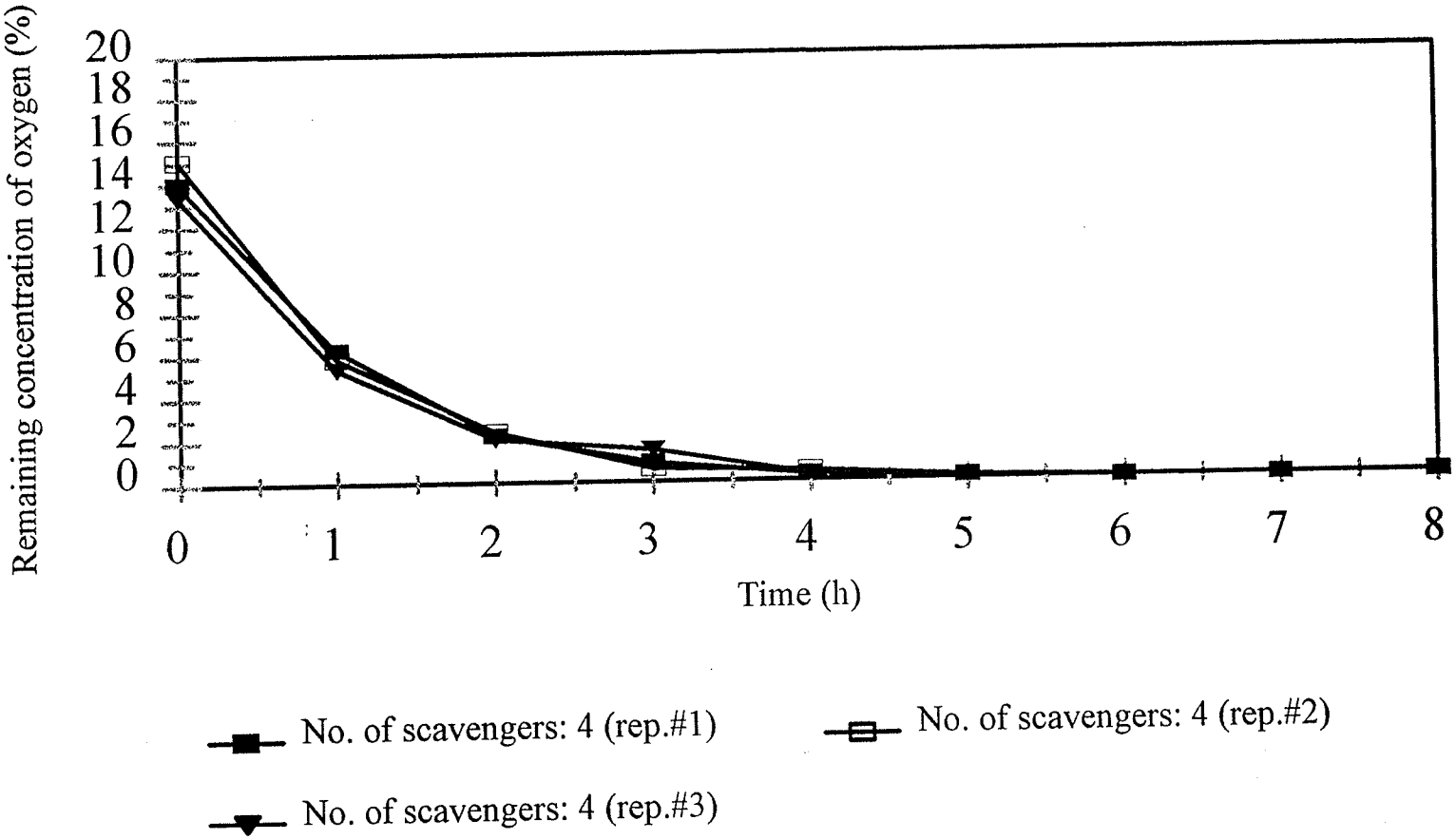

Fig. A11 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

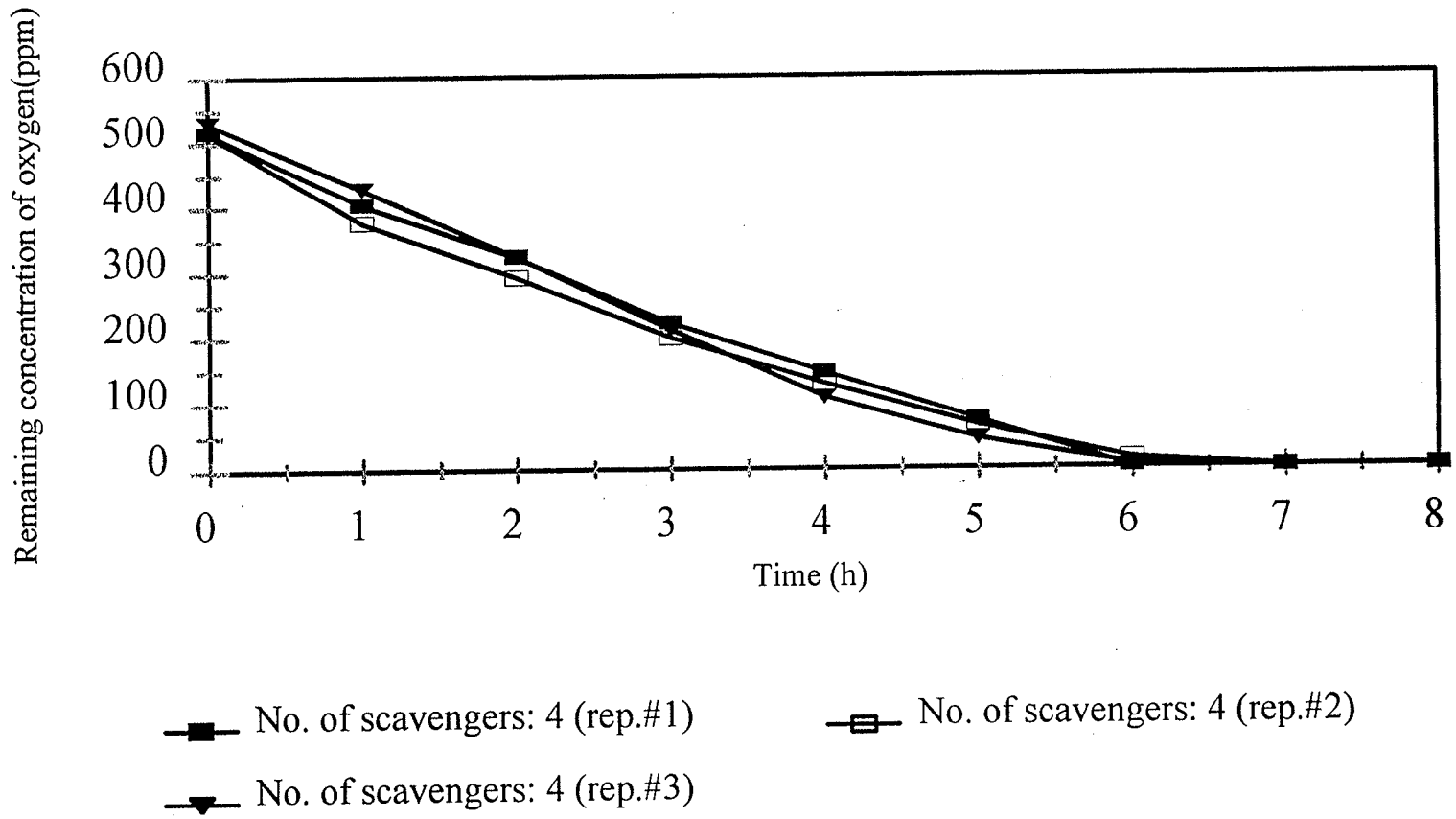

Fig. A12 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm.

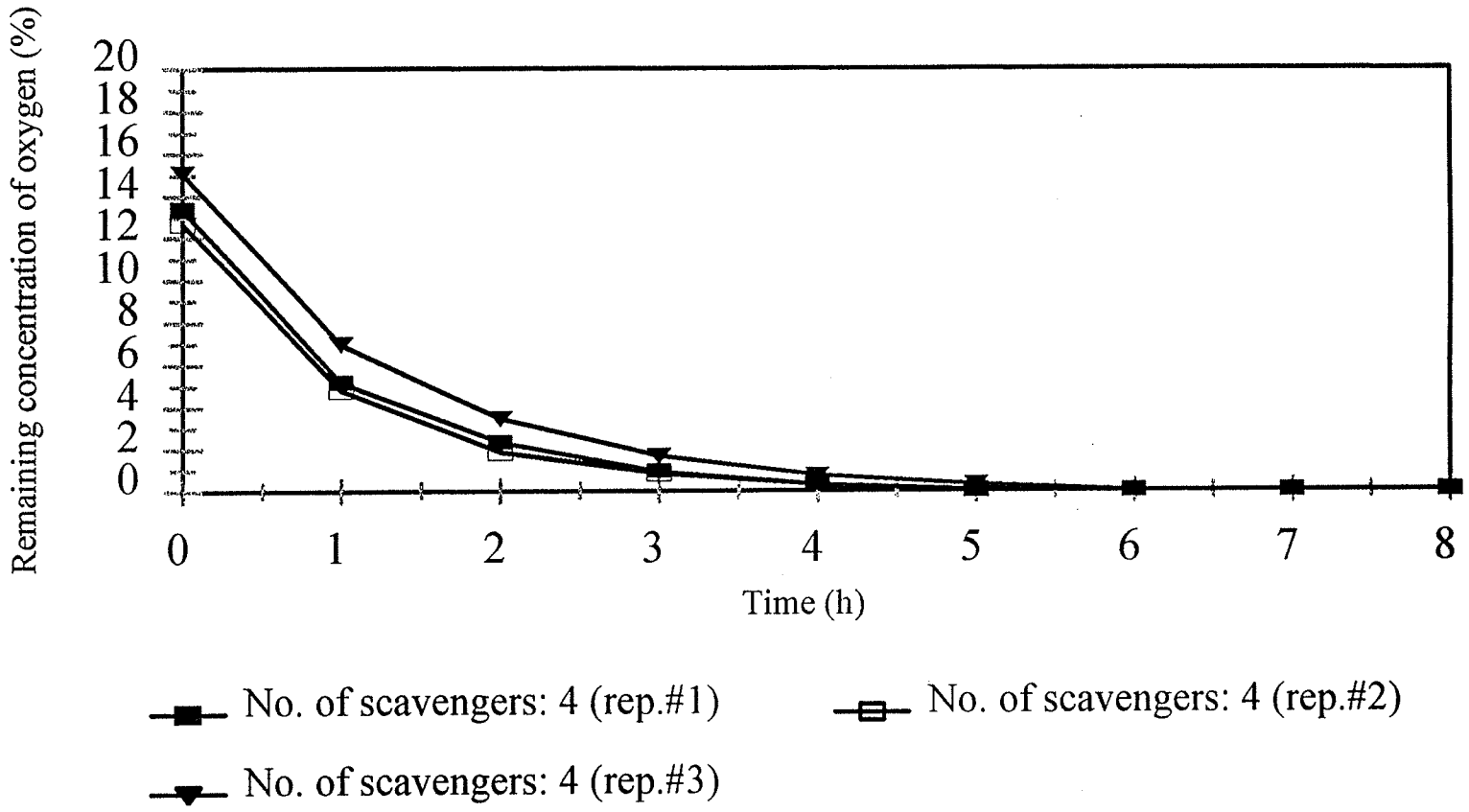

Fig. A13 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 12°C and at an initial O_2 concentration of 20%.

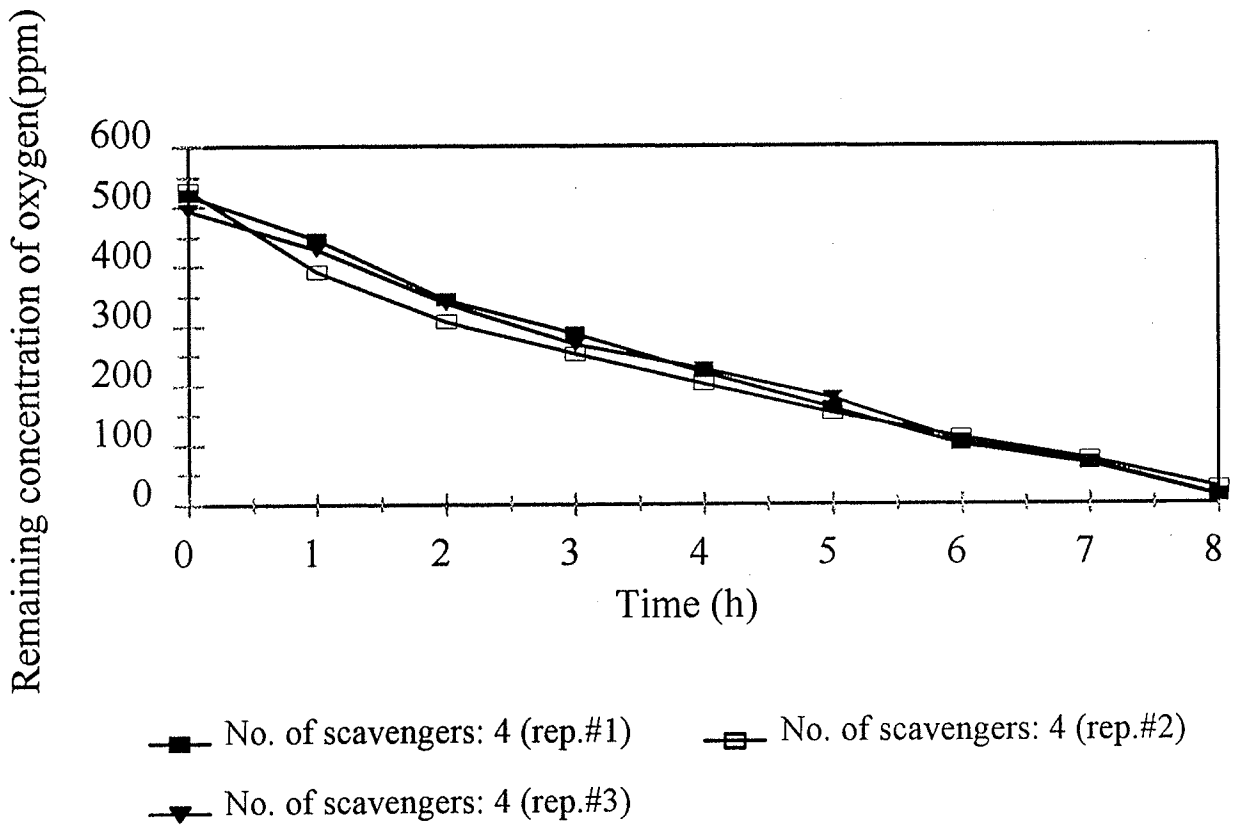

Fig. A14 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 12°C and at an initial O_2 concentration of 500 ppm.

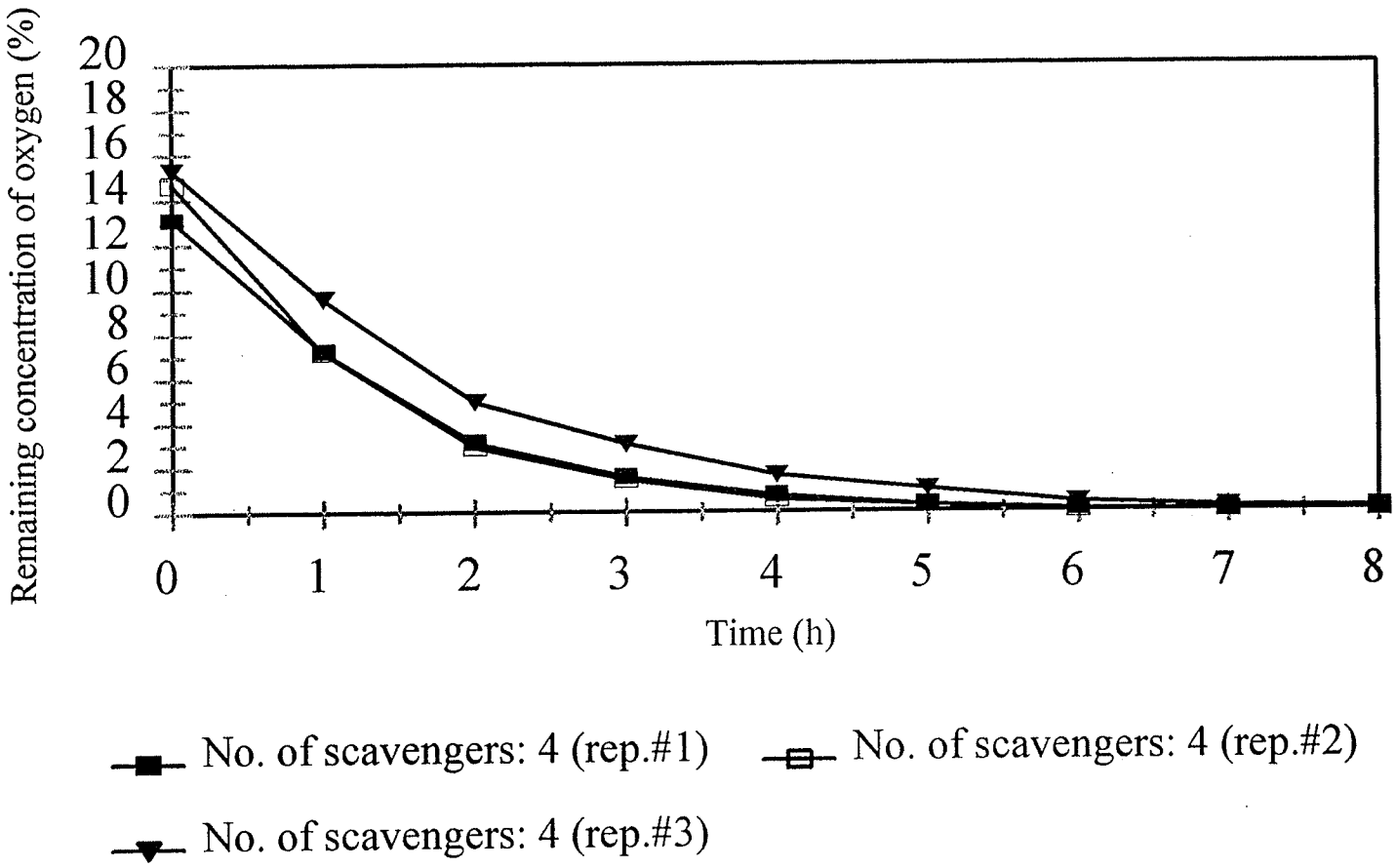

Fig. A15 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 2°C and at an initial O_2 concentration of 20%.

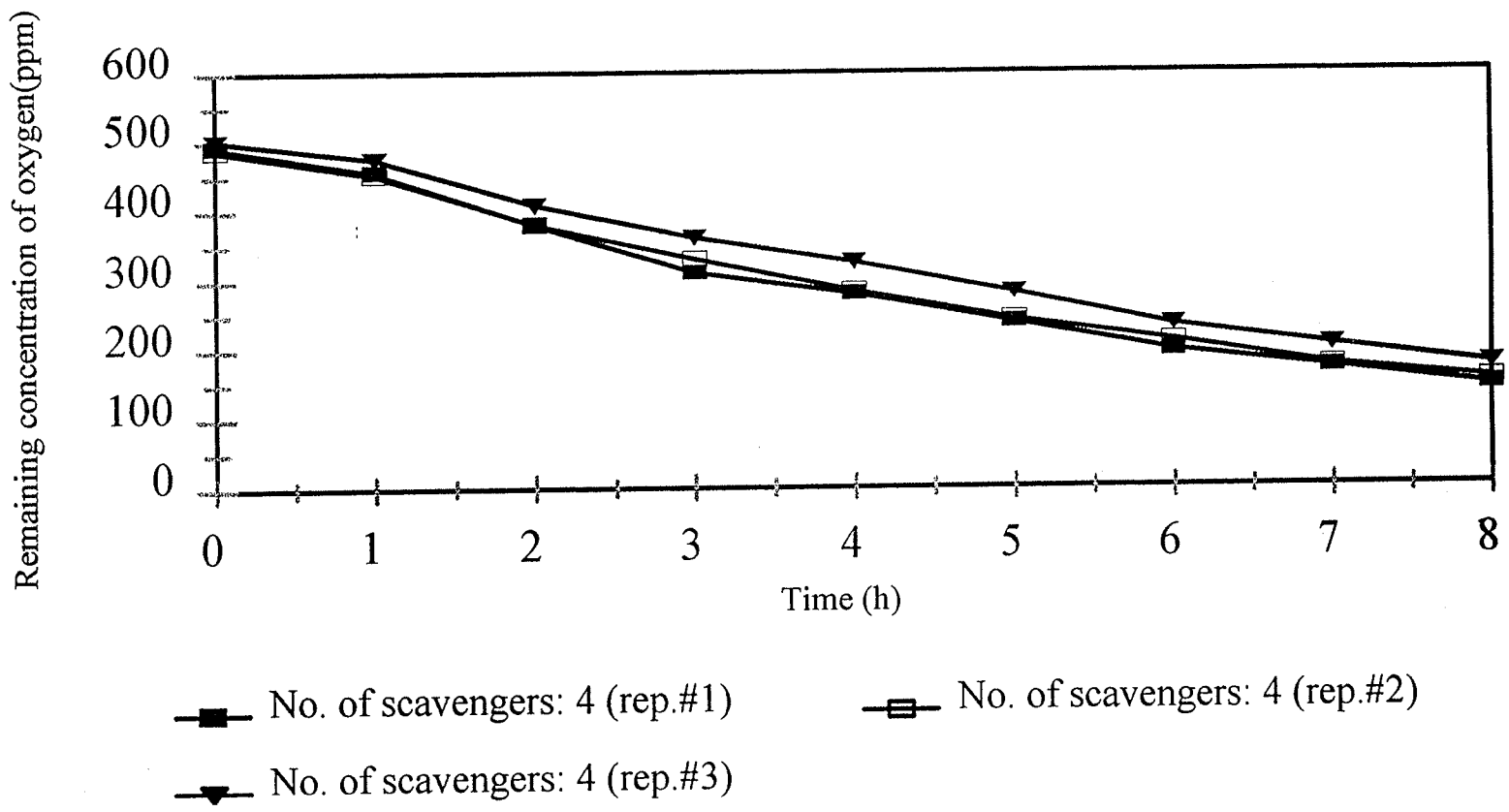

Fig. A16 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 2°C and at an initial O_2 concentration of 500 ppm.

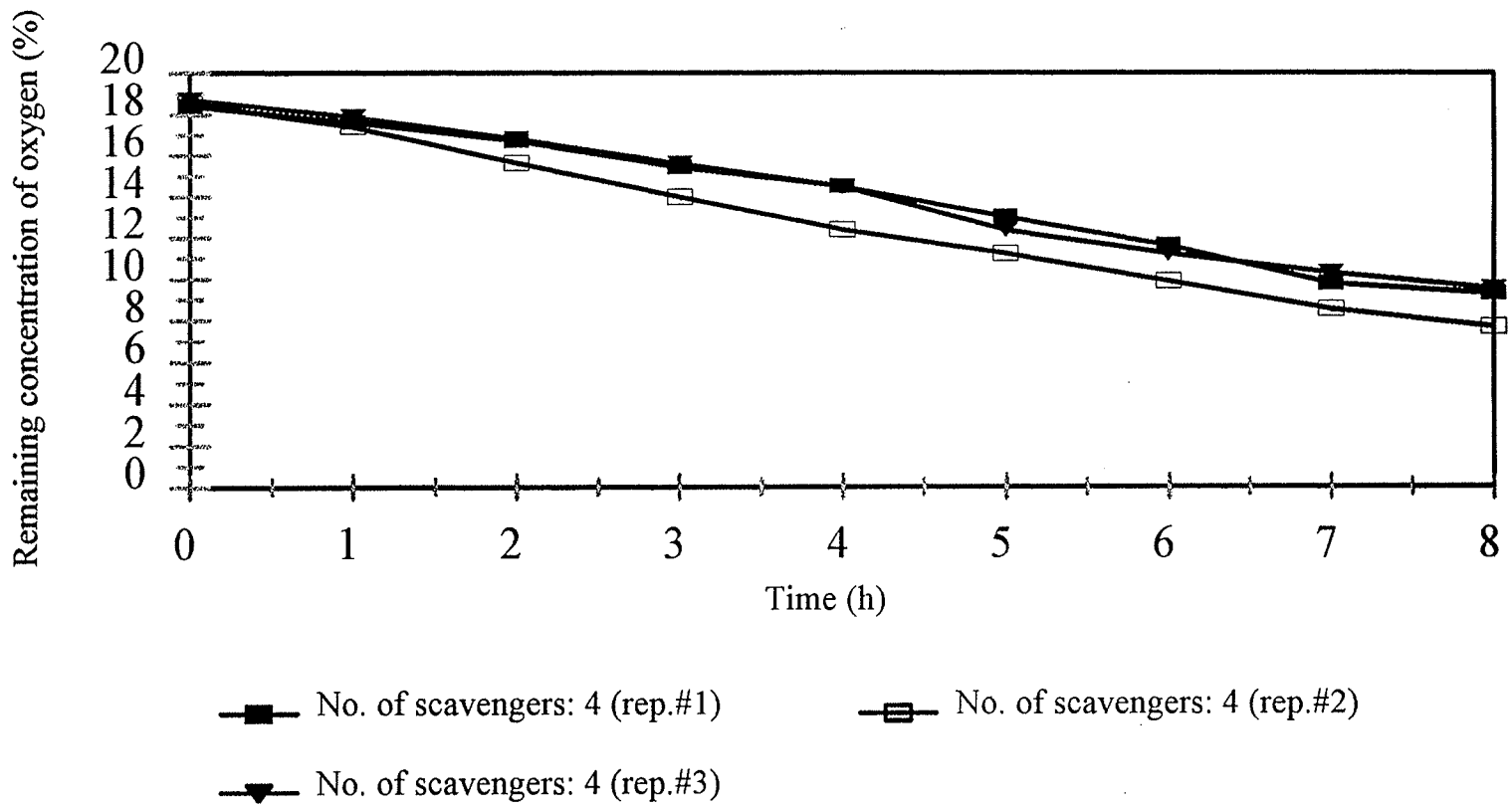

Fig. A17 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 20%

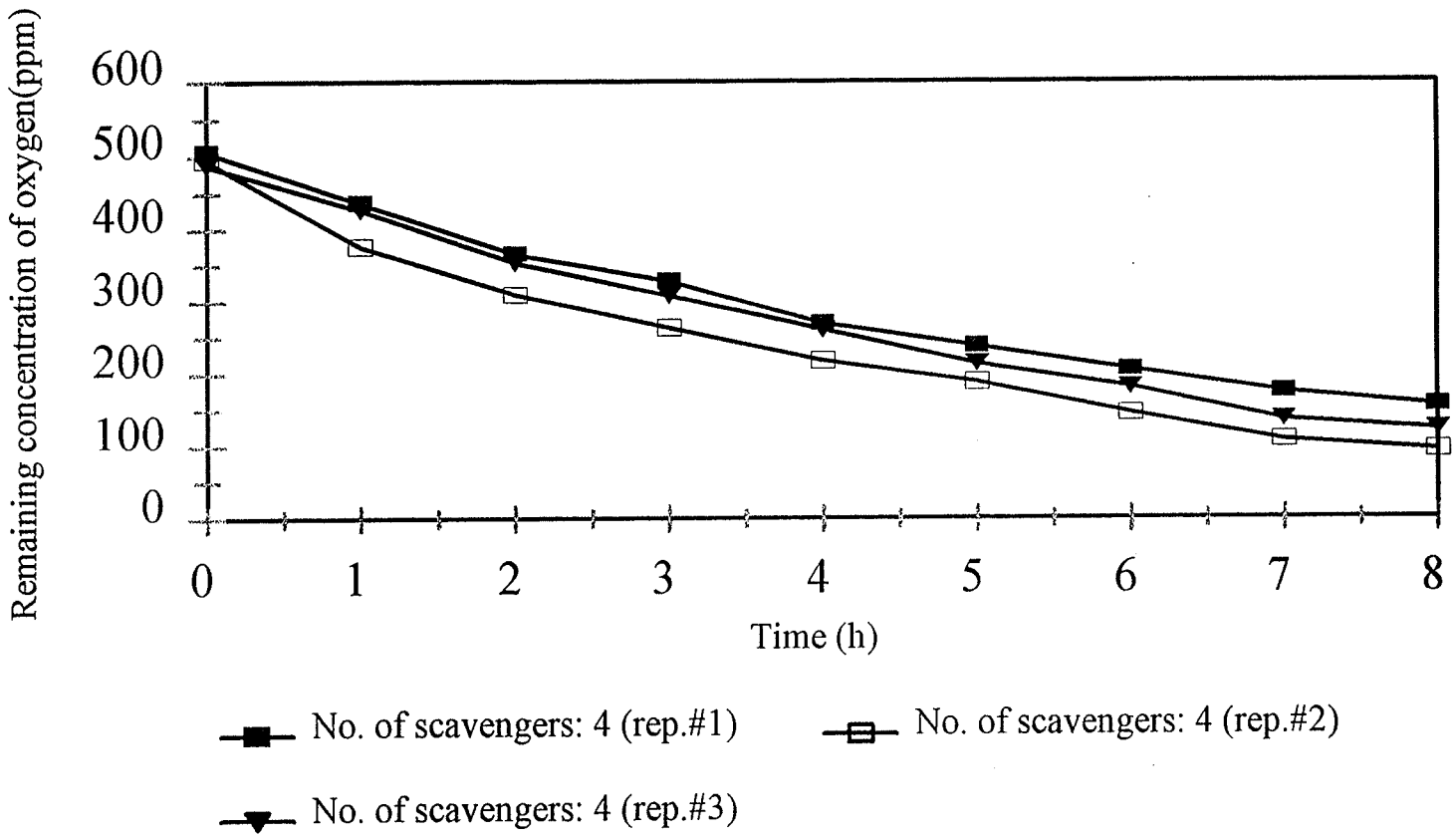

Fig. A18 Oxygen absorption rates of FreshPax® R-300 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 500 ppm.

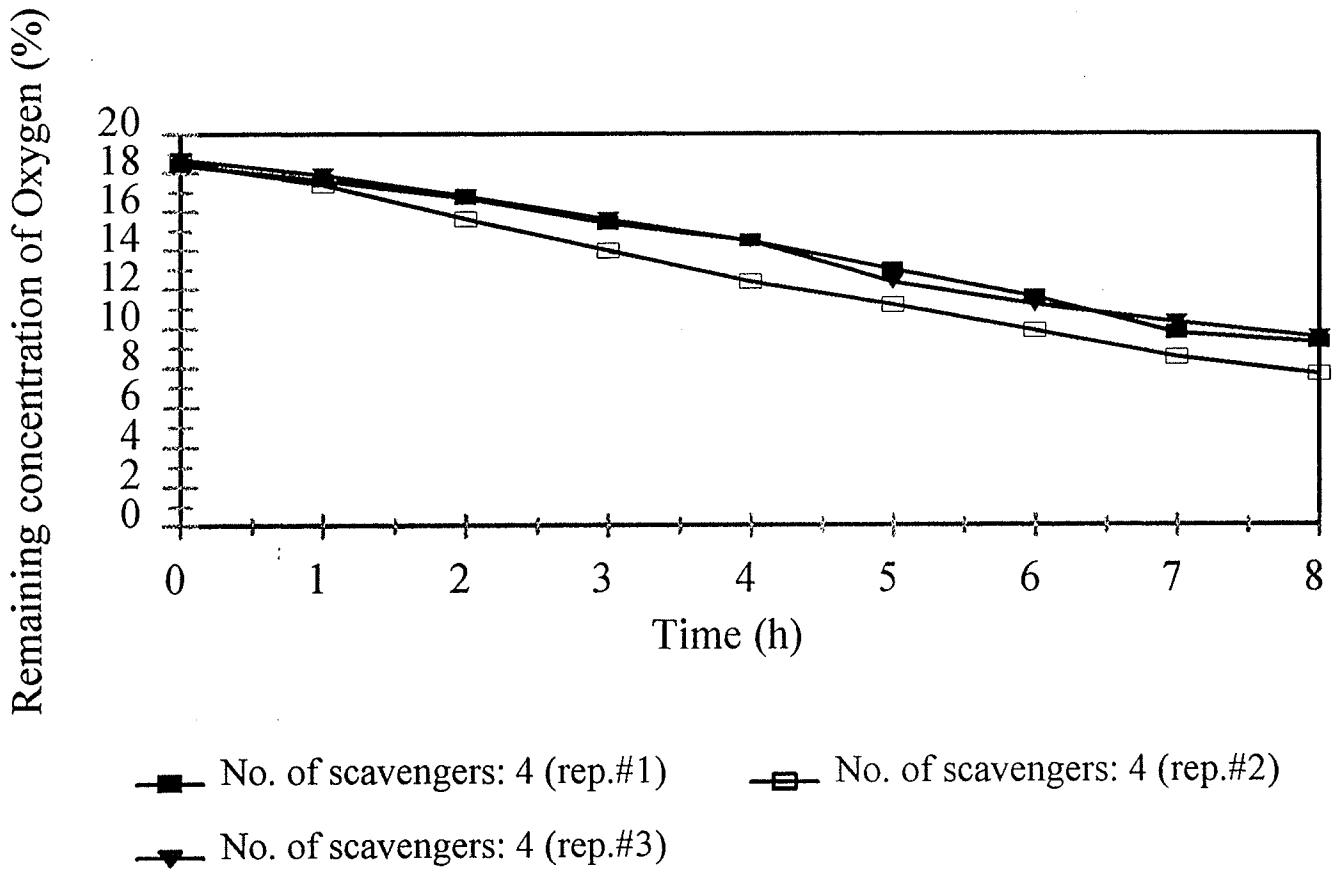

Fig. A19 Effect of position (in a simulated master pack system) on the oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

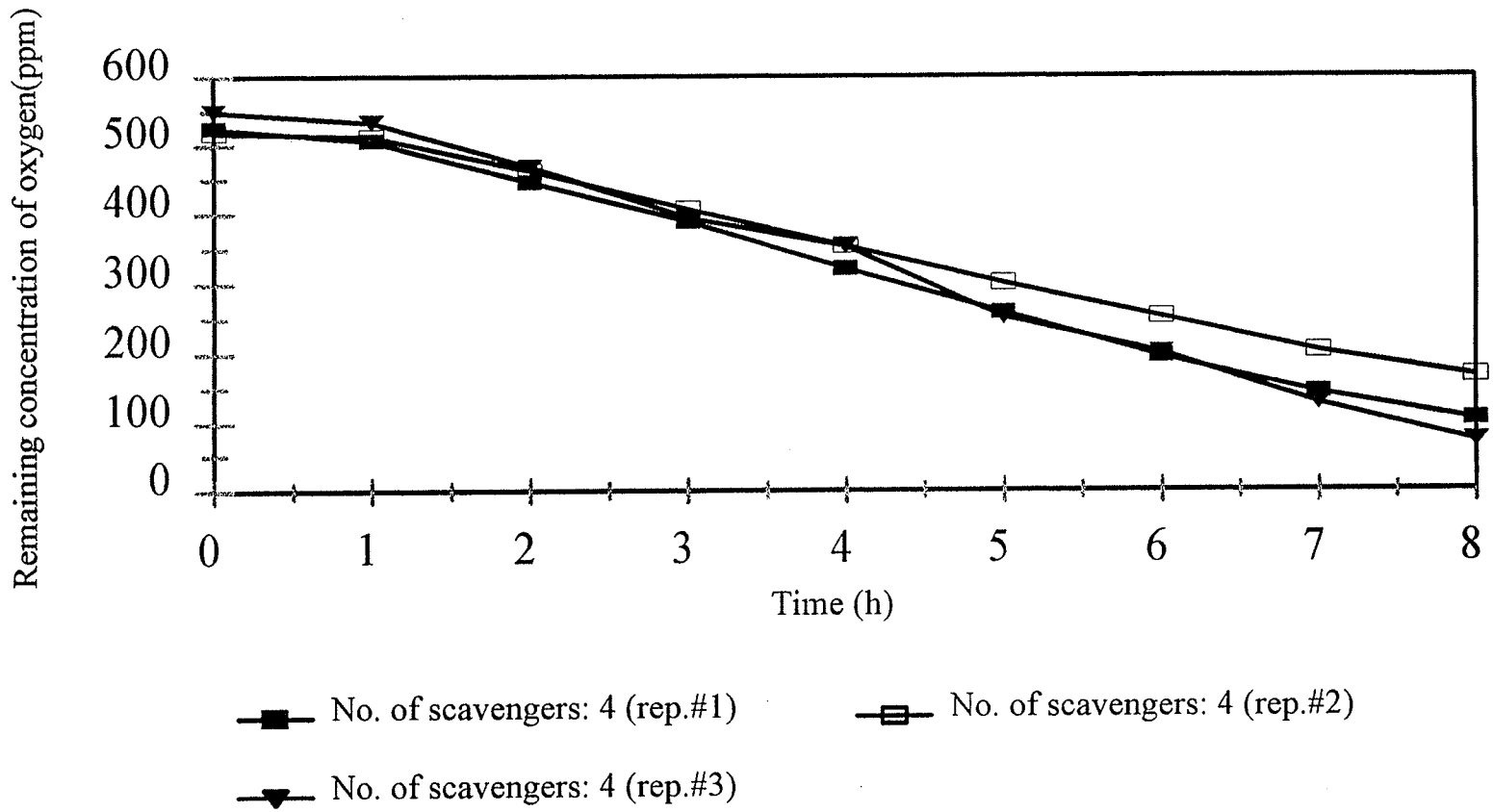

Fig. A20 Effect of position (simulated master pack system) on the oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm.

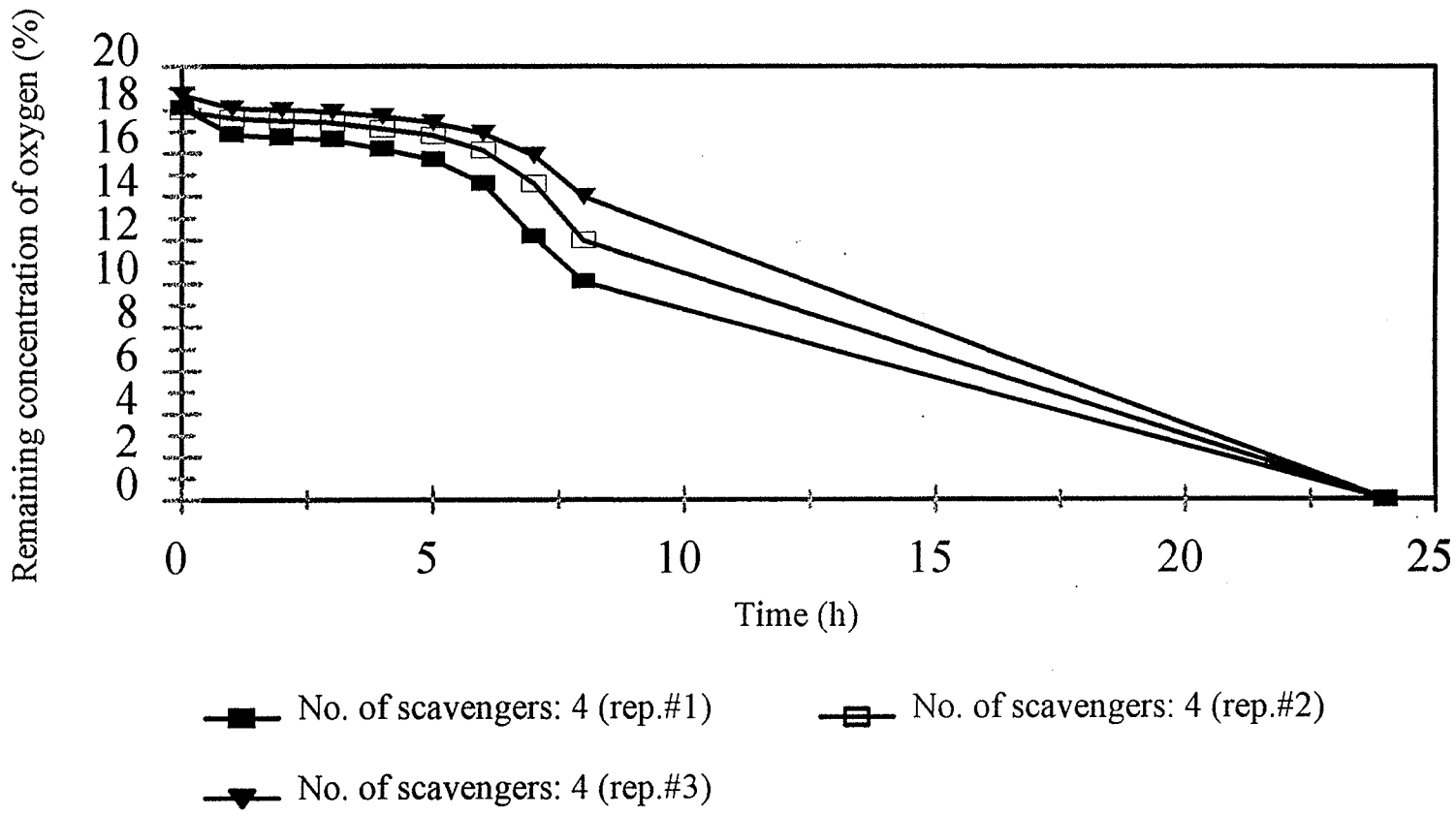

Fig. A21 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

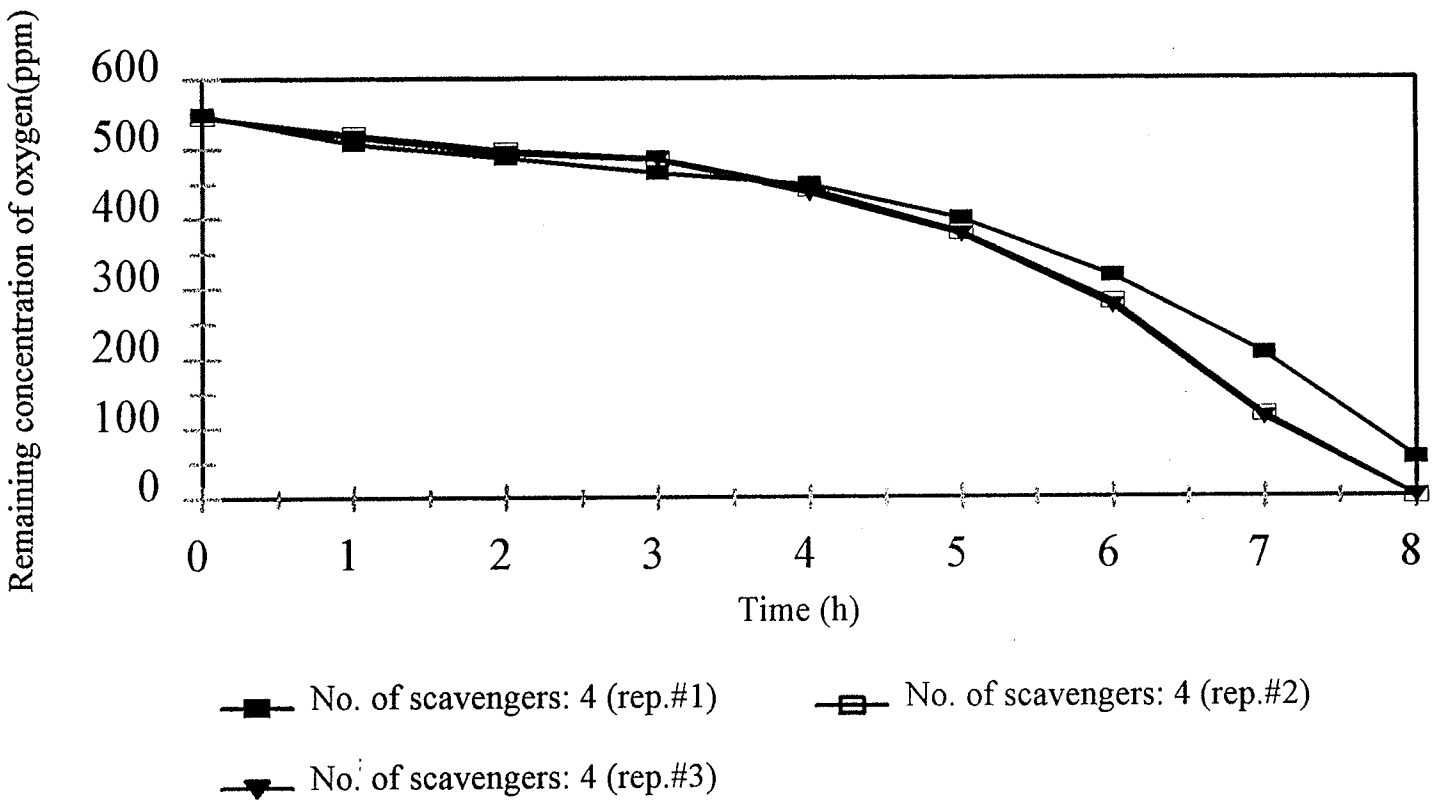

Fig. A22 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm (under nitrogen atmosphere).

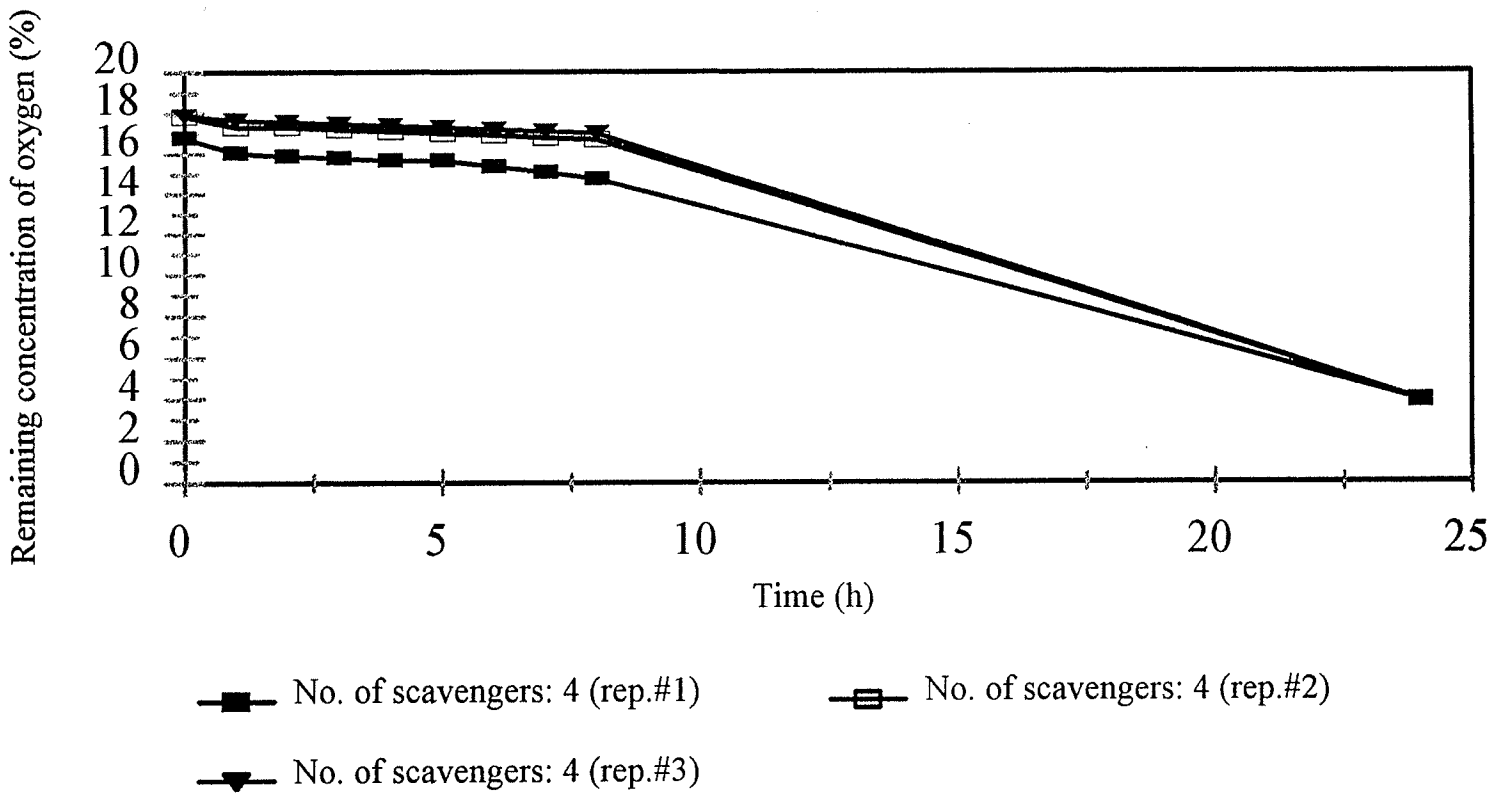

Fig. A23 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 20%.

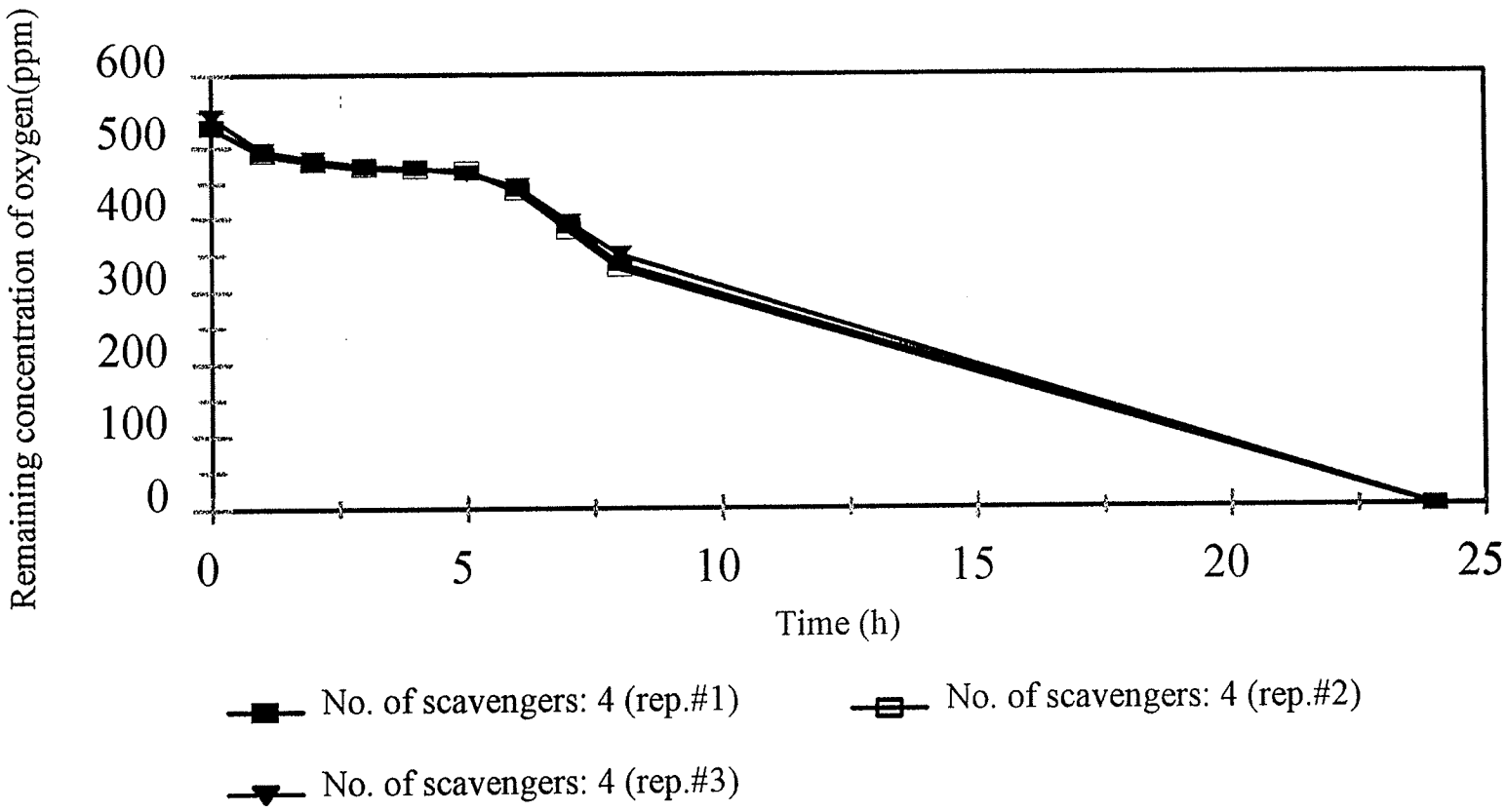

Fig. A24 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 500 ppm.

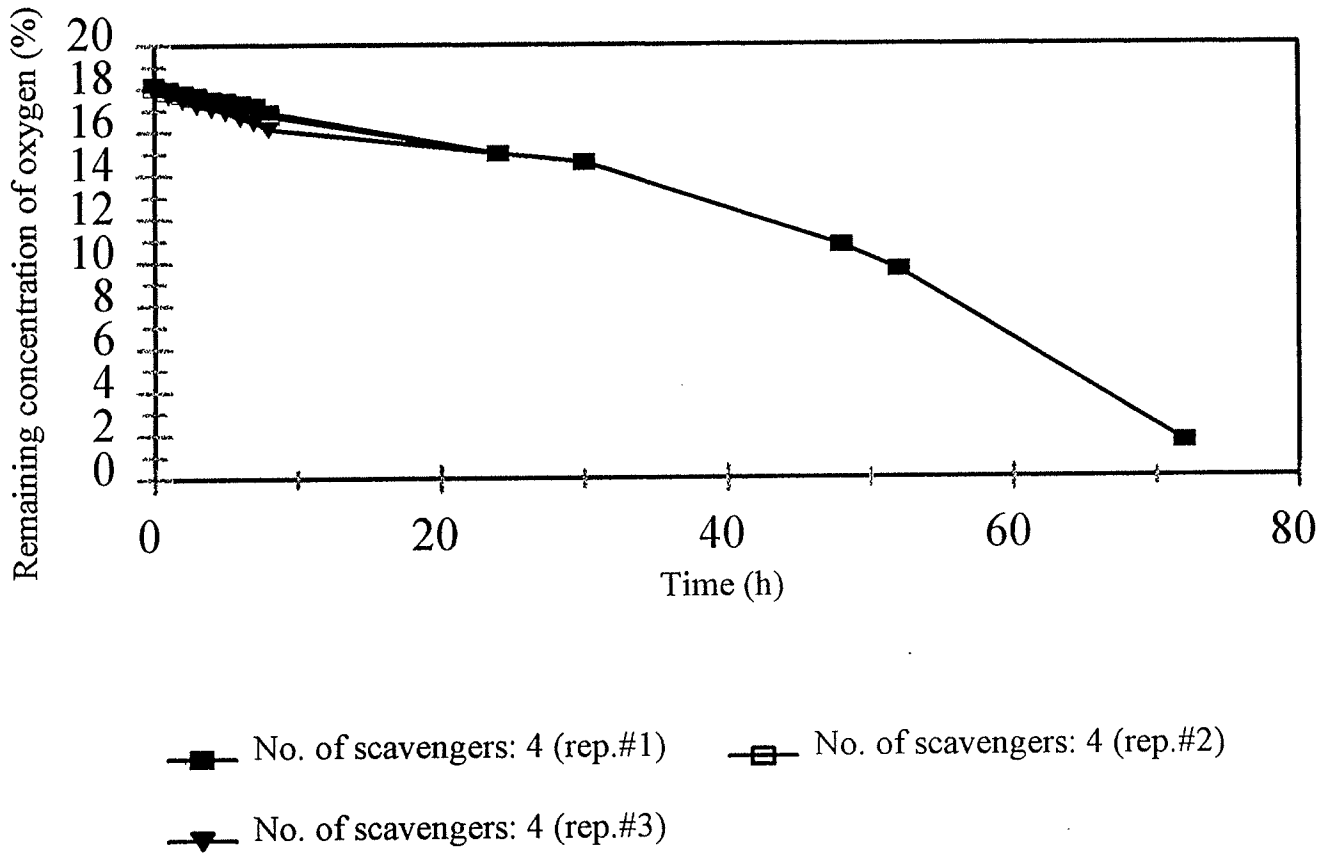

Fig. A25 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 2°C and at an initial O_2 concentration of 20%.

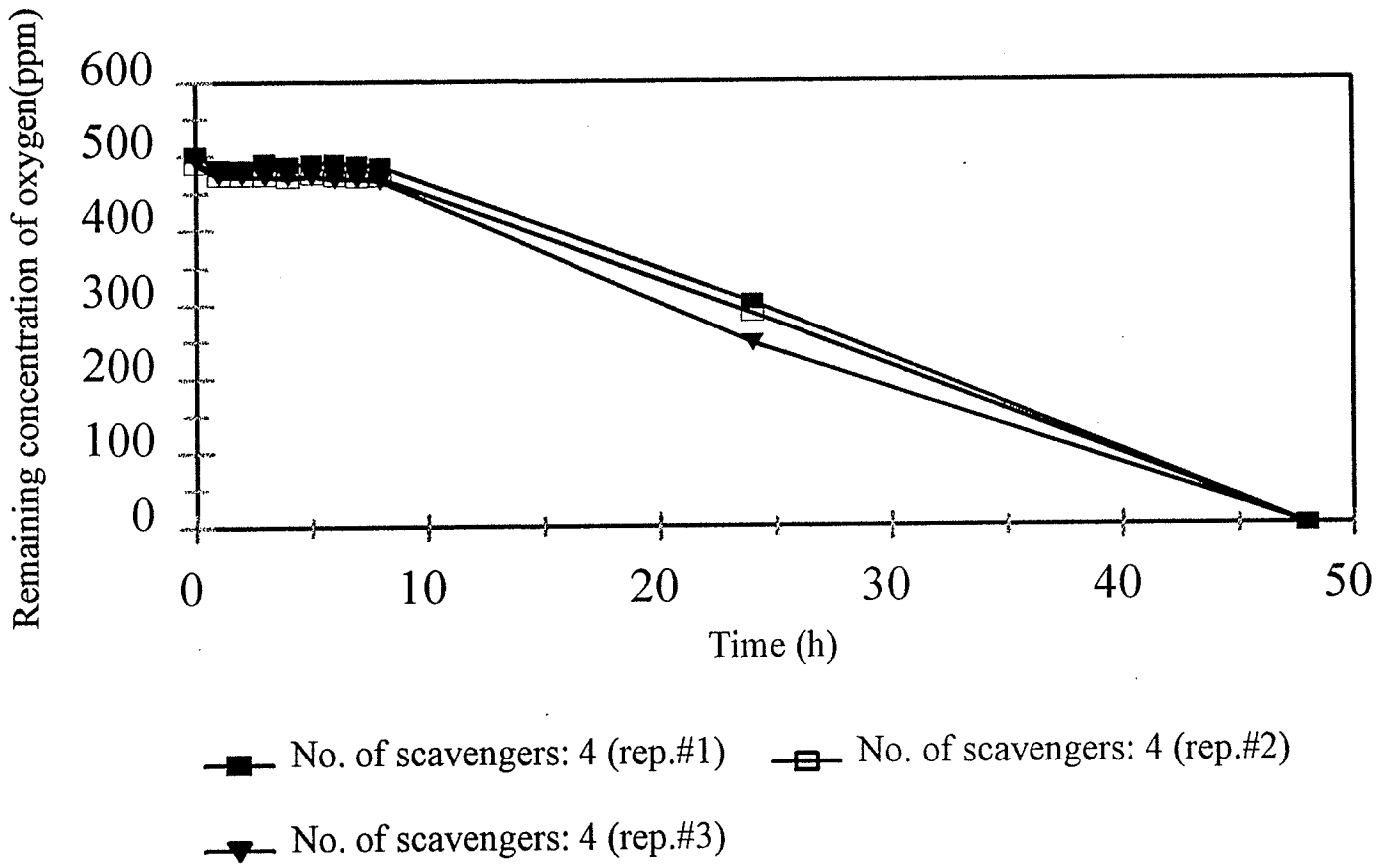

Fig. A26 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 2°C and at an initial O_2 concentration of 500 ppm.

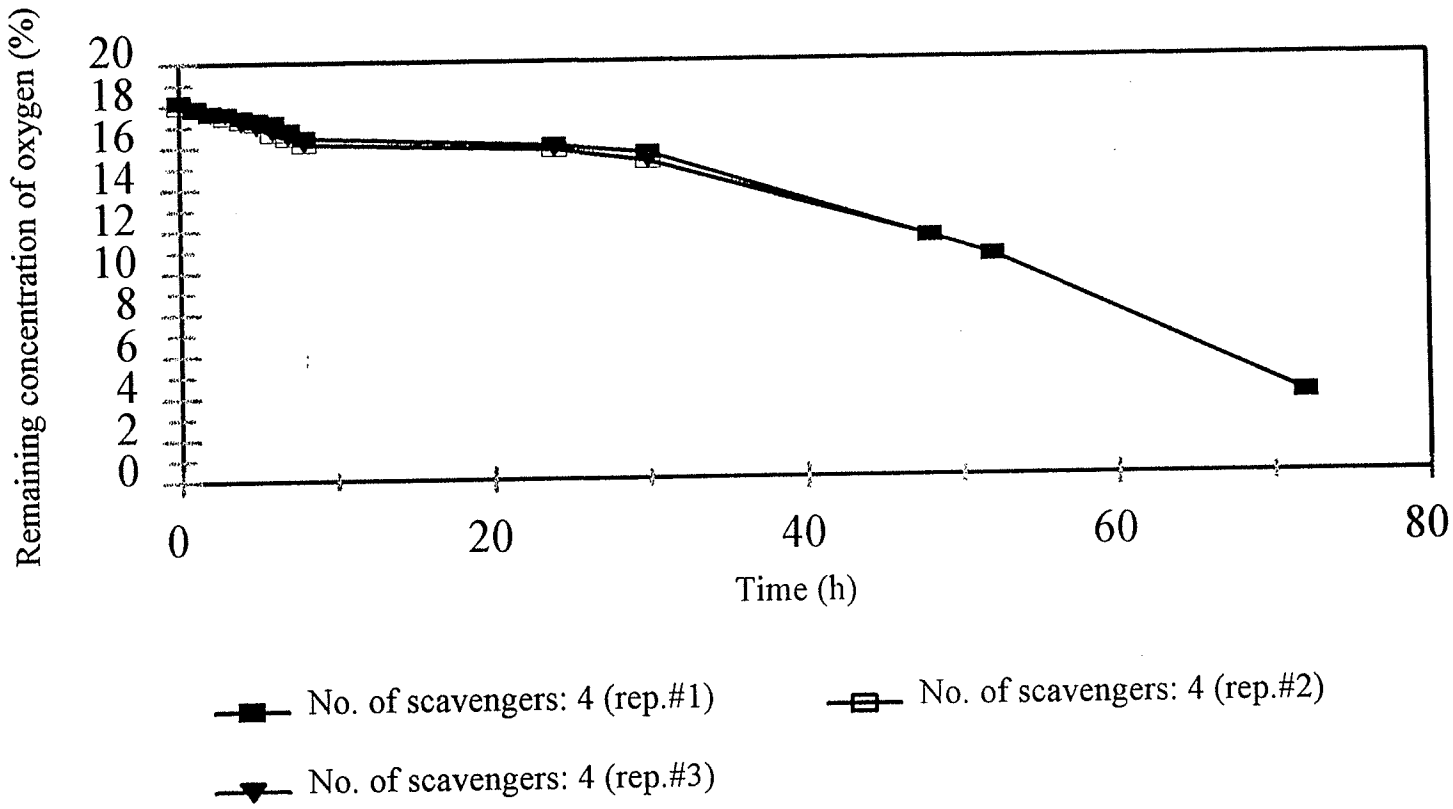

Fig. A27 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 20%.

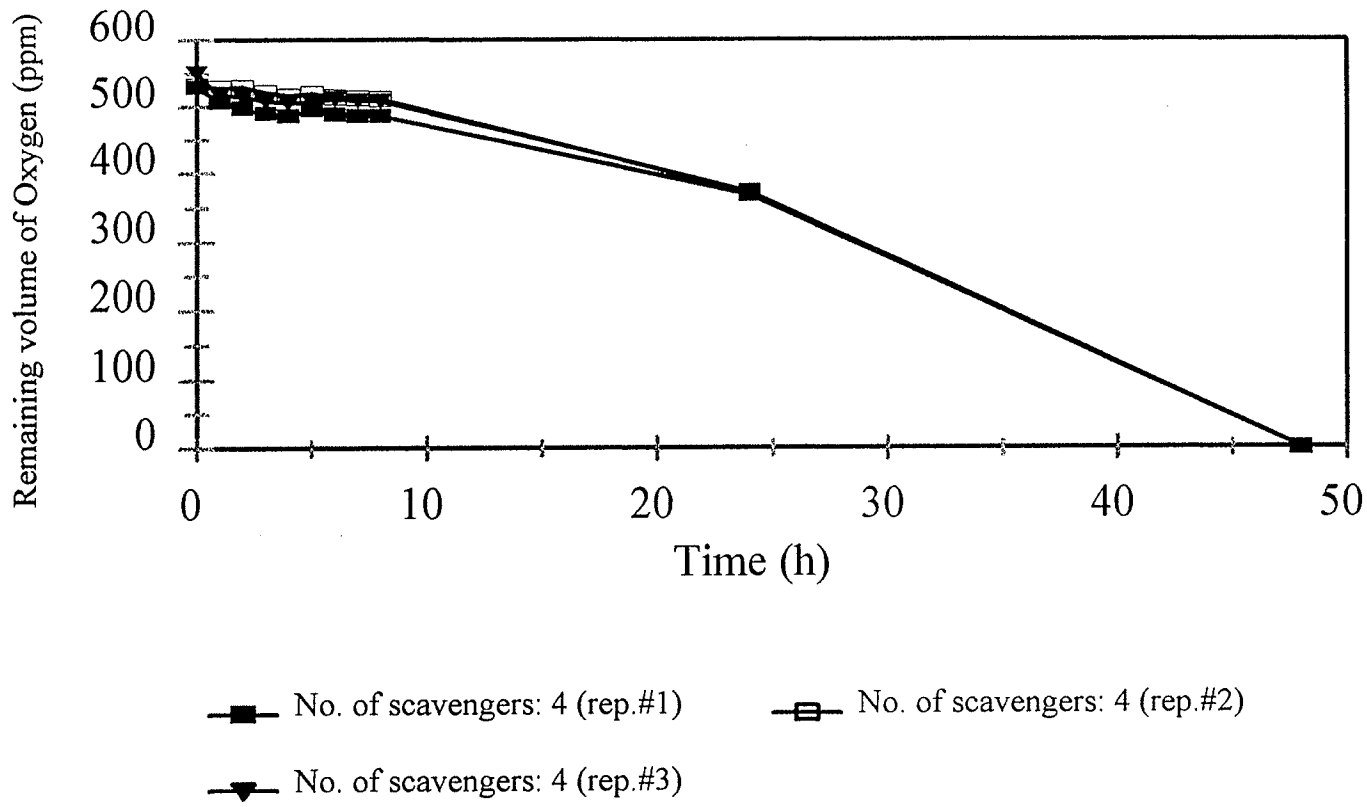

Fig. A28 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 500 ppm.

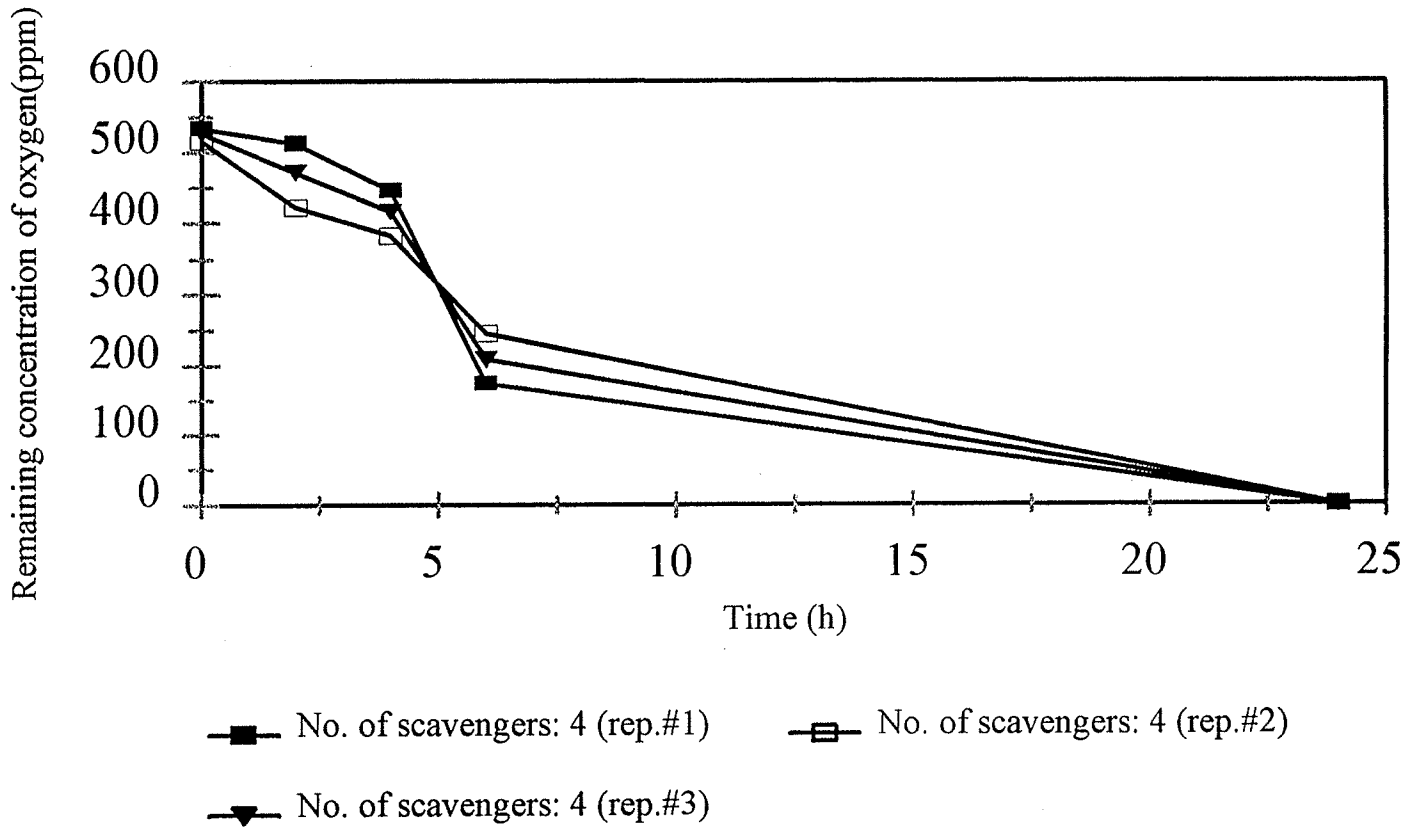

Fig. A29 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm (under carbon dioxide atmosphere).

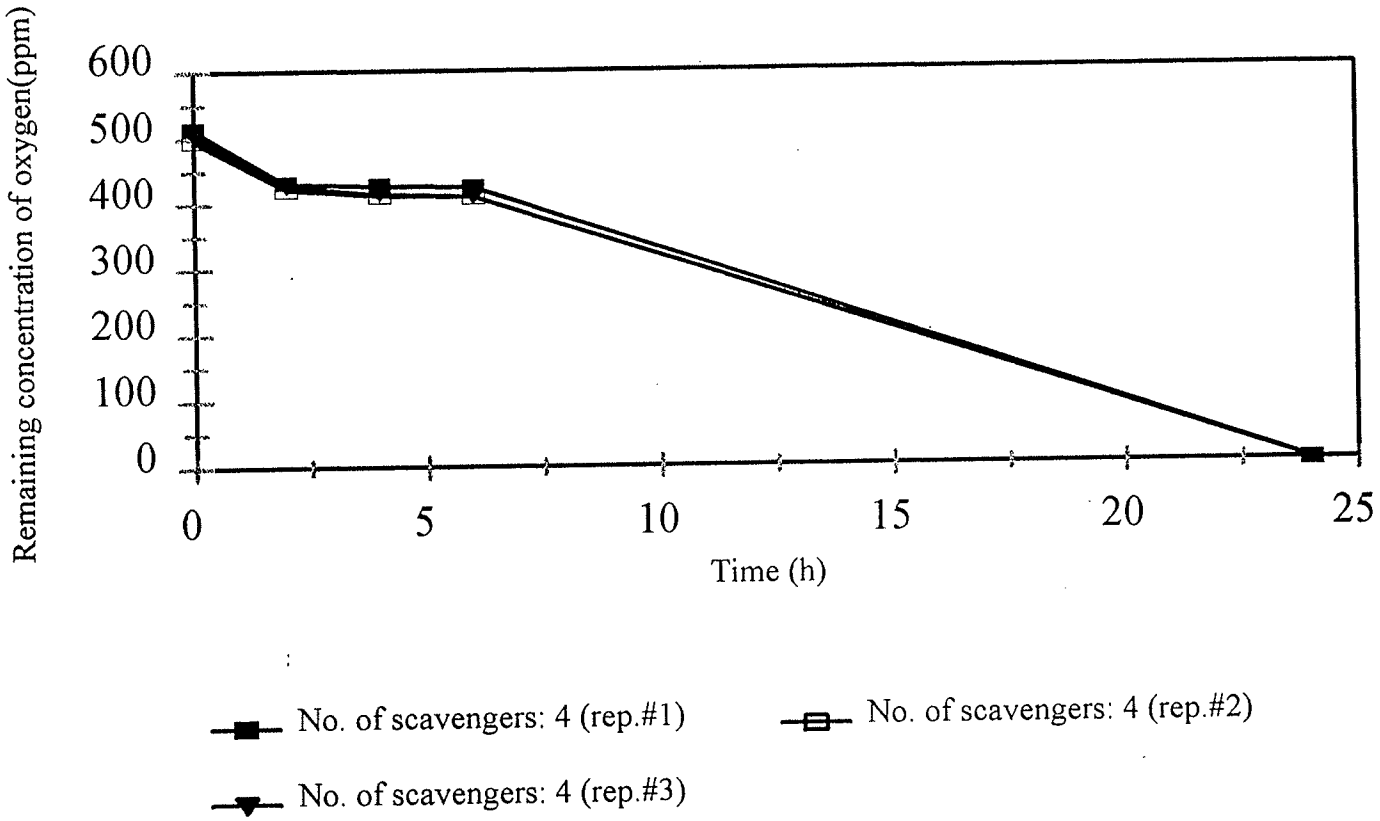

Fig. A30 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 500 ppm (under carbon dioxide atmosphere).

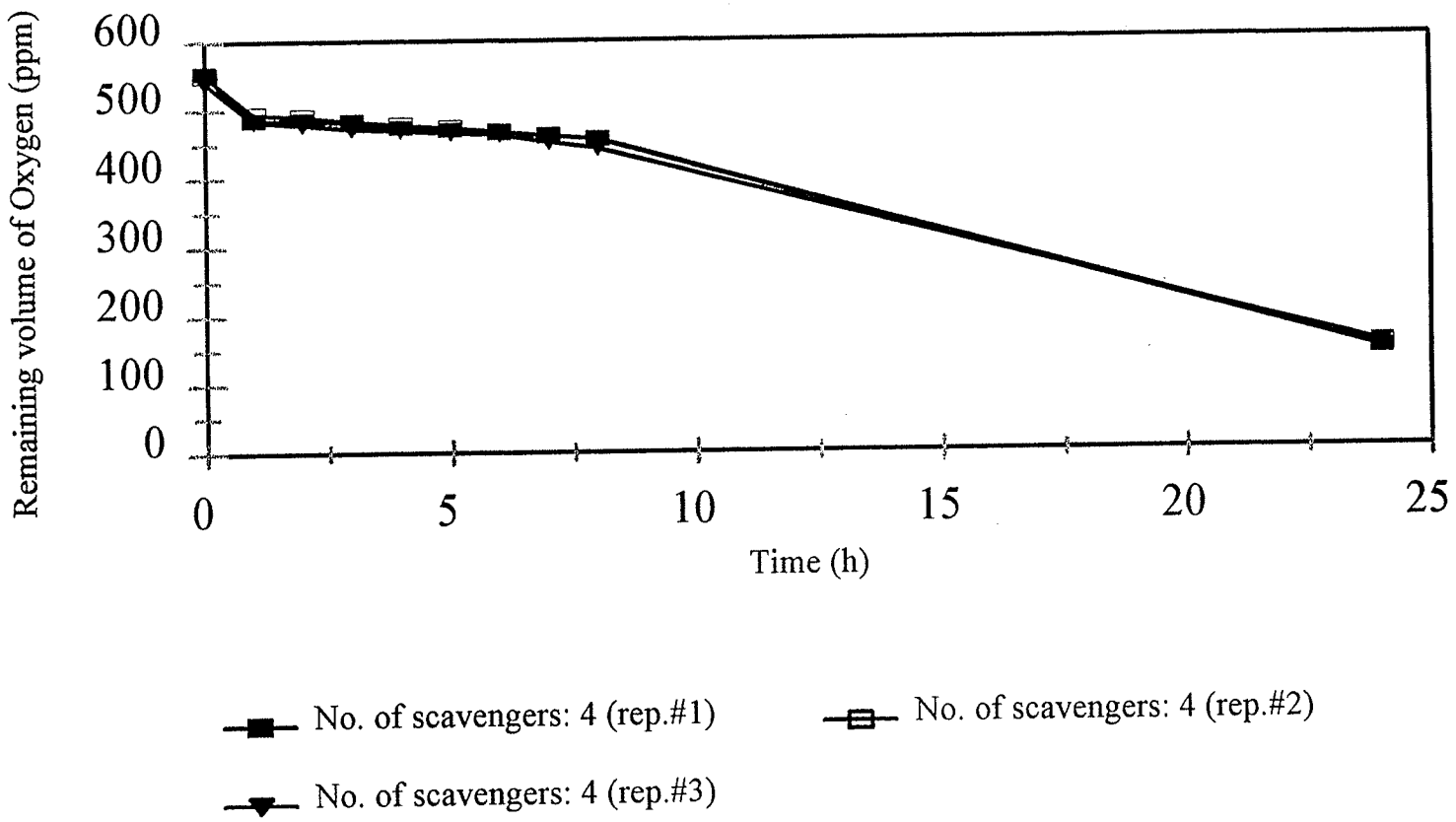

Fig. A31 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at 2°C and at an initial O_2 concentration of 500 ppm (under carbon dioxide atmosphere).

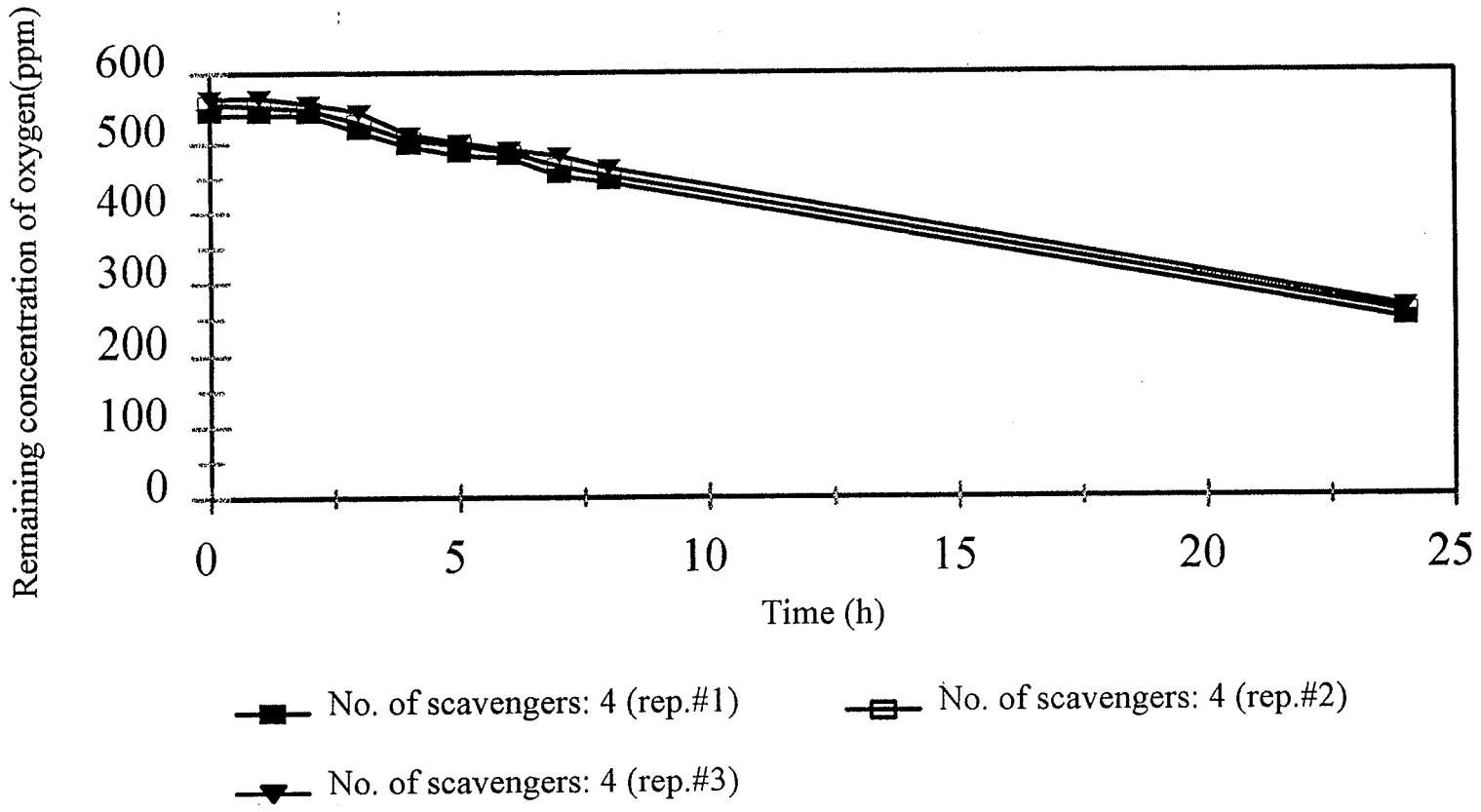

Fig. A32 Oxygen absorption rates of FreshPax® M-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 500 ppm (under carbon dioxide atmosphere).

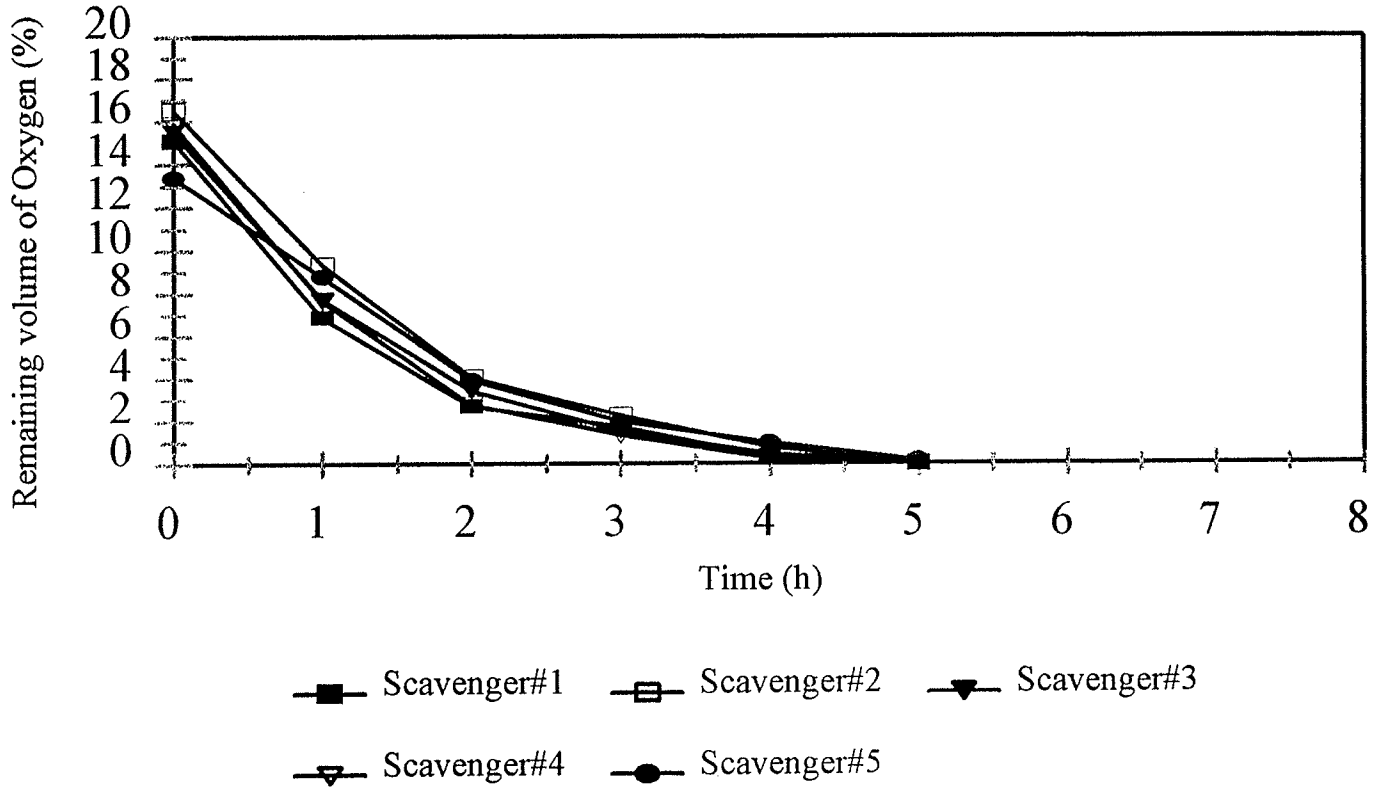

Fig. A33 Variability in O_2 absorption rates of individual FreshPax® R-2000 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

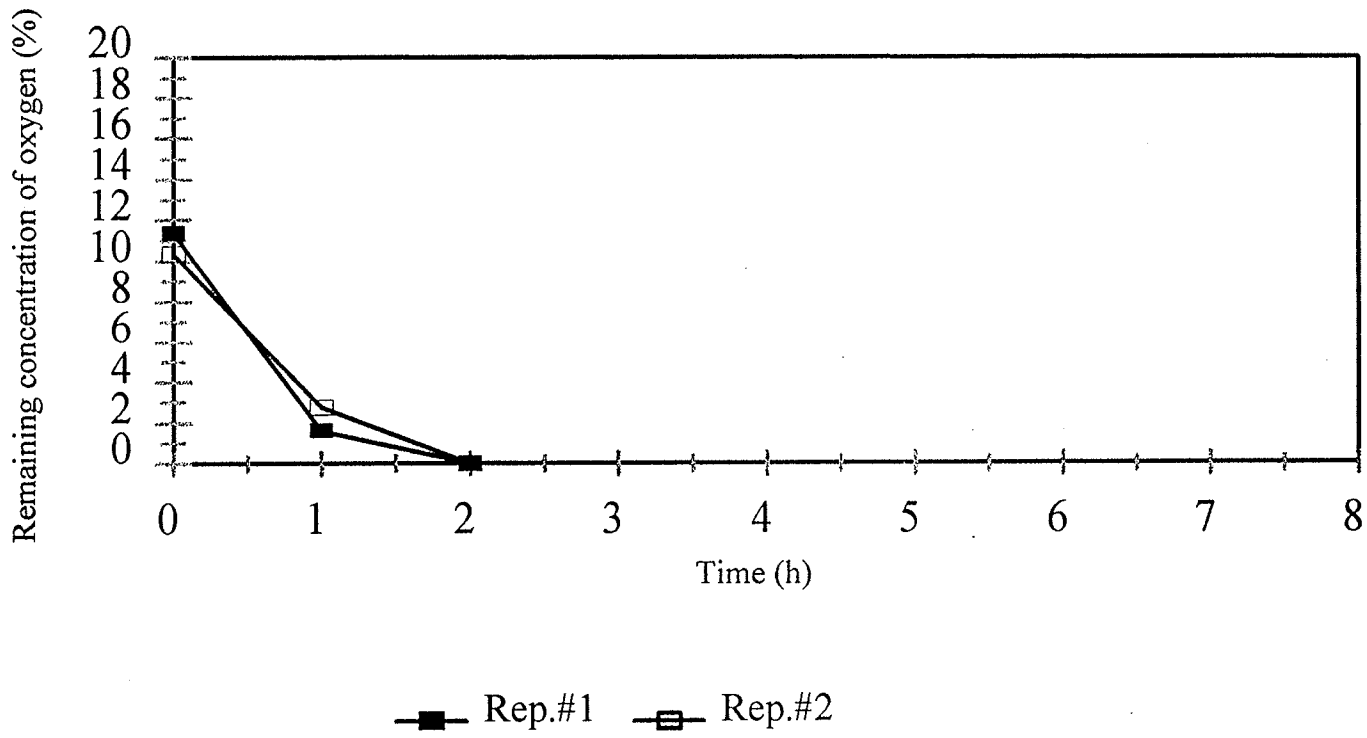

Fig. A34 Oxygen absorption rates of FreshPax® R-2000 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

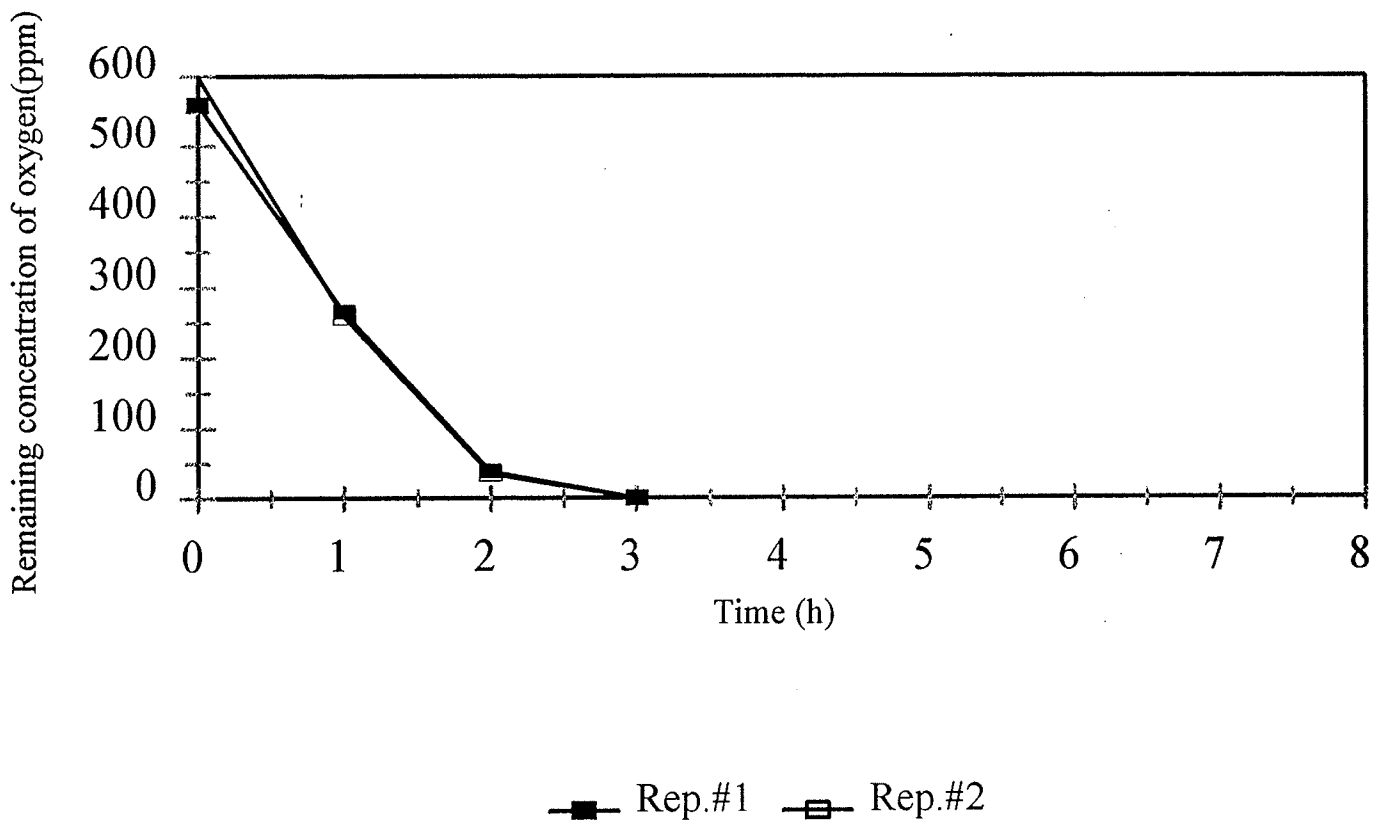

Fig. A35 Oxygen absorption rates of FreshPax® R-2000 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm.

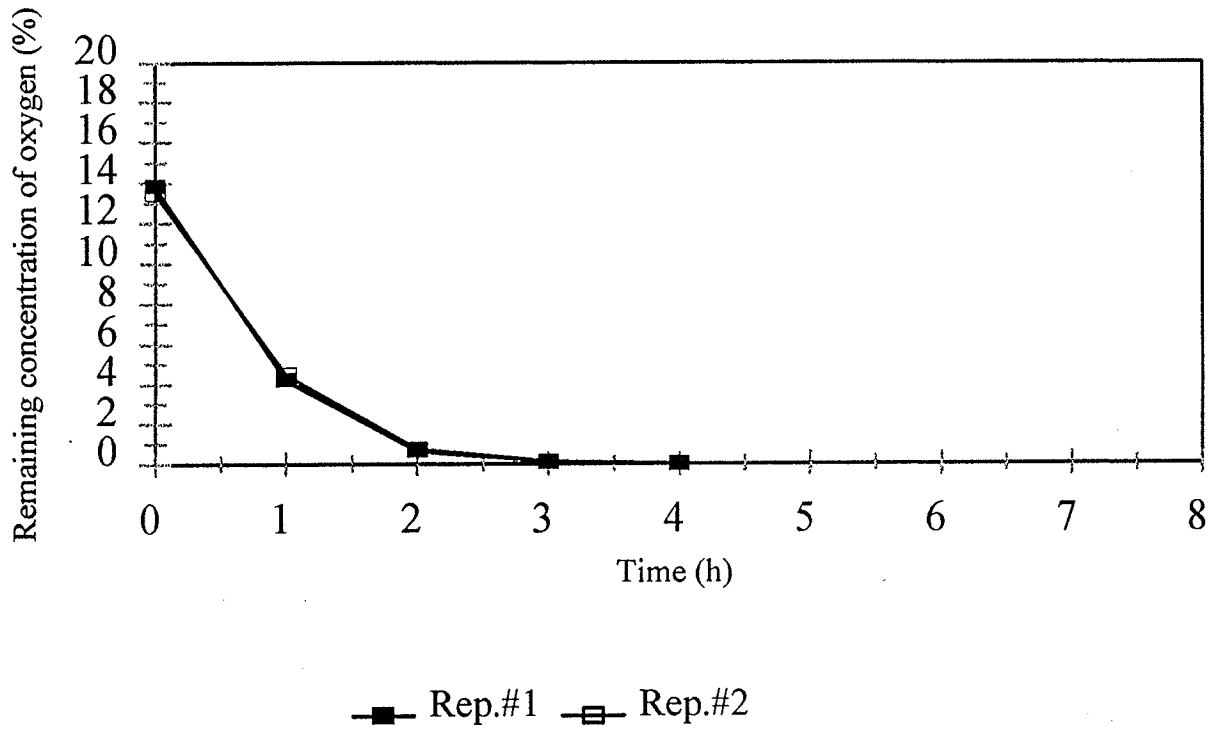

Fig. A36 Oxygen absorption rates of FreshPax® R-2000 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 20%.

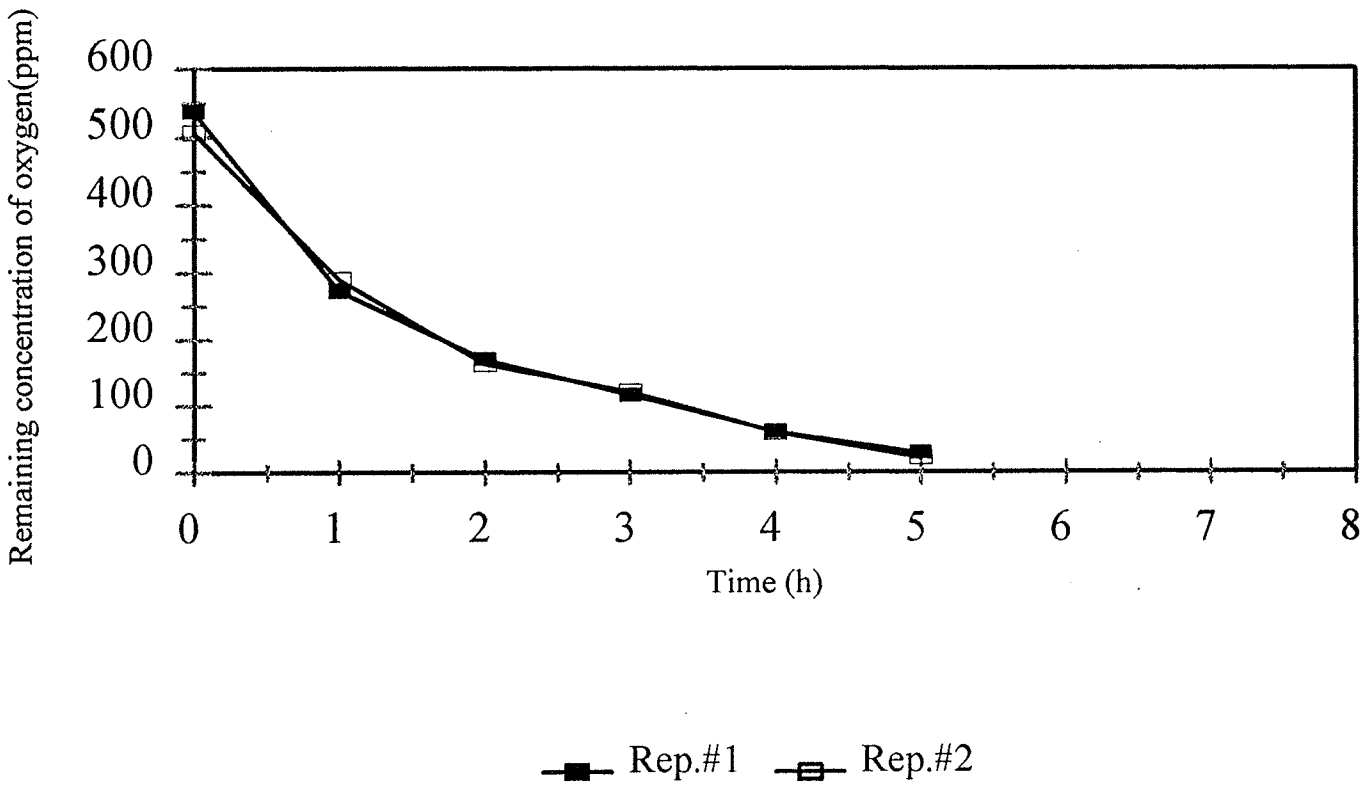

Fig. A37 Oxygen absorption rates of FreshPax® R-2000 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 500 ppm.

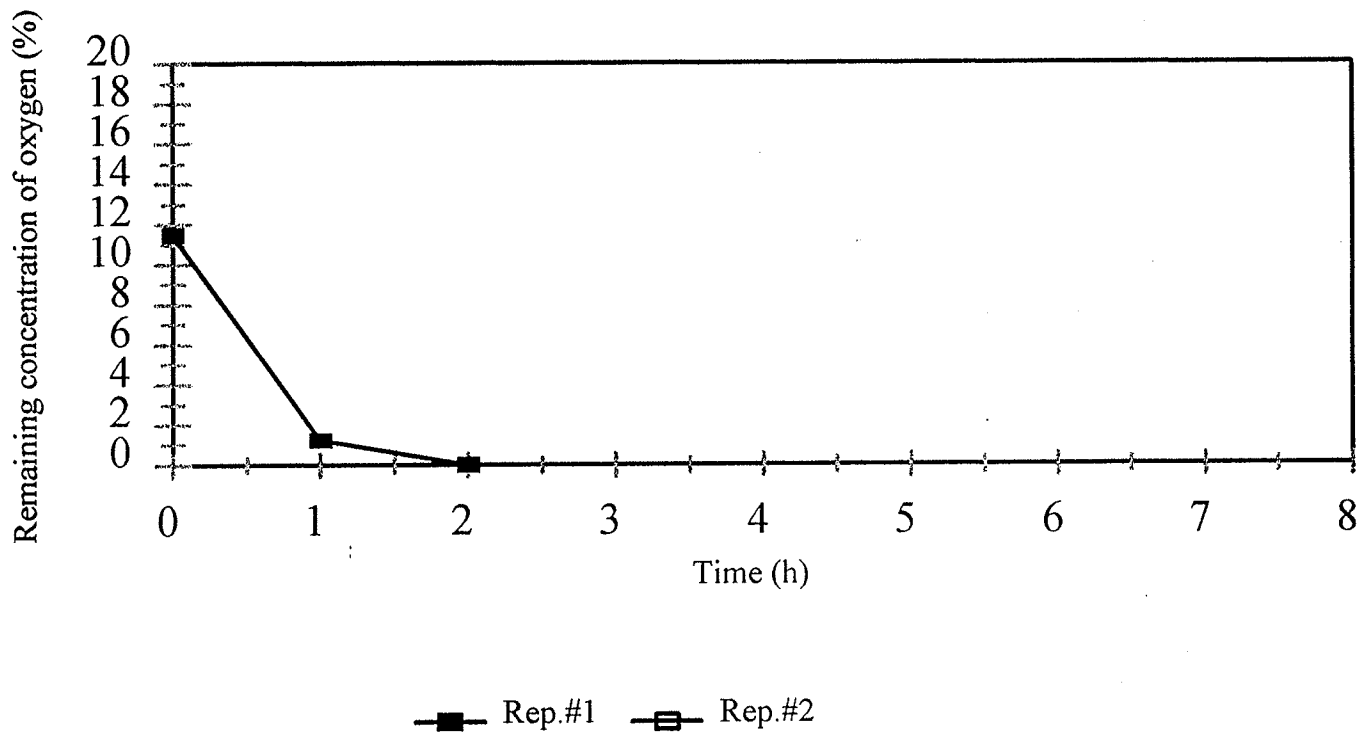

Fig. A38 Oxygen absorption rates of FreshPax® R-2000 O_2 scavengers at 2°C and at an initial O_2 concentration of 20%.

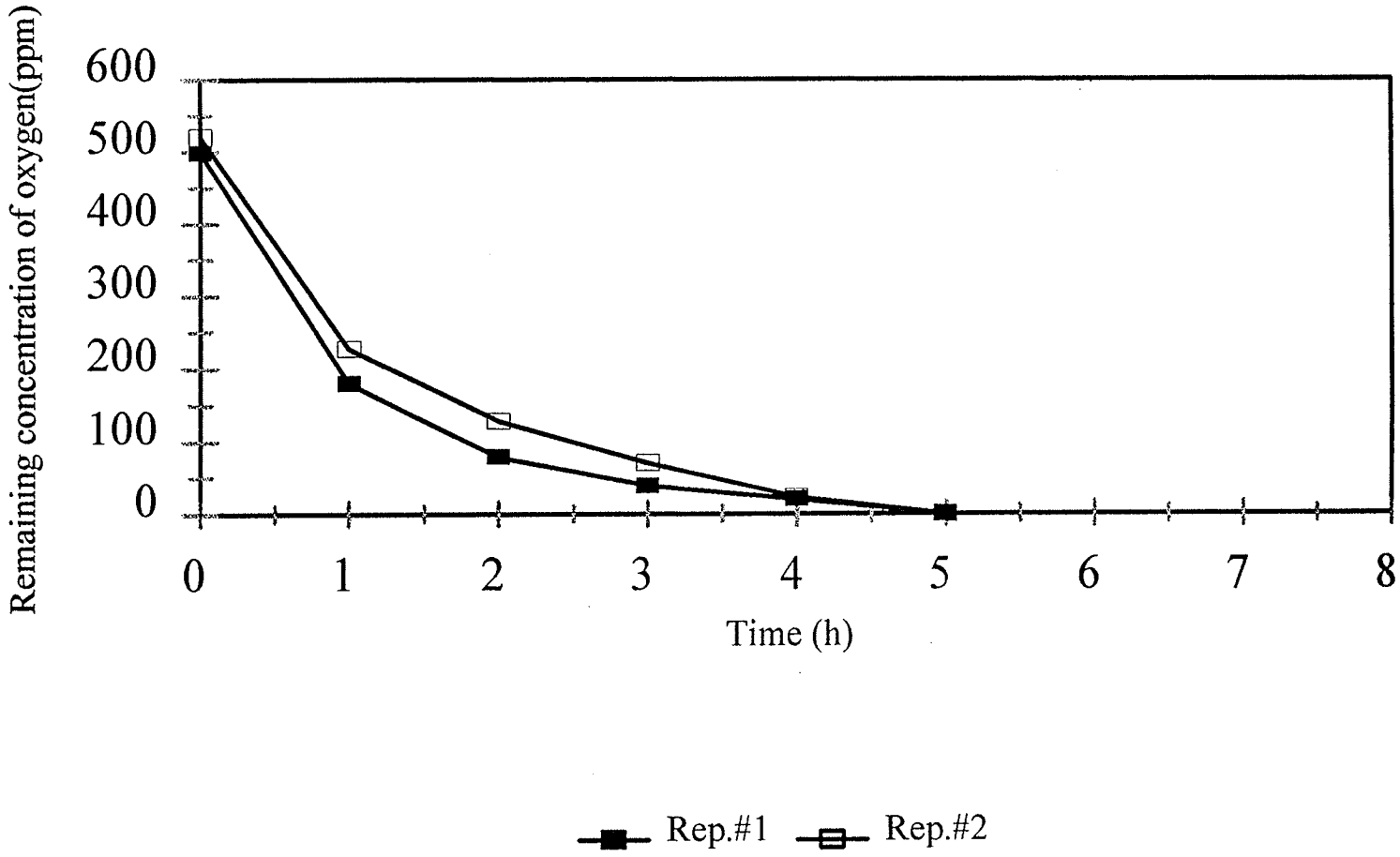

Fig. A39 Oxygen absorption rates of FreshPax® R-2000 O_2 scavengers at 2°C and at an initial O_2 concentration of 500 ppm.

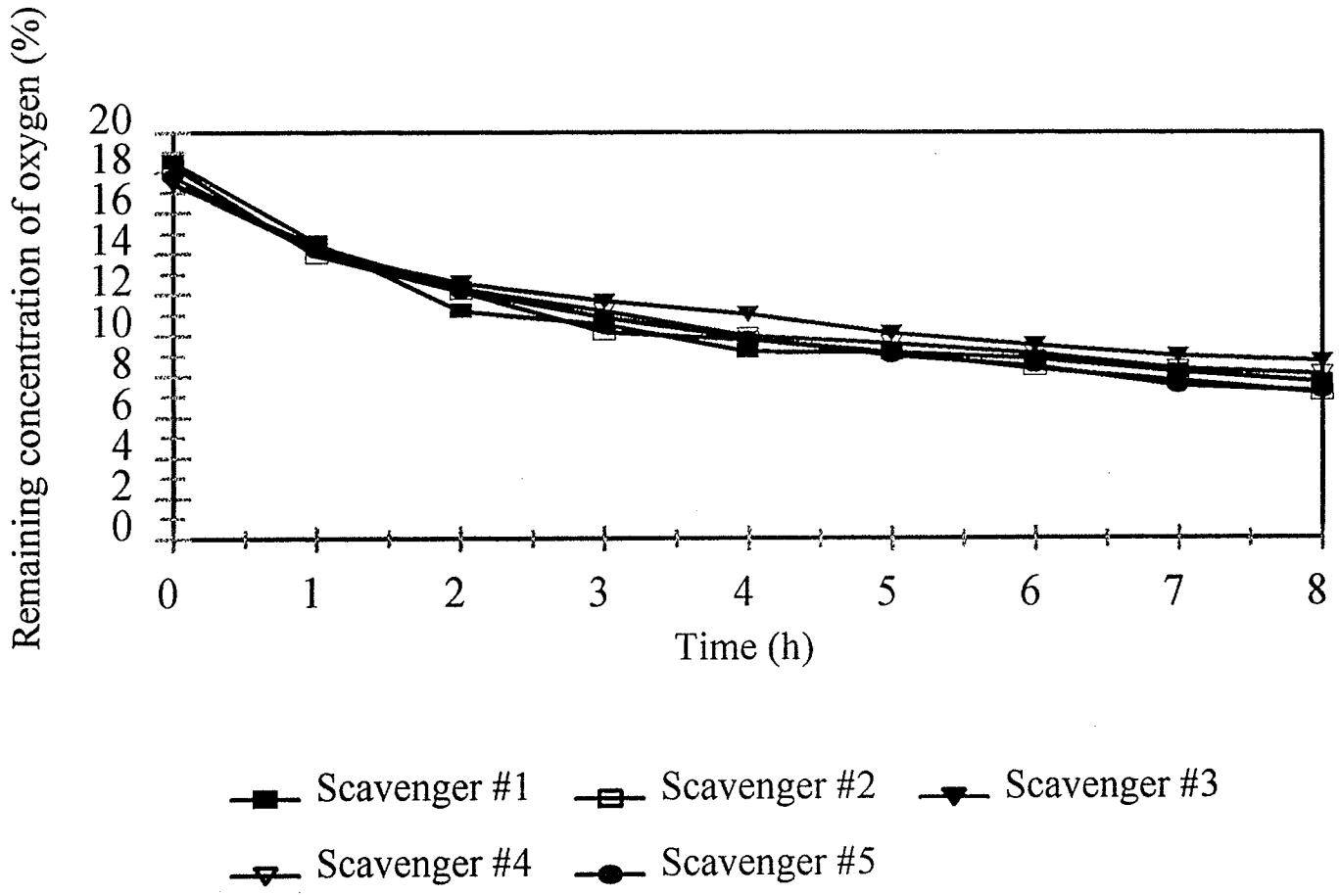

Fig. A40 Variability in oxygen absorption rates among individual Bioka® S-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

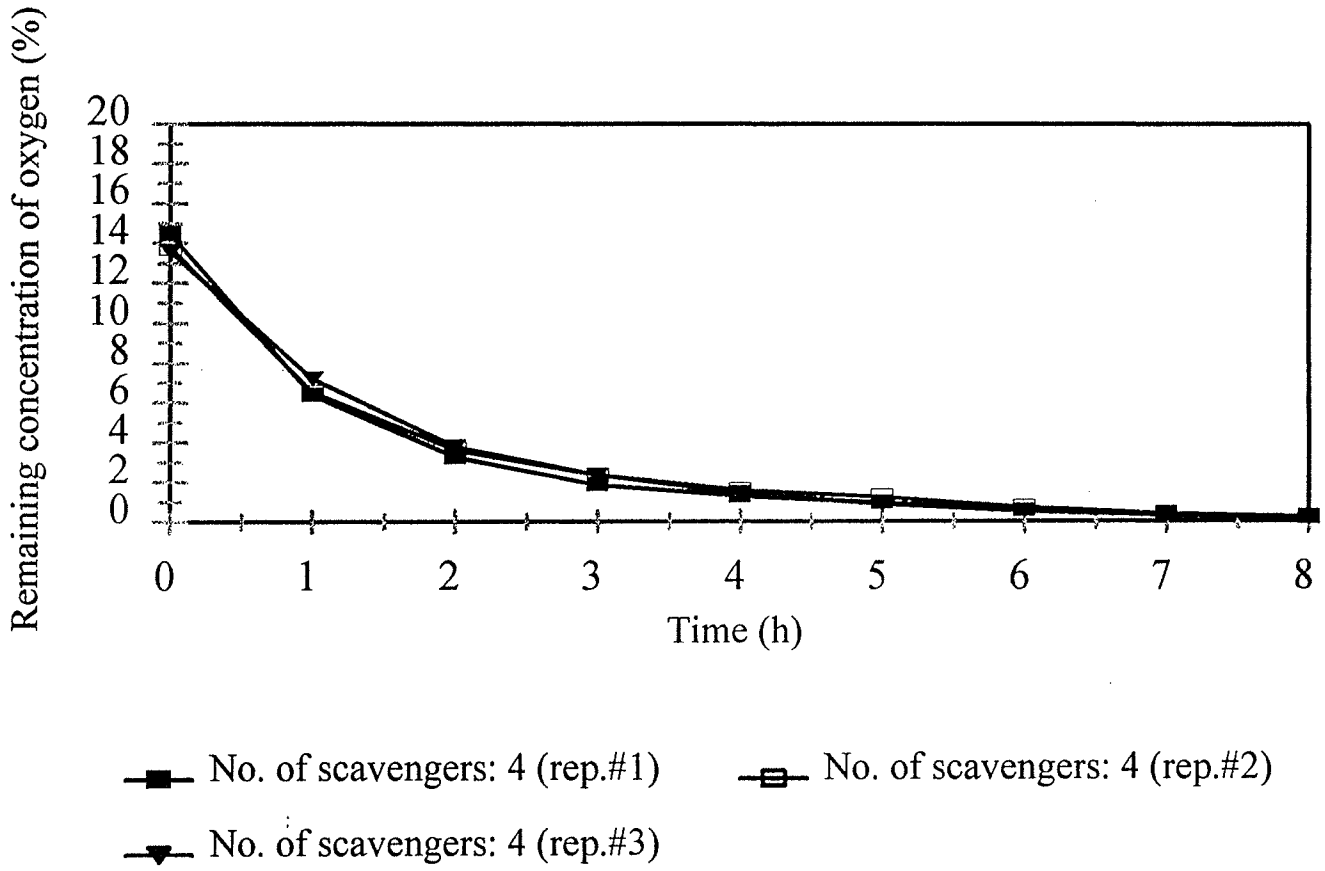

Fig. A41 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

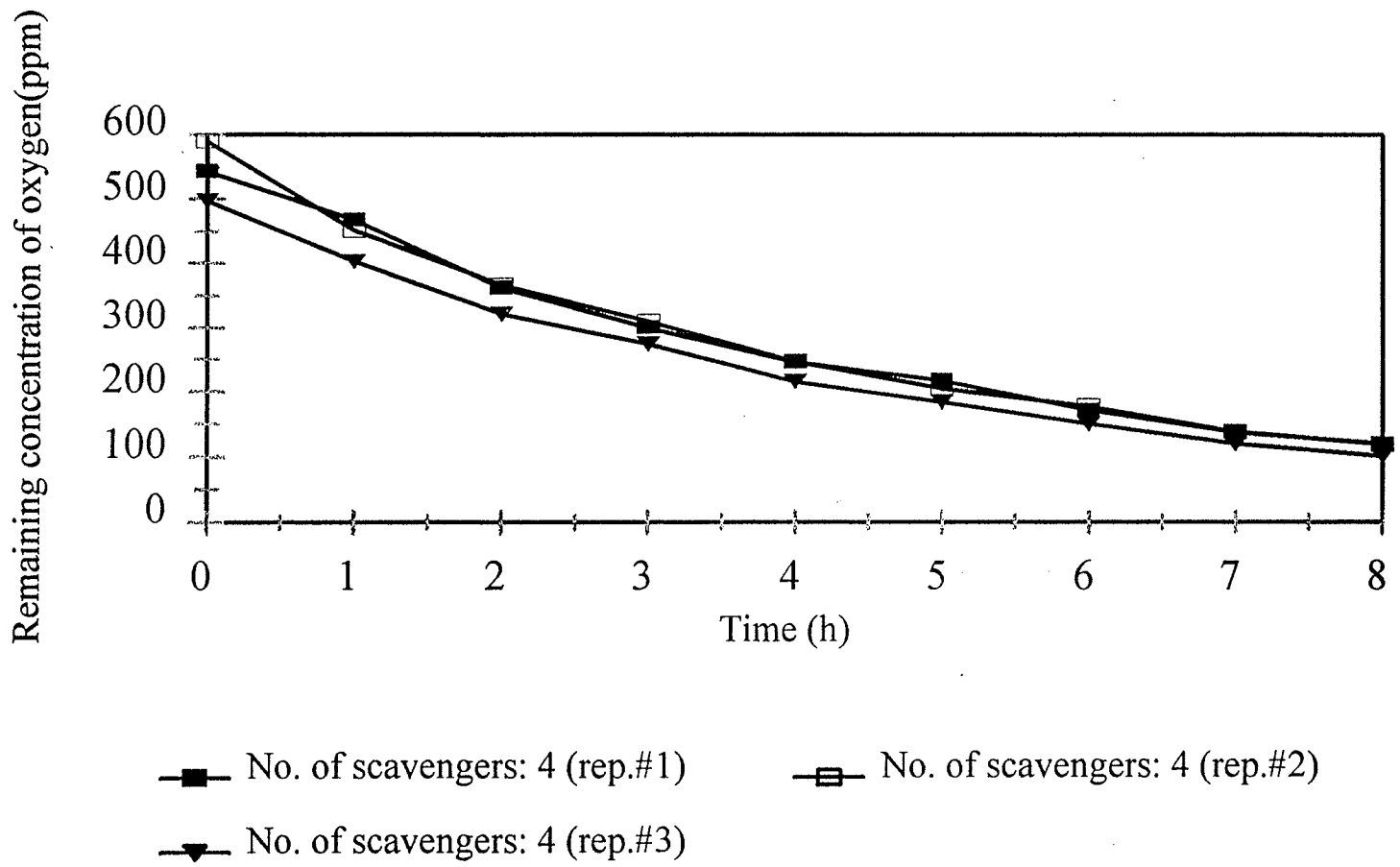

Fig. A42 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm.

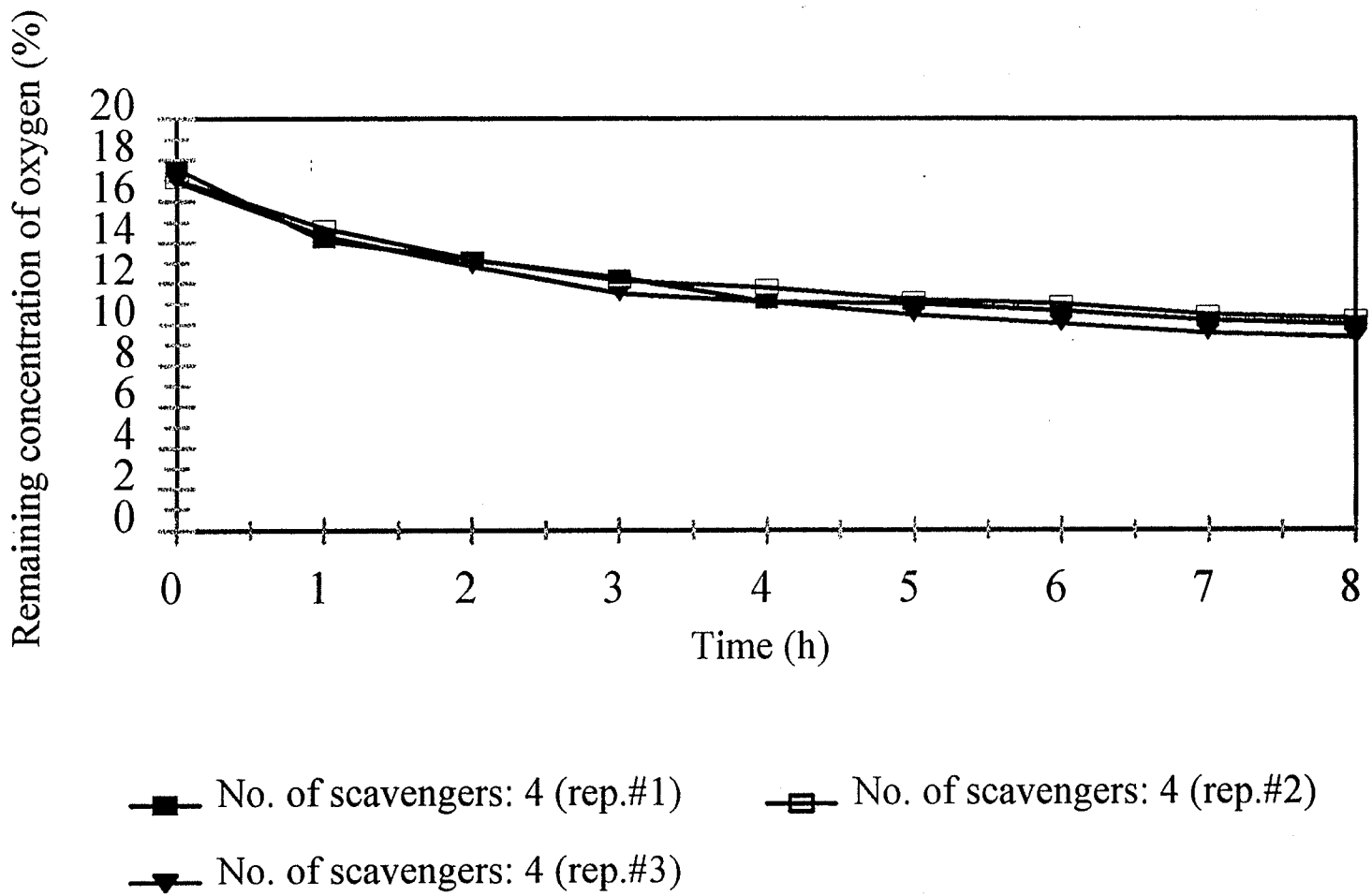

Fig. A43 Effect of suspension on the oxygen absorption rates of Bioka® S-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

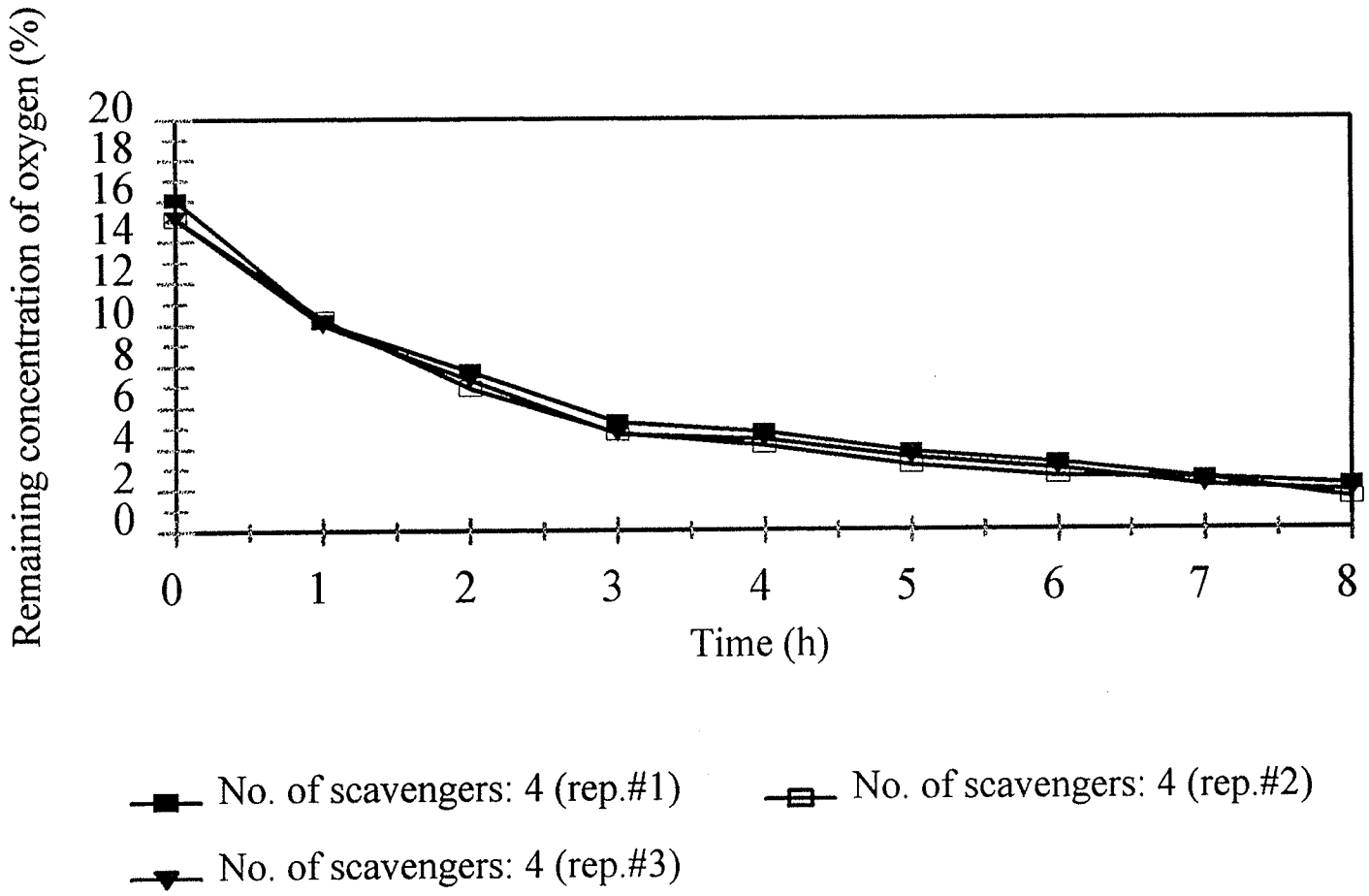

Fig. A44 Oxygen absorption rates of Bioka® S-75 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

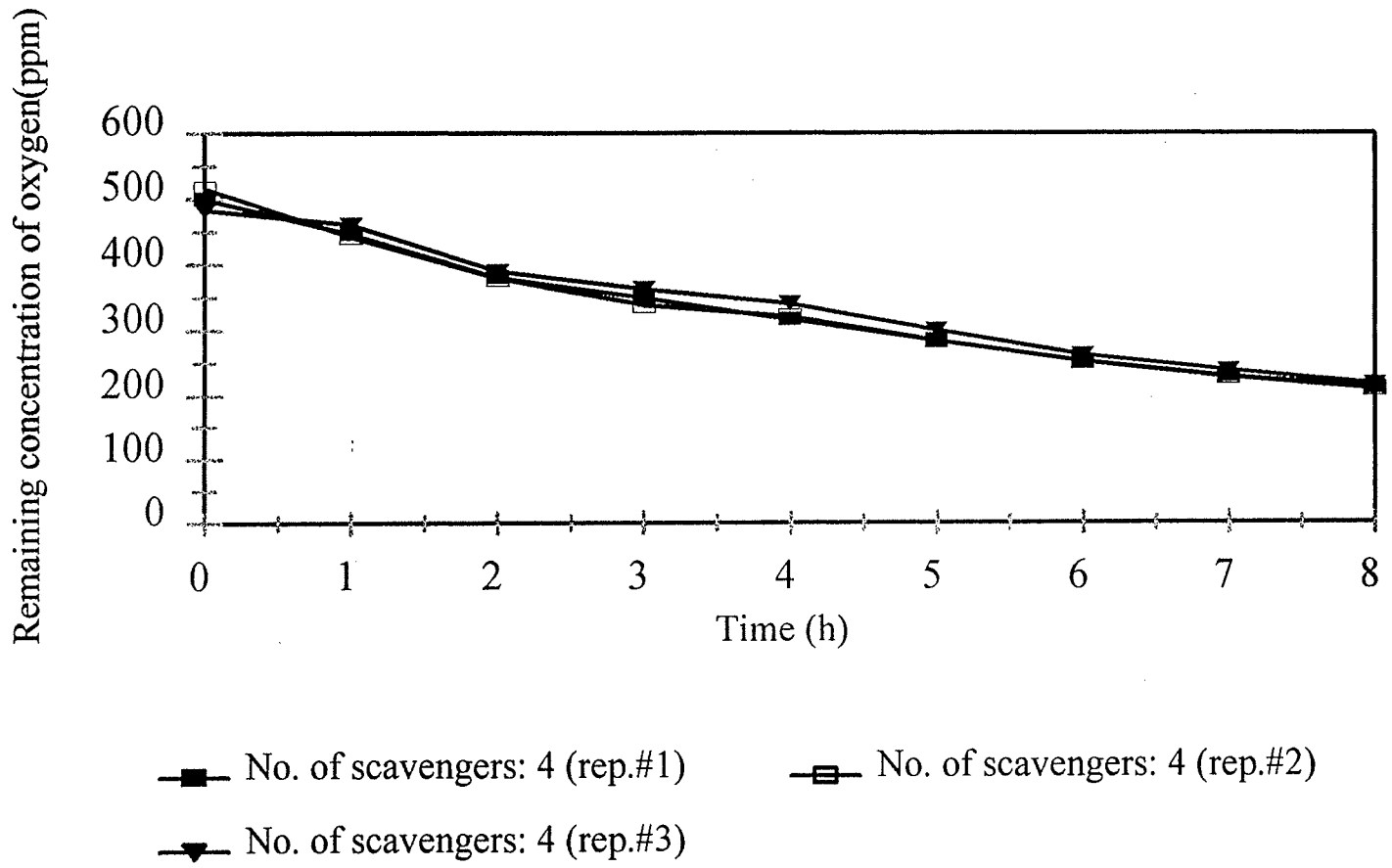

Fig. A45 Oxygen absorption rates of Bioka® S-75 O_2 scavengers at 25°C and at an initial O_2concentration of 500 ppm

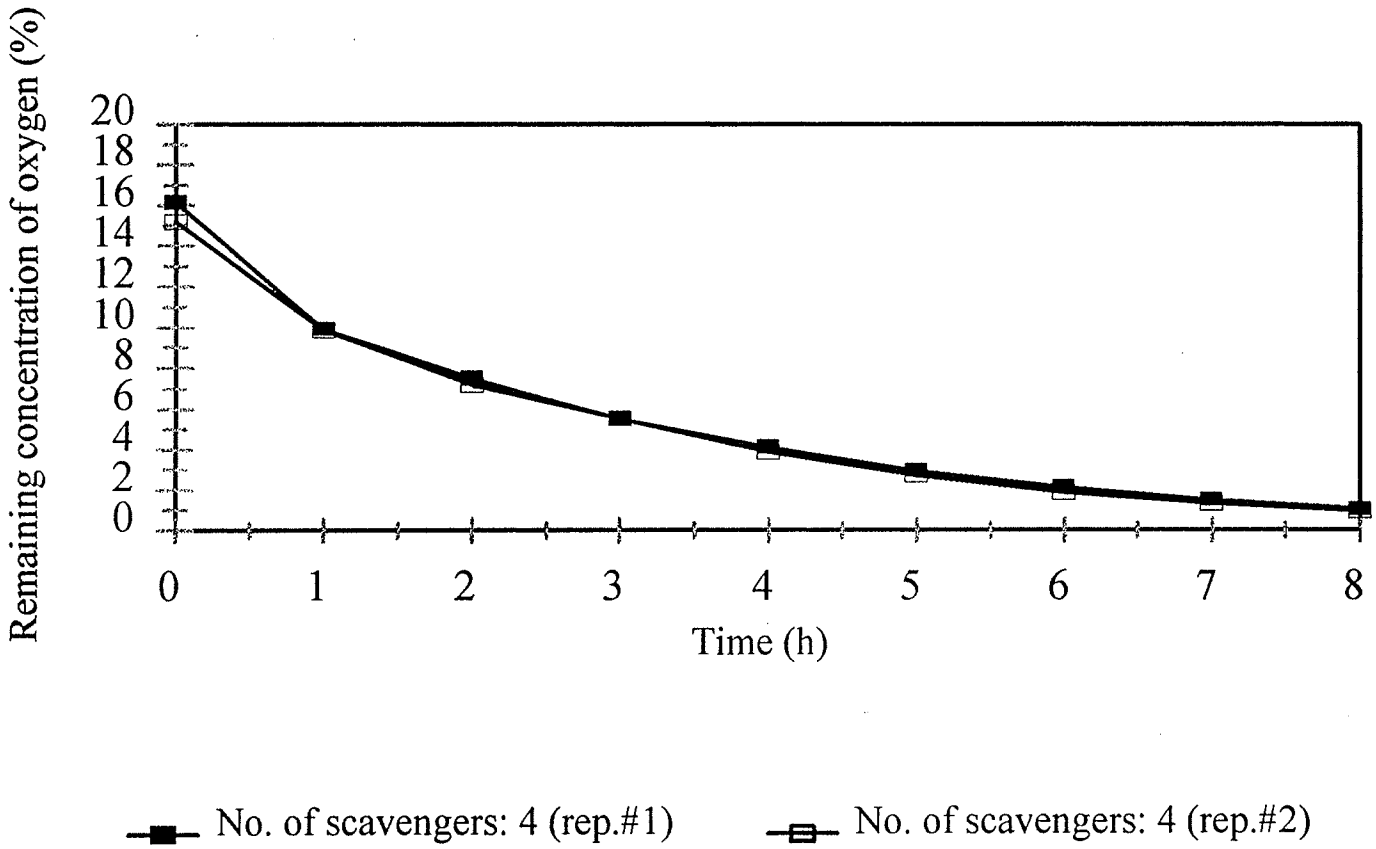

Fig. A46 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 20%.

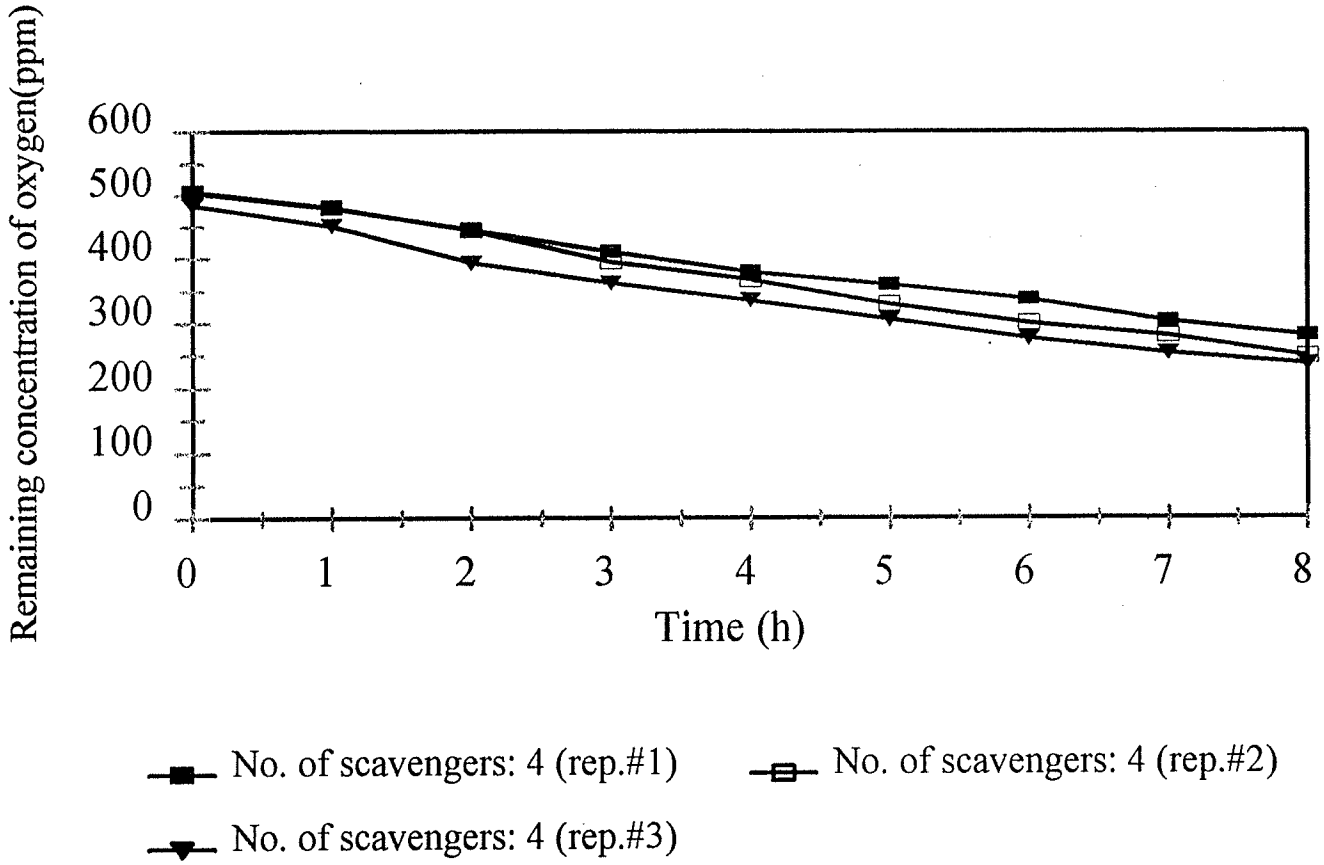

Fig. A47 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at 12°C and at an initial O_2 concentration of 500 ppm.

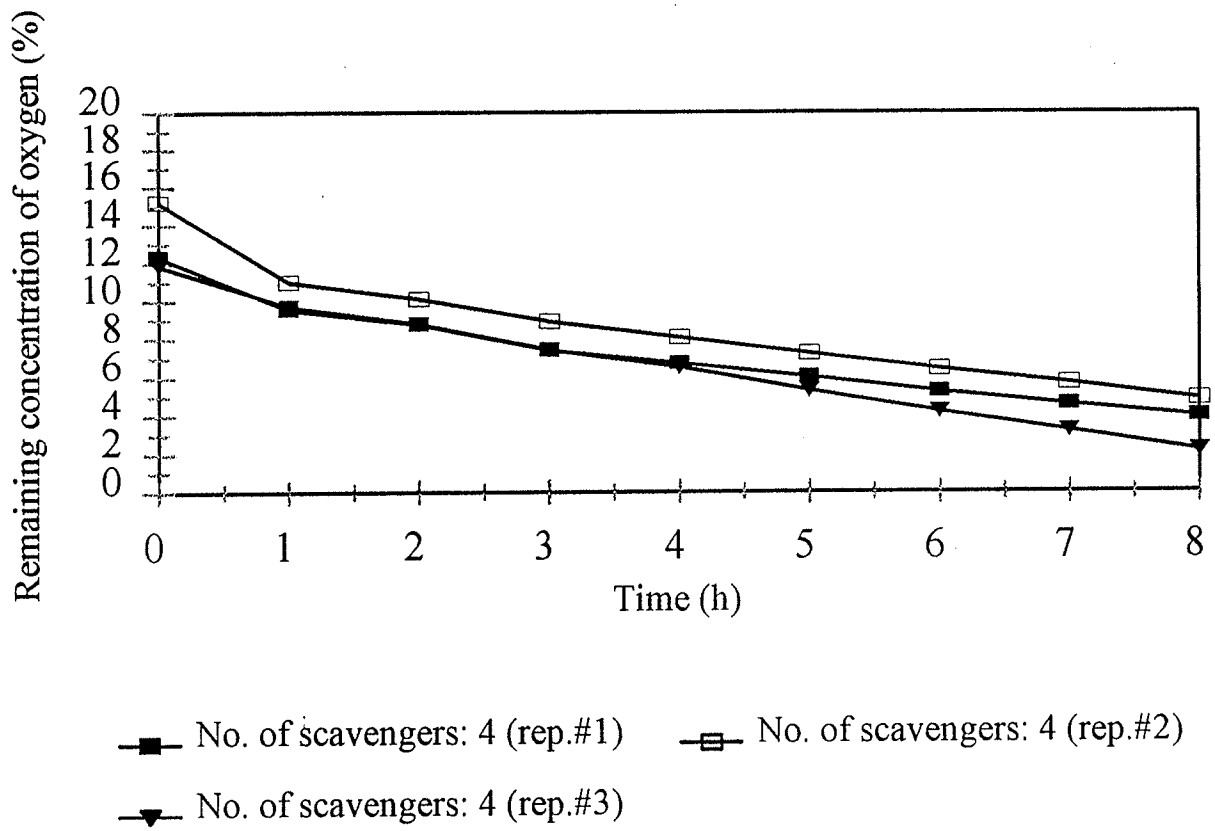

Fig. A48 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at 2°C and at an initial O_2 concentration of 20%.

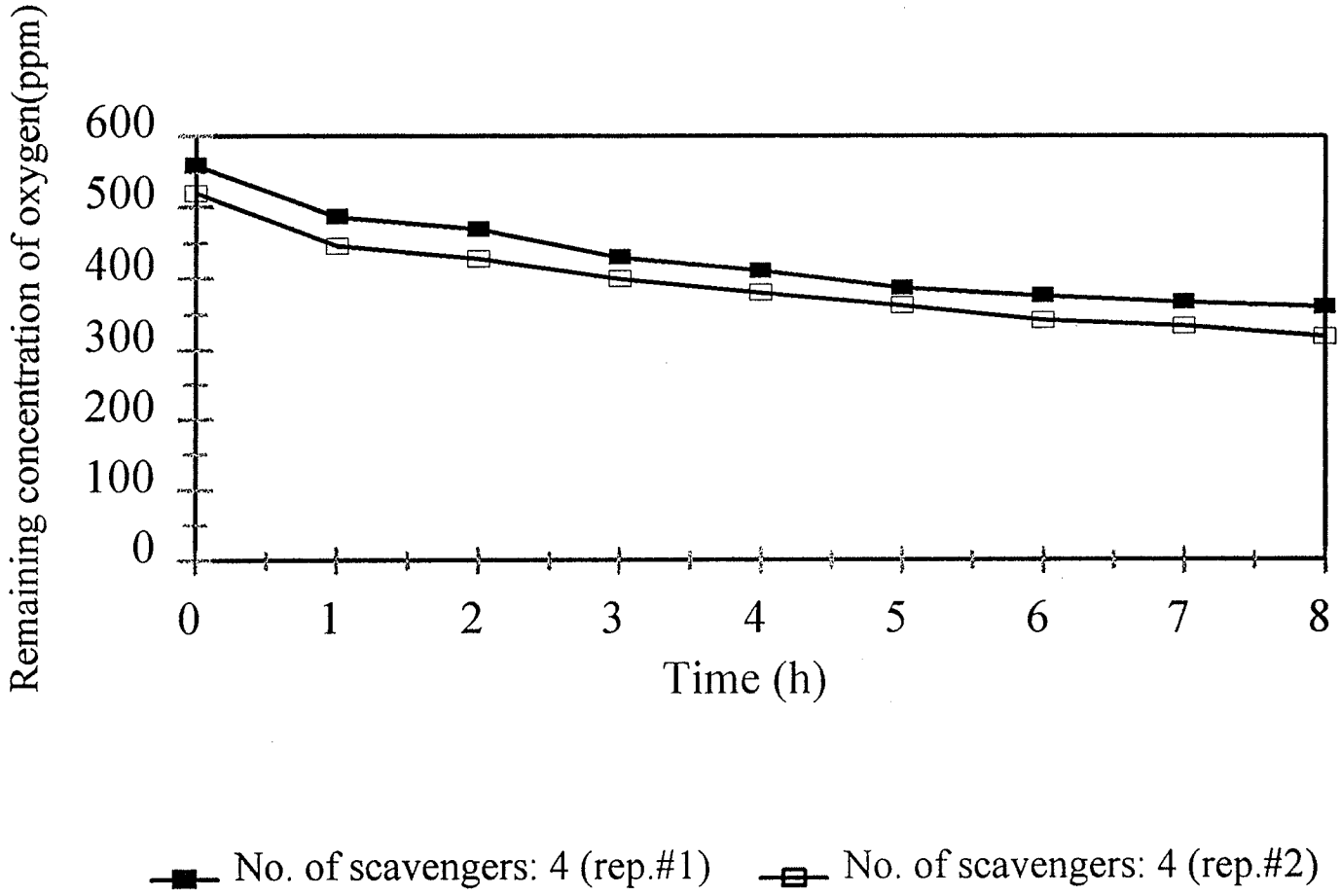

Fig. A49 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at 2°C and at an initial O_2 concentration of 500 ppm.

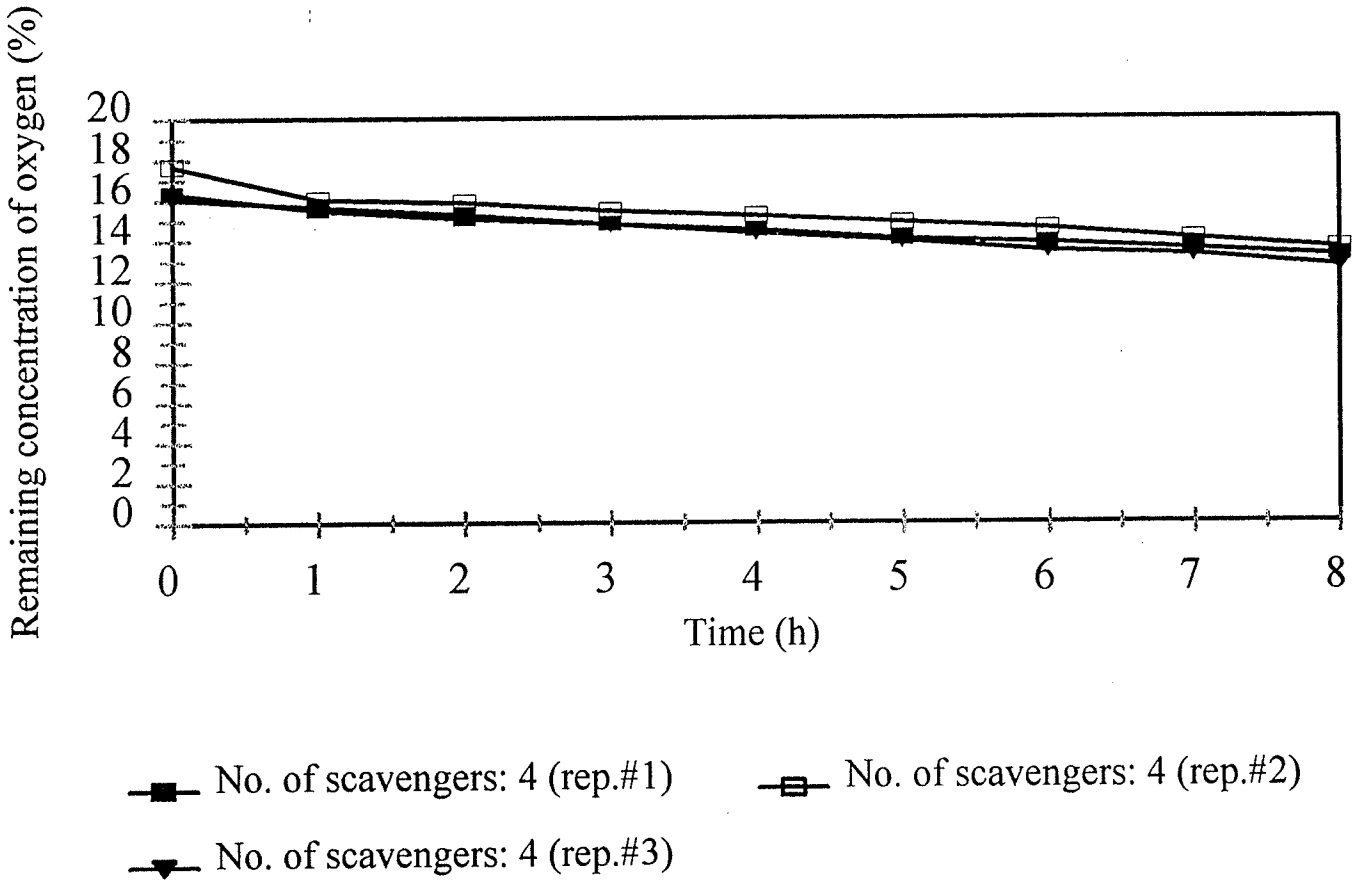

Fig. A50 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 20%.

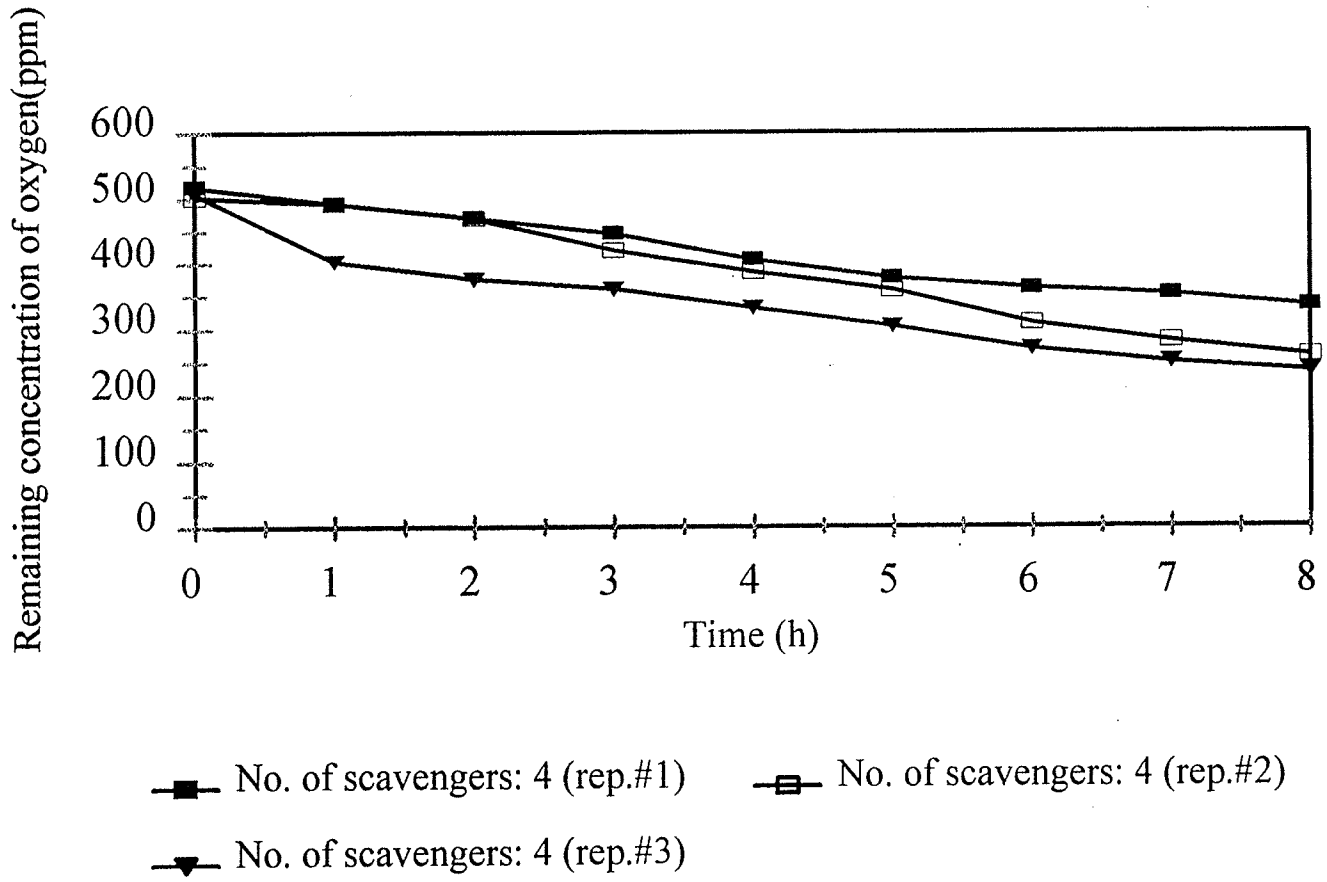

Fig. A51 Oxygen absorption rates of Bioka® S-100 O_2 scavengers at -1.5°C and at an initial O_2 concentration of 500 ppm.

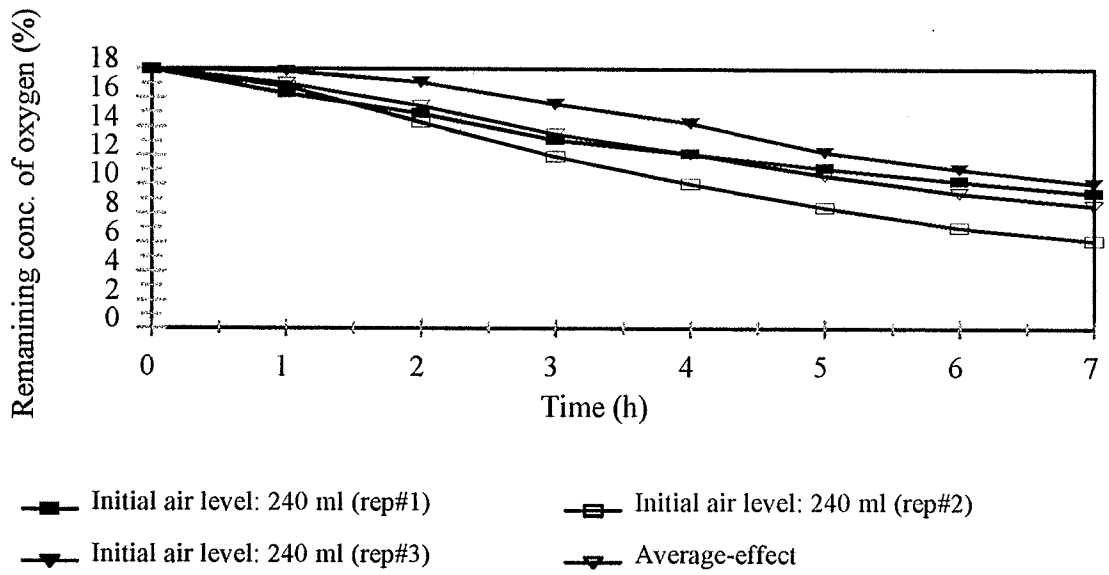

Fig. A52 Effect of position (in a simulated master pack system) on the oxygen absorption rates of Ageless® FX-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

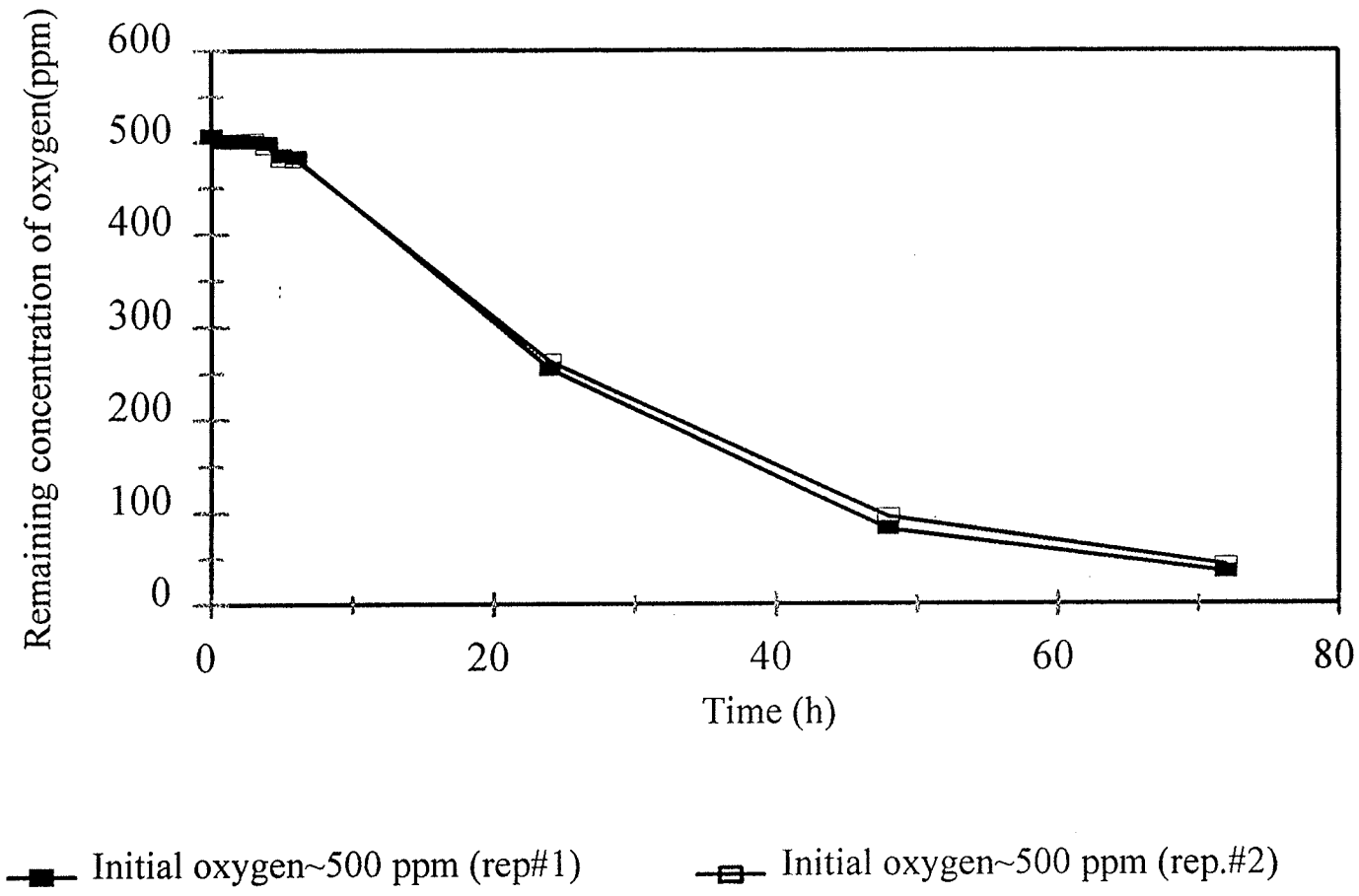

Fig. A53 Effect of position (in a simulated master pack system) on the oxygen absorption rates of Ageless® FX-100 O_2 scavengers at 25°C and at an initial O_2 concentration of 500 ppm.

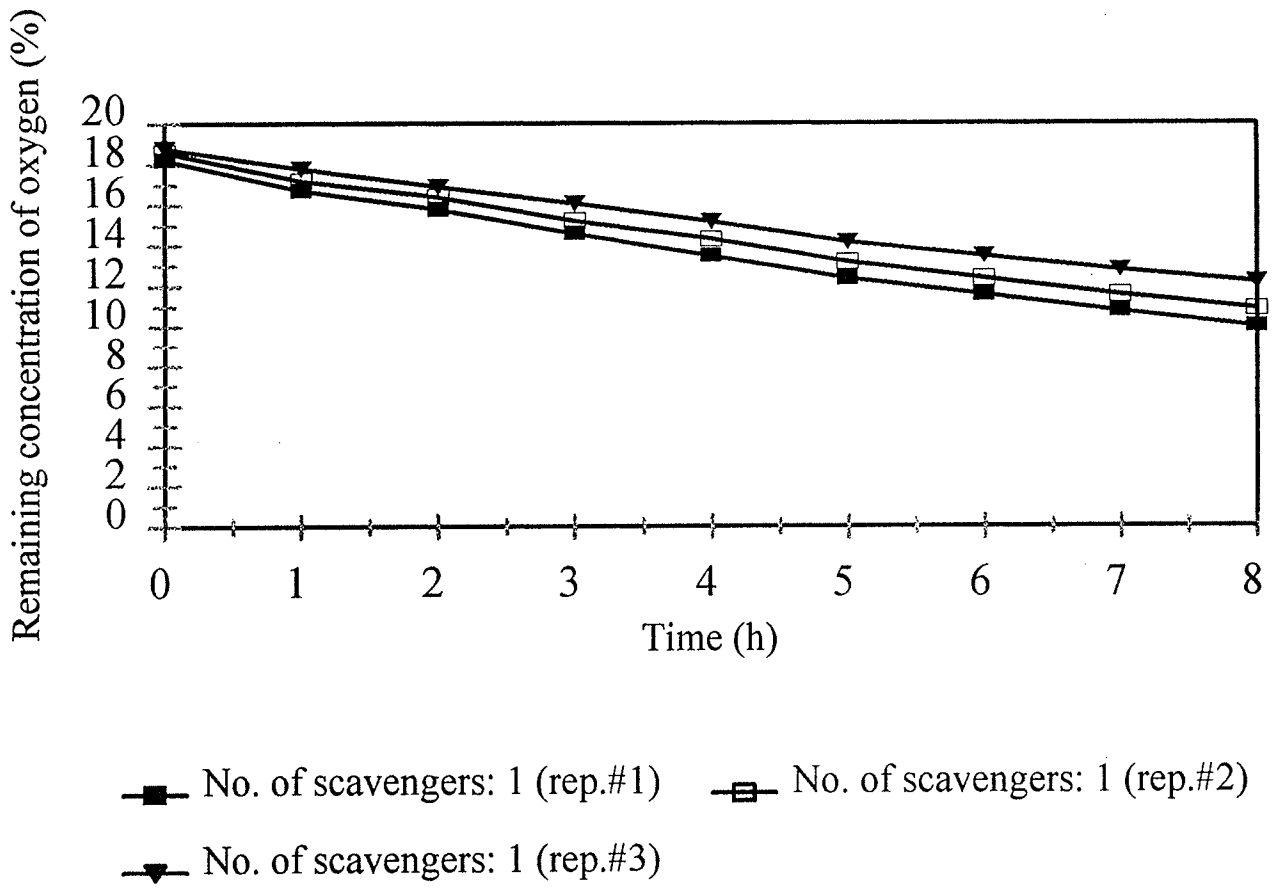

Fig. A54 Effect of suspension on the oxygen absorption rates of FreshPax® R-300 O_2 scavengers at 25°C and at an initial O_2 concentration of 20%.

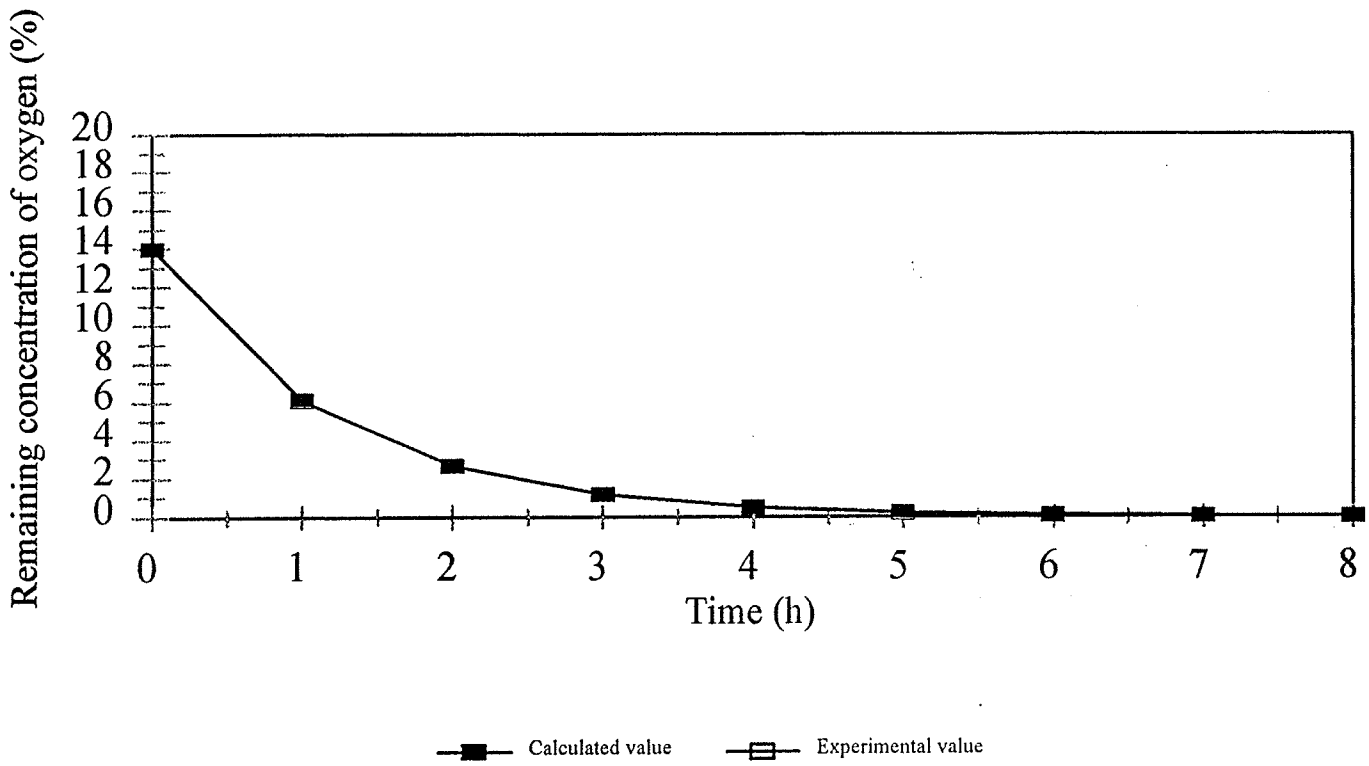

Fig. A55 Experimental and observed O_2 absorption rates of FreshPax® R-300 O_2 scavengers at 7°C and at an initial O_2 concentration of 20%.

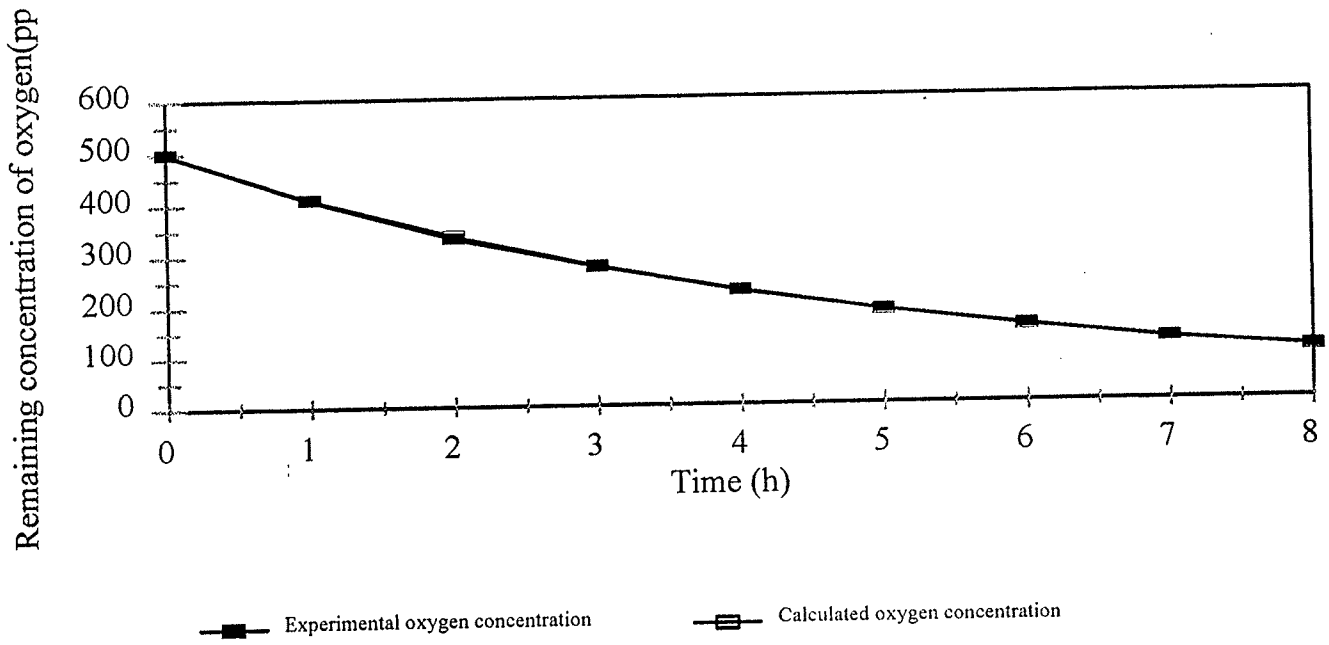

Fig. A56 Experimental and observed O_2 absorption rates of FreshPax® R-300 O_2 scavengers at 7°C and at an initial O_2 concentration of 500 ppm.

APPENDIX B

Table B1. Visual scores by panelist #1 for the different treatments of pork chops and beef (*psoas major*, PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Experiment# I).

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
A (Control: lidded tray with meat)	PORK1	3	6	2
	PORK2	3	5	2
	PORK3	3	2	5
B (Lidded tray with meat and grid)	PORK1	3	2	6
	PORK2	3	3	5
	PORK3	3	4	4
C (Lidded tray with meat and soaker pad)	PORK1	3	1	7
	PORK2	3	2	6
	PORK3	3	2	6
D (Lidded tray with meat and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
E (Lidded tray with meat, grid, and soaker pad)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
F (Lidded tray with meat, grid, and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PORK1	3	2	6
	PORK2	3	1	7
	PORK3	3	2	6
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
D1 (Lidded tray with meat and O_2 scavengers***)	PORK1	3	5	6
	PORK2	3	5	6
	PORK3	3	5	6
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
A (Control: lidded tray with meat)	PM1	0	7	1
	PM2	0	7	1

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM3	0	7	1
B (Lidded tray with meat and grid)	PM1	6	6	2
	PM2	6	6	2
	PM3	5	5	3
C (Lidded tray with meat and soaker pad)	PM1	5	5	3
	PM2	5	5	3
	PM3	5	5	3
D (Lidded tray with meat and O_2 scavengers**)	PM1	5	1	7
	PM2	5	1	7
	PM3	5	1	7
E (Lidded tray with meat, grid, and soaker pad)	PM1	6	3	2
	PM2	0	7	1
	PM3	6	3	2
F (Lidded tray with meat, grid, and O_2 scavengers**)	PM1	5	1	7
	PM2	5	1	7
	PM3	5	1	7
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PM1	5	1	6
	PM2	5	1	6
	PM3	5	1	6
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PM1	6	4	3

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM2	6	3	3
	PM3	6	3	3
D1 (Lidded tray with meat and O_2 scavengers***)	PM1	6	1	6
	PM2	6	1	6
	PM3	6	1	6
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PM1	6	1	6
	PM2	6	1	6
	PM3	6	1	6
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PM1	6	6	2
	PM2	0	7	2
	PM3	5	5	2
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PM1	6	1	6
	PM2	6	1	6
	PM3	6	1	6

* Three lidded trays, each containing either a pork chop or a beef (PM) steak with a specific treatment, were placed in a master package.
**Eight O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed inside each lidded tray.
***Twenty-four O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed in the master package atmosphere (outside the lidded trays).
† Color scale (pork chop): 0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark; Color scale (beef steak): 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale (pork chop or beef steak): 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale (pork chop or beef steak): 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B2. Visual scores by panelist #2 for the different treatments of pork chops and beef (PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Experiment I).

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
A (Control: lidded tray with meat)	PORK1	3	4	3
	PORK2	3	4	4
	PORK3	3	3	5
B (Lidded tray with meat and grid)	PORK1	3	2	6
	PORK2	3	4	4
	PORK3	3	5	3
C (Lidded tray with meat and soaker pad)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
D (Lidded tray with meat and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
E (Lidded tray with meat, grid, and soaker pad)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
F (Lidded tray with meat, grid, and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	2	1	6
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
D1 (Lidded tray with meat and O_2 scavengers***)	PORK1	2	1	6
	PORK2	2	1	6
	PORK3	2	1	6
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
A (Control: lidded tray with meat)	PM1	6	6	2
	PM2	6	6	2

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM3	6	6	2
B (Lidded tray with meat and grid)	PM1	6	6	1
	PM2	6	6	1
	PM3	5	5	2
C (Lidded tray with meat and soaker pad)	PM1	5	5	2
	PM2	5	5	2
	PM3	5	6	2
D (Lidded tray with meat and O_2 scavengers**)	PM1	5	1	6
	PM2	5	1	6
	PM3	5	1	6
E (Lidded tray with meat, grid, and soaker pad)	PM1	5	4	2
	PM2	0	7	1
	PM3	6	4	2
F (Lidded tray with meat, grid, and O_2 scavengers**)	PM1	5	3	5
	PM2	5	2	5
	PM3	5	3	5
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PM1	5	2	5
	PM2	5	2	5
	PM3	5	2	5
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PM1	6	5	3

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM2	6	3	5
	PM3	6	5	3
D1 (Lidded tray with meat and O_2 scavengers***)	PM1	6	4	3
	PM2	6	4	3
	PM3	6	4	3
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PM1	5	4	2
	PM2	6	6	1
	PM3	5	4	2
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PM1	5	6	1
	PM2	6	6	1
	PM3	5	5	2
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PM1	6	2	5
	PM2	6	3	5
	PM3	6	2	5

* Three lidded trays, each containing either a pork chop or a beef (PM) steak with a specific treatment, were placed in a master package.
**Eight O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed inside each lidded tray.
***Twenty-four O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed in the master package atmosphere (outside the lidded trays).
† Color scale (pork chop): 0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark; Color scale (beef steak): 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale (pork chop or beef steak): 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale (pork chop or beef steak): 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B3. **Visual scores by panelist #3 for the different treatments of pork chops and beef (PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Experiment# I).**

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
A (Control: lidded tray with meat)	PORK1	2	6	1
	PORK2	3	3	3
	PORK3	3	2	6
B (Lidded tray with meat and grid)	PORK1	3	2	6
	PORK2	2	3	3
	PORK3	3	5	2
C (Lidded tray with meat and soaker pad)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	2	6
D (Lidded tray with meat and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
E (Lidded tray with meat, grid, and soaker pad)	PORK1	4	1	6
	PORK2	4	1	6
	PORK3	4	1	6
F (Lidded tray with meat, grid, and O_2 scavengers**)	PORK1	3	2	6
	PORK2	4	1	7
	PORK3	3	2	6

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PORK1	3	1	6
	PORK2	3	1	7
	PORK3	2	1	6
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PORK1	3	2	6
	PORK2	3	1	7
	PORK3	3	2	6
D1 (Lidded tray with meat and O_2 scavengers***)	PORK1	2	1	5
	PORK2	2	1	5
	PORK3	2	1	5
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PORK1	3	2	6
	PORK2	3	1	7
	PORK3	3	1	7
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PORK1	3	2	6
	PORK2	3	1	7
	PORK3	3	1	7
A (Control: lidded tray with meat)	PM1	7	3	3
	PM2	7	6	1

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM3	7	3	3
B (Lidded tray with meat and grid)	PM1	5	6	1
	PM2	6	6	1
	PM3	5	4	2
C (Lidded tray with meat and soaker pad)	PM1	5	5	1
	PM2	5	5	1
	PM3	5	6	1
D (Lidded tray with meat and O_2 scavengers**)	PM1	6	1	6
	PM2	5	1	6
	PM3	6	1	6
E (Lidded tray with meat, grid, and soaker pad)	PM1	5	3	2
	PM2	2	7	1
	PM3	5	4	2
F (Lidded tray with meat, grid, and O_2 scavengers**)	PM1	5	1	7
	PM2	5	1	7
	PM3	5	1	7
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PM1	5	1	3
	PM2	4	1	3
	PM3	6	1	6
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PM1	6	4	2

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM2	6	2	4
	PM3	6	3	3
D1 (Lidded tray with meat and O_2 scavengers***)	PM1	6	1	7
	PM2	6	1	7
	PM3	6	1	7
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PM1	5	1	7
	PM2	7	1	6
	PM3	6	1	7
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PM1	6	6	1
	PM2	6	7	1
	PM3	6	4	2
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PM1	6	1	7
	PM2	6	2	5
	PM3	5	1	7

* Three lidded trays, each containing either a pork chop or a beef (PM) steak with a specific treatment, were placed in a master package.
**Eight O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed inside each lidded tray.
***Twenty-four O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed in the master package atmosphere (outside the lidded trays).
† Color scale (pork chop): 0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark; Color scale (beef steak): 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale (pork chop or beef steak): 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale (pork chop or beef steak): 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B4. **Visual scores by panelist #4 for the different treatments of pork chops and beef (PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Experiment I).**

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
A (Control: lidded tray with meat)	PORK1	2	5	4
	PORK2	2	4	4
	PORK3	3	2	5
B (Lidded tray with meat and grid)	PORK1	3	1	6
	PORK2	2	4	6
	PORK3	2	5	4
C (Lidded tray with meat and soaker pad)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
D (Lidded tray with meat and O_2 scavengers**)	PORK1	3	1	6
	PORK2	3	1	6
	PORK3	3	1	6
E (Lidded tray with meat, grid, and soaker pad)	PORK1	3	1	6
	PORK2	3	1	6
	PORK3	3	1	6
F (Lidded tray with meat, grid, and O_2 scavengers**)	PORK1	3	1	6
	PORK2	3	1	6
	PORK3	3	1	6

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PORK1	3	2	6
	PORK2	3	2	6
	PORK3	3	2	6
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
D1 (Lidded tray with meat and O_2 scavengers***)	PORK1	3	4	5
	PORK2	3	4	5
	PORK3	3	4	5
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PORK1	3	1	7
	PORK2	3	1	7
	PORK3	3	1	7
A (Control: lidded tray with meat)	PM1	7	5	3
	PM2	7	6	2

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM3	7	5	3
B (Lidded tray with meat and grid)	PM1	5	6	2
	PM2	6	6	2
	PM3	5	4	4
C (Lidded tray with meat and soaker pad)	PM1	5	5	3
	PM2	5	5	3
	PM3	5	5	3
D (Lidded tray with meat and O_2 scavengers**)	PM1	5	1	6
	PM2	5	1	6
	PM3	5	1	6
E (Lidded tray with meat, grid, and soaker pad)	PM1	5	3	3
	PM2	0	7	2
	PM3	5	4	3
F (Lidded tray with meat, grid, and O_2 scavengers**)	PM1	5	2	6
	PM2	5	2	6
	PM3	5	2	6
G (Lidded tray with meat, soaker pad, and O_2 scavengers**)	PM1	5	4	4
	PM2	4	4	4
	PM3	6	2	4
H (Lidded tray with meat, grid, soaker pad, and O_2 scavengers**)	PM1	6	4	3

Treatment	Meat-type & replicate #	Color†	Discoloration††	Retail Acceptance†††
	PM2	6	3	4
	PM3	6	3	3
D1 (Lidded tray with meat and O_2 scavengers***)	PM1	6	1	6
	PM2	6	1	6
	PM3	6	1	6
F1 (Lidded tray with meat, grid, and O_2 scavengers***)	PM1	5	1	6
	PM2	6	1	6
	PM3	5	1	6
G1 (Lidded tray with meat, soaker pad, and O_2 scavengers***)	PM1	5	6	3
	PM2	0	7	2
	PM3	5	5	3
H1 (Lidded tray with meat, grid, soaker pad, and O_2 scavengers***)	PM1	5	2	6
	PM2	5	2	5
	PM3	5	1	6

* Three lidded trays, each containing either a pork chop or a beef (PM) steak with a specific treatment, were placed in a master package.
**Eight O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed inside each lidded tray.
***Twenty-four O_2 scavengers (Ageless® FX-100, Mitsubishi Co., Tokyo, Japan) were placed in the master package atmosphere (outside the lidded trays).
† Color scale (pork chop): 0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark; Color scale (beef steak): 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale (pork chop or beef steak): 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale (pork chop or beef steak): 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B5. Visual scores by panelist #1 for the different treatments of beef (*longissimus dorsi*, LD) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part II).

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LT1	1	5	1	7
G	LD2	1	5	1	7
G	LD3	1	5	1	7
G	LD4	1	5	1	7
G	LD1	2	5	2	6
G	LD2	2	5	1	7
G	LD3	2	5	2	6
G	LD4	2	5	1	7
G	LD1	3	5	4	4
G	LD2	3	0	7	1
G	LD3	3	5	2	6
G	LD4	3	5	5	2
G	LD1	4	5	1	7
G	LD2	4	5	1	7
G	LD3	4	5	1	7
G	LD4	4	5	1	7
G	LD1	5	5	1	7
G	LD2	5	5	1	7
G	LD3	5	5	1	7
G	LD4	5	5	1	7
G	LD1	6	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD2	6	5	1	7
G	LD3	6	5	1	7
G	LD4	6	5	1	7
H	LD1	1	5	1	6
H	LD2	1	6	1	6
H	LD3	1	6	1	6
H	LD4	1	6	1	6
H	LD1	2	-	-	-
H	LD2	2	-	-	-
H	LD3	2	-	-	-
H	LD4	2	-	-	-
H	LD1	3	6	2	5
H	LD2	3	6	2	5
H	LD3	3	6	5	2
H	LD4	3	6	6	1
H	LD1	4	5	1	7
H	LD2	4	5	1	7
H	LD3	4	6	1	6
H	LD4	4	5	1	7
H	LD1	5	5	1	7
H	LD2	5	5	1	7
H	LD3	5	5	1	7
H	LD4	5	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H	LD1	6	5	1	7
H	LD2	6	5	1	7
H	LD3	6	6	1	6
H	LD4	6	6	1	6
G1	LD1	1	5	1	7
G1	LD2	1	5	1	7
G1	LD3	1	6	1	7
G1	LD4	1	5	1	7
G1	LD1	2	5	1	7
G1	LD2	2	5	1	7
G1	LD3	2	5	1	7
G1	LD4	2	5	1	7
G1	LD1	3	5	1	7
G1	LD2	3	5	1	7
G1	LD3	3	5	1	7
G1	LD4	3	5	1	7
G1	LD1	4	6	1	6
G1	LD2	4	6	1	6
G1	LD3	4	6	1	6
G1	LD4	4	6	1	6
G1	LD1	5	5	1	7
G1	LD2	5	5	1	7
G1	LD3	5	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G1	LD4	5	5	1	7
G1	LD1	6	5	1	7
G1	LD2	6	5	1	7
G1	LD3	6	5	1	7
G1	LD4	6	5	1	7
H1	LD1	1	5	2	6
H1	LD2	1	5	3	5
H1	LD3	1	5	3	5
H1	LD4	1	5	3	5
H1	LD1	2	6	4	5
H1	LD2	2	6	3	5
H1	LD3	2	6	3	5
H1	LD4	2	6	4	4
H1	LD1	3	6	1	7
H1	LD2	3	6	1	7
H1	LD3	3	6	1	7
H1	LD4	3	6	1	7
H1	LD1	4	6	3	5
H1	LD2	4	6	3	5
H1	LD3	4	5	3	5
H1	LD4	4	5	2	6
H1	LD1	5	5	2	6
H1	LD2	5	5	2	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H1	LD3	5	5	3	5
H1	LD4	5	5	3	5
H1	LD1	6	6	2	6
H1	LD2	6	6	1	7
H1	LD3	6	6	1	7
H1	LD4	6	6	1	7

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B6. Visual scores by panelist #2 for the different treatments of beef (*longissimus dorsi*, LD) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part II).

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD1	1	5	3	6
G	LD2	1	5	2	6
G	LD3	1	5	3	6
G	LD4	1	5	1	7
G	LD1	2	5	3	6
G	LD2	2	5	1	7
G	LD3	2	5	3	6
G	LD4	2	5	2	7
G	LD1	3	5	4	4
G	LD2	3	0	7	2
G	LD3	3	5	3	6
G	LD4	3	5	5	3
G	LD1	4	5	2	6
G	LD2	4	5	3	5
G	LD3	4	5	3	4
G	LD4	4	5	3	5
G	LD1	5	6	2	6
G	LD2	5	6	2	6
G	LD3	5	6	2	6
G	LD4	5	6	3	5
G	LD1	6	5	2	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD2	6	5	3	5
G	LD3	6	5	3	5
G	LD4	6	5	3	5
H	LD1	1	6	3	5
H	LD2	1	6	5	4
H	LD3	1	6	5	3
H	LD4	1	6	5	4
H	LD1	2	-	-	-
H	LD2	2	-	-	-
H	LD3	2	-	-	-
H	LD4	2	-	-	-
H	LD1	3	5	4	3
H	LD2	3	5	4	3
H	LD3	3	5	4	3
H	LD4	3	5	6	2
H	LD1	4	5	3	5
H	LD2	4	5	3	4
H	LD3	4	6	6	3
H	LD4	4	5	4	5
H	LD1	5	6	4	4
H	LD2	5	6	4	4
H	LD3	5	5	4	5
H	LD4	5	5	4	4

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H	LD1	6	5	4	4
H	LD2	6	6	5	3
H	LD3	6	5	5	3
H	LD4	6	5	5	3
G1	LD1	1	6	2	6
G1	LD2	1	6	3	5
G1	LD3	1	5	1	7
G1	LD4	1	5	1	7
G1	LD1	2	6	2	6
G1	LD2	2	6	2	6
G1	LD3	2	6	2	6
G1	LD4	2	5	1	7
G1	LD1	3	6	2	6
G1	LD2	3	5	1	7
G1	LD3	3	5	3	5
G1	LD4	3	5	2	6
G1	LD1	4	5	2	6
G1	LD2	4	6	2	6
G1	LD3	4	6	2	6
G1	LD4	4	6	2	6
G1	LD1	5	6	2	5
G1	LD2	5	6	2	5
G1	LD3	5	6	2	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G1	LD4	5	6	2	6
G1	LD1	6	6	2	5
G1	LD2	6	6	3	5
G1	LD3	6	6	2	5
G1	LD4	6	5	2	6
H1	LD1	1	5	2	6
H1	LD2	1	5	2	6
H1	LD3	1	5	2	6
H1	LD4	1	5	2	5
H1	LD1	2	6	1	7
H1	LD2	2	6	2	6
H1	LD3	2	5	3	5
H1	LD4	2	5	3	5
H1	LD1	3	6	4	3
H1	LD2	3	6	3	5
H1	LD3	3	6	3	5
H1	LD4	3	6	2	6
H1	LD1	4	5	4	4
H1	LD2	4	5	4	4
H1	LD3	4	5	4	4
H1	LD4	4	5	3	5
H1	LD1	5	5	3	5
H1	LD2	5	5	4	4

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H1	LD3	5	5	2	6
H1	LD4	5	5	2	6
H1	LD1	6	6	4	4
H1	LD2	6	6	3	5
H1	LD3	6	6	4	4
H1	LD4	6	6	4	4

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B7. Visual scores by panelist #3 for the different treatments of beef (*longissimus dorsi*, LD) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part II).

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD1	1	5	1	7
G	LD2	1	5	1	7
G	LD3	1	5	1	7
G	LD4	1	5	1	7
G	LD1	2	5	1	7
G	LD2	2	5	1	7
G	LD3	2	5	1	7
G	LD4	2	5	1	7
G	LD1	3	5	4	2
G	LD2	3	7	1	3
G	LD3	3	5	2	3
G	LD4	3	5	5	2
G	LD1	4	5	1	7
G	LD2	4	5	1	7
G	LD3	4	5	1	7
G	LD4	4	5	1	7
G	LD1	5	5	1	7
G	LD2	5	5	1	7
G	LD3	5	5	1	7
G	LD4	5	5	2	6
G	LD1	6	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD2	6	5	1	7
G	LD3	6	5	1	7
G	LD4	6	5	1	7
H	LD1	1	5	1	7
H	LD2	1	5	1	7
H	LD3	1	5	1	7
H	LD4	1	5	1	7
H	LD1	2	-	-	-
H	LD2	2	-	-	-
H	LD3	2	-	-	-
H	LD4	2	-	-	-
H	LD1	3	5	2	6
H	LD2	3	5	1	7
H	LD3	3	5	5	2
H	LD4	3	5	7	1
H	LD1	4	4	2	5
H	LD2	4	5	1	7
H	LD3	4	5	1	7
H	LD4	4	5	1	7
H	LD1	5	5	1	7
H	LD2	5	5	2	6
H	LD3	5	5	1	7
H	LD4	5	5	2	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H	LD1	6	5	1	7
H	LD2	6	5	1	7
H	LD3	6	5	1	7
H	LD4	6	5	1	7
G1	LD1	1	5	1	7
G1	LD2	1	5	1	7
G1	LD3	1	6	1	7
G1	LD4	1	5	1	7
G1	LD1	2	6	1	7
G1	LD2	2	6	1	7
G1	LD3	2	5	1	7
G1	LD4	2	5	1	7
G1	LD1	3	6	1	7
G1	LD2	3	5	1	7
G1	LD3	3	5	1	7
G1	LD4	3	6	1	7
G1	LD1	4	5	1	7
G1	LD2	4	6	1	6
G1	LD3	4	6	1	6
G1	LD4	4	5	1	7
G1	LD1	5	6	1	7
G1	LD2	5	6	1	7
G1	LD3	5	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G1	LD4	5	5	1	7
G1	LD1	6	6	1	7
G1	LD2	6	5	1	7
G1	LD3	6	6	2	6
G1	LD4	6	5	1	7
H1	LD1	1	4	3	5
H1	LD2	1	4	3	5
H1	LD3	1	4	2	5
H1	LD4	1	4	2	5
H1	LD1	2	6	3	6
H1	LD2	2	6	3	6
H1	LD3	2	5	3	4
H1	LD4	2	4	3	4
H1	LD1	3	5	1	7
H1	LD2	3	5	1	7
H1	LD3	3	5	1	7
H1	LD4	3	5	1	7
H1	LD1	4	5	1	7
H1	LD2	4	5	1	7
H1	LD3	4	5	1	7
H1	LD4	4	5	1	7
H1	LD1	5	4	2	4
H1	LD2	5	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H1	LD3	5	4	3	3
H1	LD4	5	4	3	3
H1	LD1	6	6	1	7
H1	LD2	6	6	1	7
H1	LD3	6	6	1	7
H1	LD4	6	6	1	7

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B8. Visual scores by panelist #4 for the different treatments of beef (*longissimus dorsi*, LD) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part II).

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD1	1	5	2	6
G	LD2	1	5	2	6
G	LD3	1	5	2	6
G	LD4	1	5	2	6
G	LD1	2	5	1	7
G	LD2	2	5	1	7
G	LD3	2	5	1	7
G	LD4	2	5	1	7
G	LD1	3	5	3	5
G	LD2	3	5	2	7
G	LD3	3	5	6	2
G	LD4	3	5	4	5
G	LD1	4	5	1	6
G	LD2	4	5	1	6
G	LD3	4	5	1	6
G	LD4	4	5	1	6
G	LD1	5	5	1	7
G	LD2	5	5	1	7
G	LD3	5	5	1	7
G	LD4	5	5	1	7
G	LD1	6	5	1	7

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G	LD2	6	5	1	7
G	LD3	6	5	1	7
G	LD4	6	5	1	7
H	LD1	1	6	1	6
H	LD2	1	6	1	6
H	LD3	1	6	1	6
H	LD4	1	6	1	6
H	LD1	2	-	-	-
H	LD2	2	-	-	-
H	LD3	2	-	-	-
H	LD4	2	-	-	-
H	LD1	3	5	2	6
H	LD2	3	5	4	5
H	LD3	3	5	6	6
H	LD4	3	5	6	2
H	LD1	4	4	1	5
H	LD2	4	5	1	6
H	LD3	4	6	1	5
H	LD4	4	4	1	6
H	LD1	5	5	1	6
H	LD2	5	5	1	6
H	LD3	5	5	1	6
H	LD4	5	5	1	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H	LD1	6	5	1	6
H	LD2	6	5	1	6
H	LD3	6	5	1	6
H	LD4	6	5	1	6
G1	LD1	1	6	1	6
G1	LD2	1	6	1	6
G1	LD3	1	6	1	6
G1	LD4	1	6	1	6
G1	LD1	2	6	1	6
G1	LD2	2	6	1	6
G1	LD3	2	6	1	6
G1	LD4	2	6	1	6
G1	LD1	3	6	1	6
G1	LD2	3	6	1	6
G1	LD3	3	6	1	6
G1	LD4	3	6	1	6
G1	LD1	4	6	1	6
G1	LD2	4	6	1	6
G1	LD3	4	6	1	6
G1	LD4	4	6	1	6
G1	LD1	5	6	1	6
G1	LD2	5	6	1	6
G1	LD3	5	6	1	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
G1	LD4	5	6	1	6
G1	LD1	6	6	1	6
G1	LD2	6	6	1	6
G1	LD3	6	6	1	6
G1	LD4	6	6	1	6
H1	LD1	1	4	3	5
H1	LD2	1	4	4	5
H1	LD3	1	4	3	5
H1	LD4	1	4	3	5
H1	LD1	2	6	1	6
H1	LD2	2	4	4	5
H1	LD3	2	6	1	6
H1	LD4	2	4	4	5
H1	LD1	3	5	1	7
H1	LD2	3	5	1	7
H1	LD3	3	5	1	7
H1	LD4	3	5	1	7
H1	LD1	4	5	4	6
H1	LD2	4	5	2	6
H1	LD3	4	5	3	6
H1	LD4	4	5	1	6
H1	LD1	5	4	3	6
H1	LD2	5	4	3	6

Treatment	Meat-type & replicate #	Bag #	Visual Analysis of Beef Steaks		
			Color†	Discoloration††	Retail Acceptance†††
H1	LD3	5	5	4	6
H1	LD4	5	4	3	6
H1	LD1	6	6	1	6
H1	LD2	6	6	1	6
H1	LD3	6	6	1	6
H1	LD4	6	6	1	6

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B9. Visual scores by panelist #1 for the different treatments of beef (*psoas major*, PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part III).

Parameters	Meat-type & replicate #	Fresh Control					Scavenger# 2					Scavenger# 4					Scavenger#6				
		Retail display (day)					Retail display (day)					Retail display (day)					Retail display (day)				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity†	PM 1	6	7	7	6		6	6	6	6		6	7	6	7		6	6	6	6	
	PM 2	6	6	6	6		6	6	6	6		6	7	6	6		6	6	6	6	
	PM 3	6	7	6	6		6	6	6	6		6	7	6	7		6	5	5	5	
	PM 4	6	7	6	7		6	5	5	5		6	6	6	7		6	6	6	6	
Discoloration††	PM 1	1	2	3	6		1	2	2	4		1	3	4	6		2	2	4	6	
	PM 2	1	2	3	5		1	2	2	3		1	3	3	5		1	2	4	6	
	PM 3	1	2	5	6		1	2	3	4		1	2	4	6		1	2	2	3	
	PM 4	1	1	2	6		1	2	2	3		1	2	3	6		1	2	2	4	
Acceptance†††	PM 1	7	5	4	1		7	5	4	3		7	3	2	1		5	4	3	1	
	PM 2	7	6	3	2		7	5	4	3		7	3	3	1		7	4	3	1	
	PM 3	7	5	2	1		7	4	4	2		7	3	3	2		7	5	4	3	
	PM 4	7	6	5	1		7	6	5	4		7	3	3	1		7	4	3	2	

Parameters	Meat-type & replicate #	Scavenger#8				
		Retail display (day)				
		0	1	2	3	4
Color Intensity†	PM 1	6	5	5	5	
	PM 2	6	5	5	5	
	PM 3	6	5	6	6	
	PM 4	5	5	6	6	
Discoloration††	PM 1	1	1	2	3	
	PM 2	1	2	3	3	
	PM 3	1	2	4	5	
	PM 4	1	2	5	6	
Acceptance†††	PM 1	7	6	6	4	
	PM 2	7	4	4	3	
	PM 3	6	4	3	2	
	PM 4	7	3	2	1	

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B10. Visual scores by panelist #2 for the different treatments of beef (*psoas major*, PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part III).

Parameters	Meat-type & replicate #	Fresh control					Scavenger# 2					Scavenger# 4					Scavenger# 6				
		Retail display (day)					Retail display (day)					Retail display (day)					Retail display (day)				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity†	PM 1	6	7	7	8	8	6	6	6	7		6	7	7	7		6	6	6	6	
	PM 2	6	7	7	8	8	6	6	6	7		6	7	7	7		6	6	6	6	
	PM 3	6	7	7	8	8	6	7	7	7		6	7	7	7		6	5	5	5	
	PM 4	6	7	7	8	8	6	6	5	6		6	7	7	7		6	6	5	5	
Discoloration††	PM 1	1	3	4	4	5	2	1	4	6		1	4	4	6		2	2	4	6	
	PM 2	1	4	4	5	5	1	1	3	6		2	3	5	6		2	1	5	6	
	PM 3	1	4	5	5	5	1	1	3	6		2	1	3	6		2	2	2	5	
	PM 4	1	2	1	4	6	1	1	3	5		2	2	1	6		1	1	3	5	
Acceptance†††	PM 1	6	6	6	4	3	6	6	5	1		6	5	4	2		6	6	4	3	
	PM 2	6	6	5	4	2	6	6	5	1		6	5	4	2		6	6	4	3	
	PM 3	6	6	5	3	2	6	6	4	2		6	6	4	1		6	6	6	3	
	PM 4	6	6	6	4	3	6	6	6	2		6	6	4	1		6	6	5	4	

Parameters	Meat-type & replicate #	Scavenger#8				
		Retail display (day)				
		0	1	2	3	4
Color Intensity†	PM 1	6	5	5	5	
	PM 2	6	5	5	5	
	PM 3	6	5	5	5	
	PM 4	6	5	5	5	
Discoloration††	PM 1	1	1	2	3	
	PM 2	1	1	2	2	
	PM 3	1	1	4	4	
	PM 4	1	1	4	5	
Acceptance†††	PM 1	6	7	7	6	
	PM 2	6	7	7	6	
	PM 3	6	6	4	4	
	PM 4	6	6	4	5	

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B11. Visual scores by panelist #3 for the different treatments of beef (*psoas major*, PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part III).

Parameters	Meat-type & replicate #	Fresh Control					Scavenger# 2					Scavenger# 4					Scavenger# 6				
		Retail display (day)					Retail display (day)					Retail display (day)					Retail display (day)				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity†	PM 1	6	7	7	8	8	5	5	6	5	6	6	0	0	0	0	5	6	6	0	6
	PM 2	6	6	6	6	8	6	5	6	6	5	5	6	6	5	6	5	6	6	6	6
	PM 3	6	6	6	6	8	5	5	6	6	6	6	6	6	6	6	5	5	5	5	5
	PM 4	6	6	6	8	8	5	5	5	5	5	6	6	6	6	6	6	6	6	5	6
Discoloration††	PM 1	1	1	1	1	1	1	6	6	5	6	1	7	7	7	7	2	2	6	7	6
	PM 2	1	1	1	6	1	1	5	4	4	6	1	4	6	6	6	1	3	6	6	6
	PM 3	1	1	1	6	4	1	6	6	6	6	1	6	6	6	6	1	2	4	6	4
	PM 4	1	1	1	1	1	1	3	4	4	6	1	6	6	5	6	1	3	6	6	5
Acceptance†††	PM 1	6	4	3	2	2	7	2	2	3	2	6	2	2	2	2	6	5	3	2	2
	PM 2	6	5	5	3	2	6	3	3	4	2	7	4	2	2	2	7	5	3	2	2
	PM 3	7	5	4	3	1	7	2	2	2	2	6	3	2	2	2	7	6	4	3	2
	PM 4	7	5	4	2	2	7	4	4	3	2	6	3	2	2	2	7	4	2	2	3

Parameters	Meat-type & replicate #	Scavenger#8				
		Retail display (day)				
		0	1	2	3	4
Color Intensity†	PM 1	5	5	5	6	6
	PM 2	5	5	5	5	5
	PM 3	6	6	5	6	6
	PM 4	5	5	5	6	6
Discoloration††	PM 1	1	3	3	4	4
	PM 2	1	2	2	5	2
	PM 3	1	2	3	5	4
	PM 4	2	3	5	6	6
Acceptance†††	PM 1	7	4	5	4	4
	PM 2	7	6	6	2	6
	PM 3	6	6	5	3	2
	PM 4	6	5	3	3	2

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table B12. Visual scores by panelist #4 for the different treatments of beef (*psoas major*, PM) steaks stored in master packages* under nitrogen (N_2) atmosphere for 1 week at 2°C (Retail package design study: Part III).

Parameters	Meat-type & replicate #	Scavenger# 2					Scavenger# 4					Scavenger# 6									
		Retail display (day)					Retail display (day)					Retail display (day)					Retail display (day)				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity†	PM 1	6	6	6	7	7	6	6	6	8	0	6	7	8	0	0	5	5	6	7	0
	PM 2	6	6	6	7	0	6	6	6	8	0	6	7	8	0	0	6	6	6	7	0
	PM 3	6	6	6	7	0	6	6	8	8	0	6	7	8	0	0	6	5	6	7	6
	PM 4	6	6	5	7	7	6	6	6	7	7	6	7	8	0	0	6	5	7	7	0
Discoloration††	PM 1	1	1	2	3	6	3	3	5	6	7	3	5	6	7	7	2	4	5	5	7
	PM 2	1	1	3	5	7	1	4	5	6	7	3	5	6	7	7	3	4	5	6	7
	PM 3	1	3	4	5	7	3	4	6	6	7	2	5	6	7	7	2	3	3	3	4
	PM 4	1	1	1	3	6	3	3	3	5	5	3	5	6	7	7	2	3	5	5	7
Acceptance†††	PM 1	7	6	5	5	2	4	4	3	2	1	4	3	2	1	1	6	4	3	3	1
	PM 2	7	6	4	3	2	6	4	3	2	1	4	3	2	1	1	6	4	3	2	1
	PM 3	7	4	3	3	1	4	3	2	2	1	5	3	2	1	1	5	5	3	4	5
	PM 4	7	6	6	5	2	4	5	4	3	2	4	4	2	1	1	6	5	3	3	1

Parameters	Meat-type & replicate #	Scavenger#8				
		Retail display (day)				
		0	1	2	3	4
Color Intensity†	PM 1	5	5	5	5	5
	PM 2	5	5	5	5	5
	PM 3	5	6	6	6	6
	PM 4	5	5	6	6	6
Discoloration††	PM 1	1	1	1	1	2
	PM 2	1	1	1	2	1
	PM 3	2	2	2	3	4
	PM 4	1	2	2	4	4
Acceptance†††	PM 1	7	7	7	7	7
	PM 2	7	7	7	7	7
	PM 3	6	6	6	6	5
	PM 4	7	6	6	5	6

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

APPENDIX C

Appendix C1

AMSA (1991) has developed standard procedures for fresh meat color measurement. Estimation of reflectance values (R) of different myoglobin forms (deoxy, met, and oxy) at different wavelengths, and converting them to K/S values [K is the absorption coefficient and S is the scattering coefficient, K/S values are useful for the quantifying the proportion of deoxy, met, and oxy myoglobin, and are calculated at selected wavelengths using R: $K/S=(1-R)^2/2R$] is recommended for fresh color measurement. The ratios for wavelengths used for the calculations are: K/S 474÷K/S 525 for % deoxymyoglobin, K/S 572 ÷ K/S 525 for % metmyoglobin, and K/S 610 ÷ K/S 525 for oxymyoglobin. The following formulae give examples for deoxymyoglobin, metmyoglobin, and oxymyoglobin estimation:

$$\%\ \text{deoxymyoglobin} = \frac{\frac{K/S\ 474}{K/S\ 525}\text{met(standard)} - \frac{K/S\ 474}{K/S\ 525}\text{Sample}}{\frac{K/S\ 474}{K/S\ 525}\text{met(standard)} - \frac{K/S\ 474}{K/S\ 525}\text{deoxy(standard)}} \text{x}100\%$$

$$\%\ \text{metmyoglobin} = \frac{\frac{K/S\ 572}{K/S\ 525}\text{deoxy(standard)} - \frac{K/S\ 572}{K/S\ 525}\text{Sample}}{\frac{K/S\ 572}{K/S\ 525}\text{deoxy(standard)} - \frac{K/S\ 572}{K/S\ 525}\text{met(standard)}} \text{x}100\%$$

$$\%\ \text{oxyoglobin} = \frac{\frac{K/S\ 610}{K/S\ 525}\text{met(standard)} - \frac{K/S\ 610}{K/S\ 525}\text{Sample}}{\frac{K/S\ 610}{K/S\ 525}\text{met(standard)} - \frac{K/S\ 610}{K/S\ 525}\text{oxy(standard)}} \text{x}100\%$$

The reflectance spectrophotometer (Macbeth Color Eye 1500/Plus, Kollmorgen Corp., Newburg, NY) was standardized using fresh meat sample myoglobin being converted to 100% deoxy-, met-, and oxymyoglobin. The following procedure was adapted for this conversion (AMSA 1991):

(A) Deoxymyoglobin: Place samples in 10% sodium hydrosulphite for 2 min, drain, blot surface, vacuum package to reduce for 1 to 2 h at room temperature, repackage in O_2 permeable film, and scan immediately.

(B) Metmyoglobin: Place samples in 1.0% potassium ferricyanide for 1 min, drain, blot surface, package in O_2 permeable film to oxidize at 2°C for 12 h, then scan.

(C) Oxymyoglobin: Place samples in high oxygen atmosphere (pack and flush with 100% O_2) at 0-2°C for 10 min, package in O_2 permeable film and scan immediately.

After obtaining the standards, a SAS program was developed (courtesy: Ms. L.L. Gibson, Lacombe Research Station, Lacombe, AB) to obtain K/S values at desired wavelengths, i.e., 474, 525, 572, 610 nm (as the spectrophotometer gives reflectance values only at wavelengths: 360, 380, 400, 420, 440, 460, 480, 500, 520, 540, 560, 580, 600, 620, 640, 660, 680, 700, 720, 740 nm). The standard K/S values as obtained were fed into another SAS program which was used to calculate % deoxy-, met-, and oxymyglobin of the samples.

Table C1 Estimation of chemical states of myoglobin using the reflectance data as obtained by reflectance spectrophotometer (Retail Package Design Study: Part I).

		Reflectance values at wavelength (nm)																				Color**			Myoglobin form (%)		
Meat*	Treat	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met	oxy	deoxy
beef 1	A	15	14	13	12	15	17	18	18	18	17	18	17	24	28	29	35	41	44	44	44	53	14	9	49	0	51
beef 2	A	16	14	13	12	15	18	19	19	19	18	19	19	25	28	28	35	43	46	47	46	54	12	9	71	0	29
beef 3	A	15	13	12	12	14	16	17	17	17	16	17	17	23	26	28	33	39	41	42	41	51	14	8	51	0	49
beef 1	B	13	12	10	10	14	17	18	18	18	17	19	18	25	28	29	36	44	47	48	47	53	14	11	76	0	24
beef 2	B	12	10	8	8	12	15	16	16	16	15	17	17	23	25	25	33	41	45	45	44	51	13	11	90	6	5
beef 3	B	14	13	11	10	12	15	18	19	18	14	15	14	25	33	37	40	42	44	45	45	52	21	11	0	7	93
beef 1	C	16	14	12	11	13	17	20	20	19	16	17	16	26	33	36	40	42	44	45	44	54	19	11	9	2	89
beef 2	C	16	16	13	12	14	17	20	21	20	16	17	16	27	36	41	43	45	46	47	46	55	21	11	0	0	100
beef 3	C	16	15	14	13	15	17	18	18	18	17	18	18	23	26	27	33	39	41	42	42	52	12	7	61	3	37
beef 1	D	15	15	13	12	13	16	19	20	18	15	16	15	25	33	36	38	40	41	42	42	53	20	10	0	4	96
beef 2	D	19	18	16	15	16	18	21	22	20	17	18	17	27	35	38	40	42	43	44	43	55	19	9	2	0	98
beef 3	D	16	15	13	12	13	16	19	19	18	15	16	15	24	32	35	37	39	41	41	41	52	19	9	0	6	94
beef 1	D1	14	14	12	11	12	14	17	17	16	14	14	14	20	27	30	32	34	35	35	35	49	17	8	3	6	91
beef 2	D1	15	14	13	12	13	15	17	18	16	14	14	14	21	27	31	32	34	35	36	36	50	17	7	4	6	90
beef 3	D1	13	13	11	10	11	13	15	15	14	12	12	12	19	25	29	31	32	33	33	33	47	19	8	0	9	91
beef 1	E	11	11	9	8	9	12	14	15	14	11	11	11	20	27	31	33	35	37	38	38	47	22	11	0	6	94
beef 2	E	15	14	12	12	15	19	20	20	20	18	20	19	27	30	32	38	44	46	47	46	55	15	10	53	0	47
beef 3	E	13	12	11	10	11	13	15	16	15	12	13	12	20	27	31	33	34	36	37	37	48	20	9	0	0	100
beef 1	F	11	10	8	7	9	12	15	16	15	11	12	11	23	32	36	38	39	41	41	40	49	26	14	0	0	100
beef 2	F	16	15	13	12	13	16	19	20	18	15	16	15	26	34	38	40	41	42	43	42	53	22	11	0	0	100
beef 3	F	11	10	8	7	9	12	15	16	14	11	12	11	22	31	34	36	38	40	40	40	48	25	13	0	4	96
beef 1	F1	14	13	11	10	11	14	17	18	16	13	14	13	22	29	33	35	37	39	40	40	50	20	10	0	15	85
beef 2	F1	15	14	13	12	13	15	17	17	16	14	14	14	21	27	30	32	33	34	35	34	50	16	7	6	0	94
beef 3	F1	17	16	14	13	14	17	19	20	19	16	17	16	25	32	36	37	39	41	41	41	53	18	9	0	0	100
beef 1	G	19	18	16	14	17	20	23	24	22	19	20	19	29	35	38	40	42	43	44	43	56	17	8	0	12	88
beef 2	G	14	13	11	10	12	15	18	19	17	14	14	14	24	31	35	37	38	39	40	39	51	21	10	0	5	95
beef 3	G	15	14	13	12	13	15	17	17	16	14	14	14	21	28	31	33	35	36	37	36	50	18	8	6	0	94
beef 1	G1	13	12	11	11	13	16	17	16	16	15	16	16	22	25	26	32	39	42	42	42	50	14	9	59	5	35
beef 2	G1	15	14	13	12	14	16	17	17	17	16	17	16	22	25	26	32	38	40	40	40	51	13	7	53	6	42
beef 3	G1	11	11	9	8	9	12	15	16	14	11	12	11	21	30	34	36	38	40	41	41	48	23	12	0	0	100
beef 1	H	12	11	10	9	10	12	15	15	14	12	12	12	17	23	26	29	31	33	34	34	46	17	7	5	34	61
beef 2	H	14	13	12	11	12	14	16	17	16	13	14	13	21	27	30	33	35	37	37	37	49	18	9	1	7	93

		Reflectance values at wavelength (nm)																					Color**			Myoglobin form (%)		
Meat*	Treat	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met	oxy	deoxy
beef 2	H	14	13	12	11	12	14	16	16	16	14	14	14	20	25	28	31	34	35	36	36	49	16	8	18	1	81
beef 1	H1	15	14	12	10	12	15	19	20	18	14	15	14	24	32	35	37	39	40	41	40	52	20	10	0	17	83
beef 2	H1	15	14	12	11	12	15	17	18	17	14	14	14	22	29	33	35	37	38	40	39	50	19	9	0	9	91
beef 3	H1	17	16	14	13	14	17	19	20	19	16	17	16	25	33	37	39	41	42	43	42	53	19	9	0	0	100
pork 1	A	26	24	19	18	24	31	36	36	34	30	31	31	40	45	46	48	49	49	48	47	66	11	8	34	18	48
pork 2	A	25	23	18	17	23	30	35	35	33	29	30	30	39	43	45	46	47	46	45	44	65	11	8	33	19	48
pork 3	A	22	21	17	15	19	26	30	31	28	24	24	25	32	36	38	39	39	38	38	37	60	10	6	13	36	51
pork 1	B	23	22	17	14	19	26	31	32	29	24	25	24	33	38	40	41	41	40	40	38	61	11	7	0	34	66
pork 2	B	23	21	17	16	21	28	32	33	31	27	28	28	36	41	43	44	44	44	43	42	63	11	80	29	21	50
pork 3	B	23	21	17	16	21	28	32	33	30	27	28	28	36	41	42	44	45	45	44	43	63	11	8	32	19	49
pork 1	C	21	20	16	14	18	25	31	31	28	24	24	24	32	38	40	41	42	42	41	40	60	12	7	5	44	50
pork 2	C	22	21	17	15	19	26	31	31	28	24	24	24	32	38	40	41	41	42	41	40	61	11	7	7	35	58
pork 3	C	21	20	16	14	17	25	30	30	27	23	23	23	30	36	39	40	40	41	40	39	59	11	6	3	47	50
pork 1	D	21	20	16	14	17	23	29	29	26	22	22	22	30	36	39	39	39	39	39	38	59	13	7	0	44	56
pork 2	D	21	20	16	14	17	24	29	30	27	22	22	22	31	38	40	41	41	41	41	40	59	13	7	0	40	60
pork 3	D	22	21	17	14	18	24	29	30	27	23	23	23	32	39	41	42	42	42	42	41	60	14	8	0	29	71
pork 1	D1	29	27	20	16	23	32	39	40	37	31	32	31	44	51	54	55	56	56	55	53	68	14	10	0	26	74
pork 2	D1	25	23	16	13	20	28	34	36	33	27	28	27	40	48	50	51	52	52	51	50	65	15	11	0	22	78
pork 3	D1	27	26	20	16	22	30	36	37	34	29	30	29	42	49	51	52	52	52	51	49	66	14	10	0	16	84
pork 1	E	18	17	14	12	15	22	27	27	24	20	20	20	28	34	37	38	39	39	39	38	57	13	7	9	47	44
pork 2	E	19	18	14	13	16	22	26	27	24	20	20	20	28	34	37	38	39	40	39	38	57	13	7	7	42	50
pork 3	E	19	18	14	12	15	21	27	27	24	20	20	20	27	34	37	38	38	39	39	37	57	13	7	0	54	46
pork 1	F	20	19	14	11	16	23	29	30	27	22	23	22	34	41	43	44	44	44	44	43	60	16	10	0	27	73
pork 2	F	20	19	16	13	16	23	28	29	25	21	21	22	30	36	39	39	40	40	39	38	58	13	7	0	45	55
pork 3	F	21	20	16	14	17	23	28	29	26	21	22	22	31	37	39	40	40	40	40	39	59	14	7	0	34	66
pork 1	F1	23	22	17	14	19	26	32	32	29	24	25	25	34	41	44	45	45	45	45	43	62	14	8	0	38	62
pork 2	F1	22	21	16	14	18	24	29	30	27	22	23	23	33	40	43	44	44	44	44	42	60	15	9	0	19	81
pork 3	F1	25	24	18	15	20	27	32	33	30	25	26	26	36	43	45	46	46	46	45	44	63	14	8	0	29	71
pork 1	G	27	25	19	16	22	30	35	37	34	28	30	29	41	48	51	52	53	53	52	50	63	12	8	0	9	91
pork 2	G	23	22	18	16	20	28	33	34	31	26	27	27	36	42	45	46	47	47	47	45	63	12	8	6	38	56
pork 3	G	27	26	20	16	23	31	37	38	35	29	30	30	42	49	53	54	55	55	54	52	67	15	10	0	18	82
pork 1	G1	24	22	17	14	19	27	32	33	30	25	25	25	36	42	45	47	47	48	47	45	62	14	9	0	33	67
pork 2	G1	23	22	17	14	19	26	31	32	29	24	25	25	36	42	45	47	47	48	47	46	62	15	9	0	22	78
pork 3	G1	22	21	17	14	18	25	30	31	29	24	24	24	35	42	46	47	48	48	47	46	62	16	10	0	21	79

		Reflectance values at wavelength (nm)																				Color**			Myoglobin form (%)		
Meat*	Treat	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met	oxy	deoxy
pork 1	H	23	23	18	15	19	27	32	33	30	25	25	25	34	41	44	45	45	46	45	44	62	13	8	0	40	60
pork 2	H	24	23	18	15	20	27	32	33	30	25	26	25	35	42	44	45	45	45	45	43	62	13	8	0	28	72
pork 3	H	24	32	18	15	20	27	32	34	30	25	26	26	36	42	45	46	46	46	46	44	63	13	8	0	28	72
pork 1	H1	22	21	16	13	17	24	29	30	27	22	23	22	33	39	41	42	43	43	42	41	60	14	9	0	27	73
pork 2	H1	24	22	17	13	18	26	32	32	29	24	25	25	35	42	45	45	46	46	46	45	62	14	8	0	43	57
pork 3	H1	22	22	19	18	21	26	30	31	29	25	26	25	34	39	41	42	43	44	44	43	62	12	7	20	13	66

* Meat-type and replicate #.

** Hunterlab scale.

Table C2 Estimation of chemical states of myoglobin in beef (*longissimus dorsi*, LD) using the reflectance data as obtained by reflectance spectrophotometer (Retail Package Design Study: Part II).

Meat*	Treat	Bag #	Reflectance values at wavelength (nm)																				Color**			Myoglobin forms (%)		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met	oxy	deoxy
LD1	G	1	15	14	13	12	13	15	17	18	17	14	15	14	22	29	32	34	35	36	37	37	51	18	8	10	5	85
LD2	G	1	11	11	9	8	9	12	14	15	14	11	11	11	19	26	29	31	33	34	35	35	46	21	10	0	15	85
LD3	G	1	16	15	13	12	14	16	19	20	18	15	16	15	24	32	35	37	38	39	40	39	53	19	9	8	0	92
LD4	G	1	16	15	13	12	14	16	19	20	18	15	16	15	24	32	35	37	38	39	40	39	51	17	8	8	0	92
LD1	G	2	15	15	13	12	13	16	19	20	18	15	15	15	23	30	33	35	37	38	38	38	52	17	8	1	12	86
LD2	G	2	14	14	12	11	12	15	17	18	17	14	14	14	22	29	32	34	36	37	38	38	50	18	9	2	11	86
LD3	G	2	16	15	13	12	13	16	19	20	18	15	16	15	23	30	34	36	37	39	40	39	52	17	8	3	12	85
LD4	G	2	15	15	13	12	13	16	19	20	18	15	16	15	23	30	33	35	37	38	39	39	52	17	8	5	12	82
LD1	G	3	12	11	9	8	10	13	16	17	16	12	13	12	22	29	32	35	37	39	39	38	49	21	12	0	9	91
LD2	G	3	12	11	10	10	12	14	15	15	14	13	14	14	19	22	23	28	33	35	35	34	48	13	8	50	6	44
LD3	G	3	11	11	9	8	10	13	15	16	15	12	12	12	20	27	31	33	35	37	37	37	48	20	10	0	14	86
LD4	G	3	15	14	12	12	14	17	18	18	17	16	17	17	23	26	27	33	39	41	41	40	52	13	8	48	2	50
LD1	G	4	15	14	13	12	13	15	18	18	17	14	15	14	22	29	32	34	35	36	37	37	51	18	8	8	6	85
LD2	G	4	14	13	12	11	12	14	16	17	16	13	14	13	21	28	31	34	35	36	37	37	50	19	9	8	6	86
LD3	G	4	15	14	13	12	13	15	18	19	17	15	15	15	23	30	33	35	36	37	38	38	51	18	9	7	5	88
LD4	G	4	15	14	13	12	13	15	17	18	17	14	15	14	23	30	34	36	37	38	39	39	51	19	9	7	3	90
LD1	G	5	14	14	12	11	12	15	18	18	16	14	14	14	21	27	30	32	34	35	36	36	50	17	8	4	20	76
LD2	G	5	15	14	12	11	12	15	18	18	17	14	14	14	22	28	31	33	35	36	37	36	50	17	8	5	16	79
LD3	G	5	14	14	12	11	12	15	18	19	17	14	14	14	21	28	32	34	35	37	38	37	50	17	8	4	24	73
LD4	G	5	14	14	12	11	12	15	18	18	17	14	14	14	22	28	32	34	36	37	38	37	50	18	8	5	18	77
LD1	G	6	15	15	13	12	13	16	19	20	18	15	16	15	24	31	34	36	38	39	39	38	52	19	9	1	6	92
LD2	G	6	15	14	13	12	13	15	18	18	17	14	15	14	22	29	32	34	35	36	37	36	51	18	9	4	6	90
LD3	G	6	15	14	13	12	13	15	17	18	17	14	15	14	22	29	32	33	35	36	36	36	50	18	8	7	5	87
LD4	G	6	15	14	12	11	12	15	18	19	17	14	15	14	23	31	34	36	37	38	38	38	51	19	10	0	4	96
LD1	H	1	12	11	10	9	10	13	16	16	15	12	13	12	20	27	31	33	34	36	36	36	48	20	10	0	10	90
LD2	H	1	14	13	12	11	12	15	17	18	17	14	14	14	22	29	33	33	36	38	39	38	50	19	9	4	13	83
LD3	H	1	14	14	12	11	12	15	18	18	17	14	15	14	22	29	33	35	37	38	39	39	51	18	9	3	11	86
LD4	H	1	16	15	13	12	14	17	20	21	19	16	16	16	26	32	36	38	39	40	41	40	53	19	10	3	5	92
LD1	H	3	12	11	10	9	10	13	16	16	15	12	12	12	21	28	32	34	36	38	38	38	48	21	10	0	9	91
LD2	H	3	13	12	10	10	11	14	16	17	16	13	14	14	22	28	31	35	39	40	41	41	50	19	11	17	3	80

Meat*	Treat	Bag #	Reflectance values at wavelength (nm)																				Color**			Myoglobin forms (%)		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met	oxy	deoxy
LD3	H	3	16	15	14	14	15	18	18	18	18	17	18	18	23	25	26	32	38	41	41	40	52	11	7	51	3	45
LD4	H	3	15	14	13	12	14	16	18	18	17	15	16	16	23	27	29	34	38	40	41	40	51	15	8	32	2	67
LD1	H	4	18	17	14	12	15	19	24	25	23	18	19	18	32	41	45	48	50	51	51	50	58	22	12	0	5	95
LD2	H	4	15	15	13	12	13	16	19	20	18	15	16	15	24	31	35	37	39	40	41	41	52	18	9	4	11	85
LD3	H	4	15	14	12	12	13	15	18	19	17	14	15	14	22	29	33	36	38	39	40	40	51	18	8	4	19	77
LD4	H	4	16	15	13	12	13	17	20	21	19	16	16	15	26	33	37	39	40	41	41	41	53	19	10	0	6	94
LD1	H	5	14	14	12	11	12	15	17	19	17	14	15	14	24	32	35	37	39	40	40	40	51	21	11	1	0	99
LD2	H	5	13	12	10	9	11	13	16	17	15	12	13	12	22	30	34	36	37	38	39	38	50	22	11	0	0	100
LD3	H	5	15	15	13	12	13	16	18	19	18	15	16	15	24	32	35	37	39	41	41	41	52	19	10	9	0	91
LD1	H	6	15	14	12	12	13	15	18	19	18	15	15	15	24	31	35	37	39	41	41	41	52	20	10	4	1	95
LD2	H	6	16	16	14	12	14	17	20	21	19	16	17	16	26	33	37	40	41	43	43	42	54	20	10	2	3	95
LD3	H	6	15	15	13	12	13	16	18	19	18	15	15	15	24	32	16	38	40	41	42	41	52	20	10	0	2	97
LD4	H	6	16	15	13	12	14	17	20	21	19	16	17	16	26	34	38	40	41	42	43	42	54	20	10	1	0	99
LD1	G1	1	15	14	13	12	13	15	17	18	16	14	14	14	21	28	31	33	34	36	36	36	50	17	8	10	8	82
LD2	G1	1	14	14	12	12	12	14	16	17	16	14	14	14	21	28	31	34	35	37	37	37	50	18	9	14	0	86
LD3	G1	1	15	14	13	12	13	15	18	18	17	14	15	14	21	28	32	34	35	37	38	37	50	17	8	9	17	74
LD4	G1	1	15	14	13	12	13	15	18	18	17	14	15	14	23	29	33	34	36	37	38	38	51	18	9	8	5	87
LD1	G1	2	15	15	13	12	13	15	17	18	17	14	15	14	22	28	31	32	34	35	36	36	50	17	8	11	8	82
LD2	G1	2	15	14	13	12	13	15	18	18	17	14	15	14	21	27	30	32	34	36	37	36	50	16	7	9	18	73
LD3	G1	2	16	15	13	13	14	16	19	19	18	15	16	15	23	29	32	34	35	36	37	37	51	17	8	6	10	84
LD4	G1	2	16	15	13	12	13	16	18	19	18	15	15	15	23	30	33	35	36	37	37	37	51	17	8	5	7	88
LD1	G1	3	15	14	13	12	13	15	17	17	16	14	14	14	21	28	31	33	35	36	37	37	50	18	8	13	6	81
LD2	G1	3	15	14	12	12	13	15	17	18	17	14	14	14	21	28	31	33	35	36	36	36	50	17	8	8	9	83
LD3	G1	3	15	14	13	12	13	15	17	18	17	14	15	14	23	30	33	34	36	37	37	36	51	19	9	8	2	90
LD4	G1	3	14	14	12	12	13	15	17	17	16	14	14	14	21	28	31	33	35	36	37	37	50	18	9	11	2	88
LD1	G1	4	16	15	13	13	14	16	18	19	18	15	16	15	24	31	34	36	37	38	39	38	52	18	9	10	1	90
LD2	G1	4	15	14	13	12	13	15	17	18	17	14	15	14	22	29	32	34	36	37	38	38	51	18	9	10	3	87
LD3	G1	4	14	14	12	12	12	14	16	17	15	13	14	13	20	27	30	32	34	36	37	36	49	18	8	15	0	85
LD4	G1	4	15	14	13	12	13	15	17	18	16	14	15	14	22	30	33	35	37	38	39	38	51	19	9	11	0	88
LD1	G1	5	15	14	13	12	13	15	17	18	16	14	15	14	22	29	32	33	35	36	36	36	50	18	8	10	3	87
LD2	G1	5	15	14	13	12	13	15	17	18	16	14	14	14	22	29	32	34	35	36	37	36	50	18	8	9	4	87
LD3	G1	5	15	14	13	12	13	15	17	18	17	14	15	14	22	29	32	34	36	37	37	37	50	18	9	8	4	88

Meat*	Treat	Bag #	Reflectance values at wavelength (nm)																				Color**			Myoglobin forms (%)		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met	oxy	deoxy
LD4	G1	5	15	14	12	11	12	15	18	19	18	14	15	14	23	30	34	35	37	38	38	38	51	18	9	0	8	92
LD1	G1	6	15	14	13	12	13	15	17	18	17	14	15	14	23	30	33	36	37	39	40	40	51	19	9	10	0	90
LD2	G1	6	15	14	13	12	13	15	17	18	17	14	15	14	23	30	34	36	37	38	39	38	51	19	9	10	0	90
LD3	G1	6	14	14	12	12	12	14	17	17	16	14	14	14	21	28	31	33	35	37	38	37	50	18	8	11	6	82
LD4	G1	6	15	14	13	12	13	15	17	17	16	14	15	14	22	29	32	34	35	37	37	37	50	18	9	13	0	87
LD1	H1	1	16	16	13	12	14	17	20	21	20	16	17	16	28	37	41	43	45	46	47	46	55	22	12	0	0	100
LD2	H1	1	15	14	11	10	12	16	20	21	20	15	16	15	29	38	42	44	46	47	47	46	55	24	14	0	0	100
LD3	H1	1	14	13	10	9	11	15	19	20	19	14	15	14	28	37	41	43	45	46	46	46	54	25	14	0	0	100
LD4	H1	1	18	17	14	13	15	19	22	24	22	18	19	18	32	42	46	48	50	51	51	50	58	24	13	0	0	100
LD1	H1	2	16	15	13	12	13	16	18	19	18	15	15	15	23	30	33	34	36	37	37	36	51	18	9	7	3	90
LD2	H1	2	17	16	14	13	14	16	19	19	18	15	16	15	24	30	33	35	36	37	37	37	52	17	8	8	2	90
LD3	H1	2	15	15	12	11	13	16	20	21	19	15	16	15	27	35	39	41	43	44	45	44	54	21	11	0	0	100
LD4	H1	2	17	16	14	12	14	17	21	22	21	17	18	17	29	38	41	44	45	46	47	46	56	22	12	0	0	100
LD1	H1	3	14	13	11	10	12	14	17	18	17	13	14	13	24	31	35	36	38	38	39	38	51	21	11	0	0	100
LD2	H1	3	14	13	11	10	12	15	17	19	17	14	15	14	24	32	36	38	39	40	41	40	51	21	11	0	0	100
LD3	H1	3	17	16	13	12	14	17	20	21	19	16	16	16	26	33	36	38	39	40	41	40	53	19	10	0	1	99
LD4	H1	3	16	15	13	12	13	16	18	19	18	15	15	15	24	31	34	36	37	38	38	38	52	19	9	2	3	95
LD1	H1	4	16	15	13	12	13	16	19	20	18	15	16	15	25	33	37	39	41	42	43	42	53	21	11	0	0	100
LD2	H1	4	16	15	13	12	14	16	19	20	19	16	16	16	27	35	39	41	43	44	44	44	54	21	11	0	0	100
LD3	H1	4	16	15	13	12	13	16	19	20	19	15	16	15	26	34	38	40	42	43	43	42	53	21	11	1	0	99
LD4	H1	4	17	16	14	13	15	18	20	21	20	17	18	17	27	34	37	40	43	45	45	44	55	19	10	11	0	89
LD1	H1	5	16	15	13	11	13	17	20	21	20	16	17	16	30	39	42	45	47	48	49	48	56	23	13	0	0	100
LD2	H1	5	17	15	13	12	14	17	20	21	19	16	17	16	28	35	38	41	45	46	46	46	55	20	11	11	0	89
LD3	H1	5	14	13	10	9	11	15	19	20	18	14	15	14	28	37	41	43	45	46	47	46	53	25	14	0	0	100
LD4	H1	5	18	16	14	13	15	18	21	22	21	17	18	17	30	38	41	44	45	46	47	46	56	22	11	0	0	100
LD1	H1	6	15	14	12	11	13	15	18	19	18	14	15	14	24	31	34	36	37	39	39	38	51	19	10	1	3	96
LD2	H1	6	15	14	12	11	13	15	18	18	17	14	15	14	22	29	32	34	35	36	36	36	51	18	9	2	6	92
LD3	H1	6	15	14	13	12	13	15	18	19	18	15	15	15	23	30	34	36	37	38	39	38	51	19	9	3	0	97
LD4	H1	6	16	15	13	12	13	16	18	19	18	15	16	15	24	31	35	37	38	39	39	39	52	19	9	2	2	95

* Meat-type and replicate #.

** Hunterlab scale.

Table C3 Estimation of chemical states of myoglobin in beef (*longissimus dorsi*, LD) using the reflectance data as obtained by reflectance spectrophotometer (Retail Package Design Study: Part III).

Meat*	Treatment	Reflectance values at wavelength (nm)																					Color**			
		Day	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	% met
pm1	control	0.0	14.5	14.0	13.3	12.7	13.1	14.7	16.6	17.0	15.8	14.1	14.3	14.1	19.5	25.6	29.4	32.1	34.3	36.4	37.6	37.8	49.1	15.7	6.6	15.3
pm2	control	0.0	15.2	14.6	13.3	12.5	13.6	15.8	18.0	18.6	17.2	14.9	15.4	15.0	21.9	28.6	32.2	34.8	37.0	38.8	39.9	39.9	51.0	16.9	7.7	7.5
pm3	control	0.0	15.2	14.4	13.3	12.7	13.4	15.4	17.5	17.9	16.7	14.6	15.1	14.7	21.5	28.0	31.4	34.6	37.5	39.5	40.6	40.5	50.6	17.0	7.7	11.7
pm4	control	0.0	15.2	14.5	13.4	12.8	13.3	14.9	16.8	17.2	16.1	14.2	14.6	14.2	20.1	26.4	30.2	32.8	35.0	36.9	38.0	38.0	49.6	16.2	7.0	14.0
pm1	control	1.0	15.4	14.6	13.8	13.3	14.1	15.7	16.9	17.0	16.6	15.3	15.9	15.5	20.7	23.9	25.3	29.8	34.9	37.2	38.0	37.9	49.8	12.0	6.1	35.4
pm2	control	1.0	14.6	13.8	12.9	12.5	13.4	15.1	16.5	16.8	16.2	14.5	15.2	14.8	21.9	26.0	27.5	32.7	38.4	40.7	41.4	40.8	50.0	15.4	7.8	28.4
pm3	control	1.0	16.2	15.2	14.4	14.1	15.2	17.1	18.0	17.9	17.6	16.6	17.6	17.2	22.7	24.5	24.9	31.1	39.3	42.4	43.0	42.3	51.5	10.9	6.3	51.6
pm4	control	1.0	15.3	14.4	13.4	12.9	13.7	15.3	16.5	16.7	16.2	14.7	15.4	14.9	20.8	24.2	25.7	30.5	36.0	38.4	39.2	38.8	49.5	13.2	6.6	30.9
pm1	control	2.0	15.4	14.5	13.8	13.4	14.2	15.8	16.6	16.7	16.3	15.3	16.1	15.7	20.6	22.9	23.7	29.1	35.7	38.5	39.4	39.2	49.6	11.0	5.9	45.3
pm2	control	2.0	14.6	13.5	12.6	12.3	13.4	15.2	16.1	16.1	15.8	14.7	15.7	15.3	21.1	23.1	23.7	30.2	38.7	41.8	42.4	41.6	49.4	12.4	7.0	48.4
pm3	control	2.0	16.1	15.0	14.3	14.1	15.6	17.3	17.7	17.3	17.3	17.0	18.4	18.3	21.9	22.3	22.4	28.7	38.4	42.2	42.6	41.7	51.3	8.2	5.9	77.1
pm4	control	2.0	15.0	14.0	13.1	12.7	13.7	15.3	16.1	16.0	15.8	14.8	15.8	15.3	20.3	22.1	22.6	28.6	36.6	39.7	40.3	39.6	49.1	11.0	6.1	49.9
pm1	control	3.0	14.6	13.6	12.9	12.6	13.6	15.2	16.0	15.9	15.7	14.8	15.7	15.4	20.0	21.7	22.3	28.1	35.7	38.9	39.7	39.3	48.9	10.5	6.1	52.3
pm2	control	3.0	16.0	14.6	13.3	13.0	15.3	17.5	18.2	17.9	17.8	17.2	18.6	18.3	23.3	24.3	24.4	31.3	40.9	44.4	44.8	43.7	52.1	10.1	7.1	69.4
pm3	control	3.0	16.1	14.9	14.0	13.9	15.7	17.4	17.7	17.2	17.3	17.3	18.9	18.9	21.7	21.9	21.8	28.1	38.2	42.2	42.7	41.7	51.4	7.3	6.0	87.2
pm4	control	3.0	14.7	13.6	12.8	12.5	13.7	15.2	15.8	15.5	15.4	14.9	16.0	15.6	19.6	20.5	20.6	26.8	36.2	39.8	40.2	39.3	48.6	9.2	5.7	63.1
pm1	control	4.0	15.2	14.2	13.6	13.2	14.3	16.0	16.6	16.4	16.3	15.8	16.9	16.7	20.6	21.6	21.8	27.9	37.0	40.7	41.3	40.6	49.8	9.0	6.0	66.9
pm2	control	4.0	15.2	14.0	13.2	13.0	14.7	16.6	17.0	16.7	16.6	16.4	17.8	17.7	21.4	21.8	21.8	28.6	39.5	43.9	44.4	43.5	50.6	8.7	6.5	78.6
pm3	control	4.0	16.8	15.6	14.8	14.6	16.6	18.4	18.5	18.0	18.1	18.4	20.1	20.3	22.4	22.3	22.3	28.4	38.3	42.5	43.0	42.1	52.5	6.4	6.0	93.5
pm4	control	4.0	15.6	14.6	14.0	13.7	14.8	16.3	16.7	16.4	16.4	16.0	17.1	16.9	20.2	20.8	20.8	26.7	36.7	40.3	40.7	39.7	49.7	7.8	5.1	67.9
pm1	s2	0.0	15.6	14.8	13.5	12.8	13.8	15.9	17.8	18.5	17.4	15.0	15.6	15.1	23.5	30.3	33.6	36.0	37.9	39.3	39.9	39.4	51.7	18.4	8.8	8.6
pm2	s2	0.0	14.1	13.4	12.2	11.6	12.2	13.9	15.9	16.6	15.5	13.3	13.7	13.3	20.4	27.0	30.7	32.7	34.2	35.6	36.4	36.1	49.0	18.0	8.3	5.8
pm3	s2	0.0	17.4	16.4	15.1	14.4	15.3	17.2	19.0	19.6	18.6	16.4	17.0	16.5	24.6	31.2	34.4	36.8	38.8	40.2	40.8	40.3	53.1	17.3	8.1	14.5
pm4	s2	0.0	18.4	17.6	16.2	15.3	16.0	17.8	19.7	20.4	19.2	16.9	17.3	16.8	24.2	30.5	33.7	35.5	36.9	38.0	38.5	38.1	53.2	15.8	6.8	8.9
pm1	s4	0.0	14.0	13.3	12.1	11.4	12.0	13.8	15.9	16.6	15.4	13.2	13.7	13.3	20.2	27.2	31.1	33.4	35.3	37.1	38.2	38.2	49.0	18.4	8.6	6.8
pm2	s4	0.0	16.7	16.2	14.8	14.0	15.0	17.1	19.2	20.1	18.9	16.3	16.9	16.3	24.9	32.3	35.9	38.0	39.6	41.1	41.9	41.7	53.3	18.2	8.7	5.4
pm3	s4	0.0	15.0	14.2	12.8	12.1	12.8	14.8	17.1	17.9	16.6	14.1	14.6	14.1	22.7	30.3	34.0	36.2	38.0	39.5	40.4	40.1	50.9	19.8	9.4	2.5
pm4	s4	0.0	14.7	14.0	12.5	11.8	12.6	14.5	16.6	17.3	16.1	13.7	14.2	13.8	21.1	28.0	31.6	33.6	35.3	37.0	38.0	38.0	49.8	18.1	8.3	4.2
pm1	s6	0.0	18.4	17.4	15.8	14.9	15.6	17.6	19.8	20.5	19.2	16.6	17.2	16.6	24.5	31.3	34.8	37.0	38.8	40.4	41.3	41.0	53.3	16.9	7.3	6.6
pm2	s6	0.0	17.7	16.6	14.7	13.7	15.0	17.4	19.9	20.5	19.2	16.4	17.1	16.5	25.1	32.1	35.5	37.9	39.7	41.1	41.8	41.3	53.5	17.8	8.3	3.3
pm3	s6	0.0	15.0	14.3	12.6	11.8	12.8	15.1	17.4	18.2	16.8	14.1	14.6	14.1	22.0	29.0	32.8	34.9	36.4	37.8	38.4	37.9	50.6	18.4	8.5	0.0
pm4	s6	0.0	14.7	14.0	12.5	11.7	12.5	14.5	16.6	17.3	16.1	13.7	14.2	13.7	20.7	27.2	30.8	32.7	34.2	35.5	36.3	36.0	49.5	17.3	8.0	4.5

Meat*	Treatment	Reflectance values at wavelength (nm)																					Color**			
		Day	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	% met
pm1	s8	0.0	18.1	17.2	15.3	14.2	15.2	17.2	19.4	20.1	18.8	16.2	16.7	16.1	23.9	30.2	33.3	35.1	36.2	37.2	37.4	36.8	52.6	16.2	7.1	2.4
pm2	s8	0.0	17.6	16.6	14.8	13.7	14.7	16.8	19.1	19.9	18.6	15.8	16.4	15.8	24.0	30.7	34.1	35.9	37.1	38.1	38.4	37.8	52.5	17.2	7.8	1.8
pm3	s8	0.0	16.0	15.2	13.5	12.6	13.6	15.9	18.2	18.8	17.4	14.8	15.3	14.8	22.5	29.0	32.5	34.4	35.8	37.2	37.8	37.4	51.1	17.3	7.6	0.9
pm4	s8	0.0	14.2	13.5	12.1	11.4	12.2	14.1	16.3	17.0	15.6	13.3	13.7	13.3	20.3	27.0	30.9	33.0	34.7	36.3	37.2	37.1	49.1	18.0	8.1	2.3
pm1	s2	1.0	15.8	14.8	13.5	12.8	13.9	15.9	17.6	18.1	17.2	15.1	15.8	15.2	24.0	29.0	30.5	35.5	40.3	41.9	41.9	41.0	51.5	17.3	8.5	16.1
pm2	s2	1.0	14.1	13.3	12.2	11.7	12.5	14.2	15.7	16.2	15.4	13.5	14.2	13.6	21.5	26.1	27.9	32.6	37.1	38.7	38.9	38.1	49.2	17.0	8.4	17.9
pm3	s2	1.0	16.9	15.9	14.7	14.1	15.1	17.0	18.4	18.8	18.1	16.2	16.9	16.4	24.5	28.7	29.9	35.2	40.7	42.5	42.6	41.7	52.3	15.5	7.5	23.5
pm4	s2	1.0	17.3	16.3	14.9	14.1	15.0	16.9	18.5	19.1	18.2	16.0	16.6	16.0	24.7	30.0	31.8	35.7	39.1	40.1	39.9	38.8	52.5	16.7	7.9	13.9
pm1	s4	1.0	14.0	13.1	12.2	11.8	12.8	14.6	15.7	15.7	15.4	14.1	15.0	14.5	20.6	23.1	23.8	29.9	37.6	40.6	41.2	40.6	48.8	13.2	7.3	41.8
pm2	s4	1.0	16.5	15.7	14.4	13.7	14.8	17.0	18.7	19.2	18.4	16.2	17.0	16.4	25.5	30.2	31.6	36.8	42.4	44.0	44.1	43.3	52.9	16.8	8.5	17.7
pm3	s4	1.0	14.3	13.4	12.4	11.9	12.7	14.4	15.7	16.0	15.4	13.7	14.4	13.9	20.7	24.1	25.1	30.3	36.1	38.2	38.7	38.0	48.7	14.5	7.2	26.7
pm4	s4	1.0	15.1	14.2	13.0	12.5	13.4	15.2	16.6	17.0	16.3	14.5	15.1	14.6	22.2	26.3	27.8	33.1	38.6	40.6	41.0	40.5	50.1	15.8	7.8	22.4
pm1	s6	1.0	18.6	17.7	16.4	15.7	16.5	18.3	19.8	20.3	19.5	17.4	18.1	17.5	25.9	30.4	31.7	36.8	42.1	43.9	44.0	43.0	53.8	15.4	7.1	20.0
pm2	s6	1.0	16.5	15.4	14.1	13.4	14.4	16.4	18.0	18.5	17.7	15.5	16.2	15.6	25.0	30.1	31.6	37.0	42.5	44.1	44.1	43.0	52.2	17.8	8.7	16.3
pm3	s6	1.0	14.3	13.5	12.0	11.2	12.4	14.6	16.6	17.3	16.3	13.7	14.4	13.8	23.8	30.3	32.9	37.3	40.8	41.8	41.6	40.4	50.8	20.6	10.3	3.4
pm4	s6	1.0	15.6	14.4	12.5	11.7	13.3	15.6	17.5	18.1	17.2	14.7	15.6	14.9	24.3	29.5	31.1	35.8	40.2	41.6	41.6	40.5	51.5	18.0	9.3	11.1
pm1	s8	1.0	17.2	16.2	14.5	13.5	14.4	16.3	18.0	18.6	17.7	15.3	15.9	15.3	24.9	31.3	33.7	37.2	39.7	40.3	39.8	38.6	52.3	19.0	8.8	7.8
pm2	s8	1.0	17.9	16.9	14.9	13.8	14.9	17.2	19.2	19.9	18.9	16.1	16.9	16.2	26.6	33.4	36.0	39.6	42.1	42.6	42.1	40.8	53.7	19.5	9.4	4.4
pm3	s8	1.0	15.6	14.8	13.3	12.5	13.5	15.5	17.3	18.0	17.0	14.6	15.3	14.7	24.7	30.9	33.0	37.3	40.8	41.7	41.3	40.1	51.7	19.7	9.6	9.1
pm4	s8	1.0	16.5	15.5	13.6	12.5	14.0	16.5	18.4	19.1	18.0	15.4	16.2	15.5	25.4	31.2	33.2	37.8	41.7	42.8	42.6	41.6	52.5	18.6	9.2	6.2
pm1	s2	2.0	16.2	15.1	13.9	13.3	14.5	16.6	18.0	18.3	17.6	15.8	16.7	16.1	23.4	26.1	26.7	32.4	39.0	41.2	41.4	40.4	51.3	13.3	6.9	28.7
pm2	s2	2.0	14.2	13.3	12.2	11.7	12.6	14.5	15.9	16.2	15.6	13.8	14.5	14.0	21.2	24.6	25.6	31.1	37.1	39.2	39.4	38.6	49.0	14.9	7.6	24.4
pm3	s2	2.0	16.2	15.0	13.9	13.5	14.7	16.7	17.9	18.0	17.5	16.1	17.0	16.5	23.2	25.4	25.8	31.9	39.8	42.6	42.8	41.9	51.3	12.4	6.8	38.9
pm4	s2	2.0	16.1	15.1	13.7	13.0	14.0	16.1	17.9	18.3	17.5	15.3	16.0	15.4	24.1	28.6	29.9	34.9	39.7	41.1	40.9	39.8	51.6	16.5	8.2	15.1
pm1	s4	2.0	13.9	12.9	12.1	11.8	13.0	14.8	15.6	15.4	15.2	14.5	15.7	15.3	20.1	21.3	21.4	27.9	37.7	41.5	42.0	41.2	48.6	10.6	6.8	60.8
pm2	s4	2.0	16.1	15.2	14.0	13.4	14.8	17.2	18.6	18.9	18.3	16.5	17.5	16.9	24.6	27.5	28.1	34.2	41.6	44.1	44.3	43.5	52.4	13.8	7.7	32.3
pm3	s4	2.0	14.5	13.4	12.4	12.0	13.3	15.4	16.5	16.4	16.0	14.8	15.9	15.4	21.6	23.4	23.6	30.1	39.0	42.2	42.5	41.5	49.7	12.3	7.2	46.2
pm4	s4	2.0	14.6	13.5	12.6	12.2	13.4	15.3	16.3	16.4	15.9	14.7	15.6	15.2	21.0	22.8	23.3	29.5	37.5	40.5	41.0	40.5	49.3	11.9	6.6	42.6
pm1	s6	2.0	17.9	16.8	15.6	15.0	15.9	17.8	19.0	19.2	18.6	17.0	17.8	17.2	24.3	26.8	27.4	33.2	40.5	43.0	43.1	42.1	52.5	12.6	6.3	32.1
pm2	s6	2.0	16.4	15.2	14.1	13.5	14.5	16.5	17.9	18.1	17.5	15.8	16.7	16.1	23.7	26.6	27.2	33.5	41.2	43.7	43.8	42.8	51.5	14.2	7.3	30.5
pm3	s6	2.0	15.0	14.0	12.5	11.7	12.8	15.1	17.0	17.7	16.7	14.2	14.9	14.3	24.2	30.1	32.1	37.4	41.9	43.1	42.7	41.3	51.2	19.7	9.9	6.6
pm4	s6	2.0	15.3	14.2	12.6	11.9	13.4	15.8	17.5	17.9	17.2	15.0	16.0	15.3	23.8	27.5	28.4	34.1	40.1	41.9	41.7	40.4	51.2	15.8	8.6	21.6

Meat*	Treatment		Reflectance values at wavelength (nm)																				Color**			
		Day	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	% met
pm1	s8	2.0	17.0	16.1	14.6	13.7	14.4	16.1	17.7	18.2	17.4	15.2	15.8	15.3	24.3	30.2	32.3	36.6	39.8	40.5	40.0	38.7	51.9	18.3	8.4	13.2
pm2	s8	2.0	17.4	16.3	14.5	13.5	14.6	16.8	18.9	19.5	18.5	15.8	16.6	15.9	26.3	32.6	34.8	39.1	42.4	43.2	42.7	41.4	53.3	19.3	9.4	6.3
pm3	s8	2.0	15.5	14.6	13.3	12.6	13.6	15.5	17.1	17.6	16.8	14.7	15.4	14.8	23.4	27.4	28.4	33.6	39.1	40.8	40.7	39.7	50.7	16.3	8.0	17.4
pm4	s8	2.0	15.3	14.4	13.1	12.4	13.4	15.5	17.0	17.4	16.6	14.7	15.4	14.8	22.9	26.5	27.5	33.1	39.2	41.1	41.0	40.0	50.4	15.6	7.8	20.2
pm1	s2	3.0	15.4	14.2	13.1	12.7	14.1	16.3	17.4	17.5	17.0	15.6	16.6	16.0	22.3	24.0	24.3	30.1	37.4	40.0	40.3	39.5	50.5	11.6	6.6	40.5
pm2	s2	3.0	14.0	13.1	12.1	11.7	12.7	14.6	15.8	15.9	15.4	14.0	14.9	14.4	20.6	22.8	23.2	29.2	36.7	39.3	39.5	38.5	48.7	12.7	6.9	36.8
pm3	s2	3.0	16.2	15.1	14.2	13.9	15.4	17.4	18.2	18.0	17.8	16.9	18.1	17.7	22.8	23.8	23.8	30.0	39.0	42.3	42.7	41.7	51.6	9.7	6.1	56.7
pm4	s2	3.0	16.6	15.3	13.6	13.0	14.7	17.3	19.1	19.3	18.7	16.5	17.7	17.0	26.1	29.7	30.4	37.2	44.9	47.2	46.9	45.4	53.2	15.9	8.9	28.1
pm1	s4	3.0	14.1	13.0	12.2	12.0	13.4	15.3	16.0	15.8	15.6	15.1	16.4	16.0	20.6	21.4	21.5	28.1	38.5	42.5	42.9	42.0	49.3	10.0	6.9	67.5
pm2	s4	3.0	16.4	15.4	14.3	13.8	15.3	17.6	18.8	18.8	18.4	17.1	18.3	17.7	24.1	25.8	26.1	32.5	41.4	44.6	44.8	43.9	52.4	11.5	7.0	47.1
pm3	s4	3.0	14.4	13.3	12.4	12.1	13.8	15.8	16.6	16.3	16.1	15.5	16.8	16.5	21.2	21.9	21.9	28.5	38.3	42.0	42.3	41.3	49.8	9.9	6.8	67.5
pm4	s4	3.0	14.5	13.4	12.4	12.2	13.7	15.7	16.4	16.3	16.0	15.2	16.4	16.0	20.7	21.6	21.8	28.2	37.2	40.6	41.1	40.5	49.4	9.9	6.3	59.5
pm1	s6	3.0	16.6	15.4	14.4	13.9	14.9	16.7	17.6	17.6	17.2	16.0	17.0	16.5	22.3	23.8	24.0	30.1	38.6	41.6	41.8	40.8	50.8	11.0	6.0	45.6
pm2	s6	3.0	17.0	15.9	14.7	14.1	15.2	17.1	18.3	18.3	17.9	16.4	17.4	16.8	23.4	25.4	25.7	31.9	40.1	43.0	43.2	42.3	51.6	12.0	6.4	39.4
pm3	s6	3.0	15.0	14.1	12.5	11.8	13.0	15.3	17.2	17.8	16.8	14.4	15.2	14.5	24.3	29.5	31.2	37.0	42.4	43.8	43.4	42.1	51.3	18.8	9.6	9.5
pm4	s6	3.0	15.6	14.3	12.7	12.1	13.8	16.3	18.0	18.1	17.5	15.6	16.7	16.0	23.9	26.7	27.2	33.2	40.3	42.5	42.2	40.9	51.5	14.2	8.1	30.8
pm1	s8	3.0	17.7	16.6	15.3	14.5	15.1	16.6	18.0	18.4	17.7	15.7	16.3	15.8	23.9	29.0	30.6	35.3	39.4	40.4	40.0	38.7	51.9	16.4	7.4	18.7
pm2	s8	3.0	18.0	16.8	15.1	14.1	15.1	17.1	19.0	19.7	18.7	16.2	16.9	16.3	26.1	32.1	34.0	38.6	42.4	43.3	42.8	41.6	53.4	18.4	8.8	9.8
pm3	s8	3.0	15.6	14.5	13.4	12.7	13.8	15.7	17.0	17.3	16.6	14.9	15.6	15.1	22.5	25.4	25.9	31.4	38.0	40.0	40.0	39.0	50.3	14.0	7.1	26.2
pm4	s8	3.0	14.7	13.8	12.7	12.2	13.2	15.1	16.2	16.4	15.9	14.4	15.1	14.6	21.3	23.6	24.1	30.0	37.1	39.5	39.6	38.7	49.2	13.1	6.8	32.6
pm1	s2	4.0	16.0	14.8	13.7	13.3	14.9	17.1	18.0	17.8	17.5	16.5	17.7	17.2	22.5	23.4	23.5	29.6	38.0	41.0	41.3	40.4	51.2	9.8	6.2	55.2
pm2	s2	4.0	14.1	13.1	12.2	11.8	13.0	14.9	15.9	15.8	15.5	14.4	15.4	14.9	20.5	22.0	22.2	28.5	36.9	39.8	40.0	39.0	48.7	11.4	6.6	46.8
pm3	s2	4.0	15.8	14.7	13.8	13.5	15.2	17.2	17.8	17.5	17.4	16.8	18.2	17.9	22.2	22.7	22.7	29.0	38.5	42.2	42.6	41.7	51.3	8.8	6.2	69.4
pm4	s2	4.0	16.0	14.9	13.5	12.9	14.3	16.5	18.0	18.1	17.5	15.8	16.8	16.1	23.4	25.9	26.3	32.3	39.5	41.7	41.6	40.4	51.3	13.2	7.2	31.0
pm1	s4	4.0	14.1	13.0	12.2	12.0	13.4	15.4	16.0	15.7	15.6	15.1	16.5	16.2	20.6	21.3	21.3	28.0	38.8	43.0	43.4	42.3	49.3	9.8	6.9	71.2
pm2	s4	4.0	16.3	15.2	14.2	13.7	15.3	17.5	18.4	18.3	18.0	17.1	18.3	17.8	23.6	24.8	24.9	31.5	41.1	44.6	44.8	43.8	52.1	10.6	6.8	56.2
pm3	s4	4.0	14.6	13.5	12.6	12.4	14.1	16.2	16.7	16.3	16.3	15.9	17.4	17.2	21.2	21.6	21.5	28.1	38.4	42.3	42.7	41.7	50.2	8.9	6.7	77.8
pm4	s4	4.0	15.3	14.2	13.2	13.0	14.9	17.1	17.6	17.3	17.1	16.7	18.0	17.8	21.8	22.3	22.3	28.7	38.1	41.9	42.5	41.8	51.0	8.5	6.2	70.8
pm1	s6	4.0	16.2	15.1	14.1	13.7	15.1	16.9	17.6	17.4	17.1	16.4	17.5	17.1	21.9	22.7	22.8	29.1	38.4	41.9	42.3	41.3	50.8	9.4	5.8	59.2
pm2	s6	4.0	16.9	15.6	14.5	14.1	15.4	17.4	18.3	18.1	17.8	16.8	18.0	17.5	23.0	24.2	24.3	30.7	39.7	43.1	43.4	42.4	51.7	10.3	6.1	53.5
pm3	s6	4.0	15.3	14.3	12.7	12.0	13.3	15.7	17.6	18.0	17.2	14.8	15.7	15.0	24.3	28.6	29.7	35.8	42.0	43.6	43.2	41.8	51.4	17.2	9.0	14.1
pm4	s6	4.0	15.6	14.2	12.8	12.2	14.0	16.4	17.8	17.8	17.3	15.7	16.9	16.3	23.5	25.6	25.8	32.2	40.3	42.8	42.5	41.1	51.3	13.0	7.8	41.2

Meat*	Treatment		Reflectance values at wavelength (nm)																			Color**			
		Day	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	% met
pm1	s8	4.0	15.7	14.7	13.0	12.1	13.3	15.6	17.6	18.3	17.3	14.7	15.4	14.7	24.7	30.4	32.2	37.0	40.7	41.4	40.7	39.2	51.7	19.0	9.4	4.2
pm2	s8	4.0	17.8	16.7	15.2	14.3	15.2	17.2	19.0	19.5	18.6	16.2	17.0	16.3	25.8	31.4	33.1	38.2	42.6	43.8	43.3	42.0	53.2	17.8	8.5	12.1
pm3	s8	4.0	15.1	14.1	13.1	12.6	13.7	15.5	16.6	16.7	16.3	14.8	15.7	15.1	21.7	23.8	24.2	30.1	37.6	40.1	40.2	39.3	49.7	12.6	6.7	35.9
pm4	s8	4.0	14.6	13.7	12.8	12.4	13.5	15.2	16.2	16.2	15.8	14.6	15.5	15.1	20.8	22.4	22.6	28.8	36.9	39.7	39.9	38.9	49.1	11.5	6.3	33.4

* Meat-type and replicate #.

** Hunterlab scale.

APPENDIX D

Table D1. Color† scores for panelist#1 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type & replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	6	5	6				6		
	P.M. 2	5	5	7				6		
	P.M. 3	6	5	6				6		
	P.M. 4	6	5	6				6		
FX-100	P.M. 1		5	5				6		
	P.M. 2		5	6				6		
	P.M. 3		5	5				7		
	P.M. 4		5	5				7		
R-2000	P.M. 1		5	5				5		
	P.M. 2		5	5				6		
	P.M. 3		6	5				5		
	P.M. 4		6	5				6		

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.

Table D2. Discoloration†† scores for panelist#1 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type & replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	1	2	1				5		
	P.M. 2	1	1	1				4		
	P.M. 3	1	2	1				6		
	P.M. 4	1	1	1				3		
FX-100	P.M. 1		1	1				2		
	P.M. 2		1	1				2		
	P.M. 3		2	1				2		
	P.M. 4		2	1				2		
R-2000	P.M. 1		2	1				1		
	P.M. 2		2	2				1		
	P.M. 3		1	1				1		
	P.M. 4		1	1				1		

†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).

Table D3. Retail appearance[†††] scores for panelist#1 for beef (*psoas major,* PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type & replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	7	7	7				2		
	P.M. 2	7	7	7				3		
	P.M. 3	7	7	7				1		
	P.M. 4	7	7	7				5		
FX-100	P.M. 1		7	7				5		
	P.M. 2		7	7				6		
	P.M. 3		7	7				4		
	P.M. 4		7	7				5		
R-2000	P.M. 1		7	7				7		
	P.M. 2		7	6				6		
	P.M. 3		7	7				7		
	P.M. 4		7	7				6		

††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table D4. Color† scores for panelist#2 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	6	5	6	5	6	5	6	6	6
	P.M. 2	6	5	6	5	6	5	6	6	5
	P.M. 3	6	5	6	5	6	5	6	6	5
	P.M. 4	6	5	6	5	6	5	6	6	5
FX-100	P.M. 1		6	5	5	5	5	6	6	6
	P.M. 2		6	5	5	5	5	6	6	6
	P.M. 3		5	5	5	5	5	7	6	6
	P.M. 4		6	5	5	5	5	7	6	6
R-2000	P.M. 1		5	5	5	6	6	5	4	5
	P.M. 2		5	5	5	6	5	6	4	5
	P.M. 3		7	5	5	6	5	5	4	6
	P.M. 4		6	5	5	6	5	6	4	5

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.

Table D5. Discoloration†† scores for panelist#2 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	1	3	2	2	4	1	5	2	2
	P.M. 2	1	3	6	2	3	1	4	1	3
	P.M. 3	1	4	4	4	2	1	6	5	3
	P.M. 4	1	4	6	4	5	1	3	5	4
FX-100	P.M. 1		1	0	1	1	1	2	1	1
	P.M. 2		1	1	1	1	1	2	1	1
	P.M. 3		1	0	1	1	1	2	1	1
	P.M. 4		1	0	1	1	1	2	1	1
R-2000	P.M. 1		3	2	2	1	1	1	3	1
	P.M. 2		1	2	2	1	1	1	3	1
	P.M. 3		2	2	1	1	1	1	3	3
	P.M. 4		2	2	2	1	1	1	3	1

†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).

Table D6. Retail appearance[†††] scores for panelist#2 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	6	2	3	4	2	6	2	6	3
	P.M. 2	6	2	2	4	3	6	3	6	3
	P.M. 3	6	2	2	4	3	6	1	6	3
	P.M. 4	6	2	2	4	2	6	5	6	3
FX-100	P.M. 1		5	7	6	7	6	5	6	6
	P.M. 2		5	7	6	7	6	6	6	6
	P.M. 3		6	7	6	7	6	4	6	6
	P.M. 4		6	7	6	7	6	5	6	6
R-2000	P.M. 1		6	6	6	6	6	7	5	6
	P.M. 2		6	6	6	6	6	6	5	6
	P.M. 3		5	6	6	6	6	7	5	6
	P.M. 4		5	6	6	6	6	6	5	6

††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table D7. Color† scores for panelist#3 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	5	5	5	6	5	5			
	P.M. 2	5	5	6	6	6	6			
	P.M. 3	6	6	5	6	5	5			
	P.M. 4	5	6	5	6	5	5			
FX-100	P.M. 1		6	5	6	6	6			
	P.M. 2		6	6	6	5	5			
	P.M. 3		5	6	6	6	5			
	P.M. 4		6	5	6	6	6			
R-2000	P.M. 1		5	5	6	6	6			
	P.M. 2		5	5	6	6	5			
	P.M. 3		6	5	5	7	5			
	P.M. 4		6	5	5	6	5			

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.

Table D8. Discoloration†† scores for panelist#3 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	1	1	2	5	4	2			
	P.M. 2	1	1	2	5	3	2			
	P.M. 3	1	3	3	5	3	2			
	P.M. 4	1	3	2	4	4	1			
FX-100	P.M. 1		3	3	5	2	3			
	P.M. 2		3	2	4	2	3			
	P.M. 3		3	2	4	1	3			
	P.M. 4		5	2	4	2	2			
R-2000	P.M. 1		1	1	3	2	1			
	P.M. 2		1	1	3	2	2			
	P.M. 3		1	1	3	2	3			
	P.M. 4		1	2	3	2				

†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).

Table D9. Retail appearance[†††] scores for panelist#3 for beef (PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	7	7	6	3	3	5			
	P.M. 2	7	6	5	3	4	5			
	P.M. 3	7	3	5	3	4	6			
	P.M. 4	7	4	6	3	4	7			
FX-100	P.M. 1		4	5	4	5	5			
	P.M. 2		4	5	4	6	4			
	P.M. 3		5	5	4	6	4			
	P.M. 4		4	6	4	5	4			
R-2000	P.M. 1		7	7	4	5	6			
	P.M. 2		7	7	5	5	5			
	P.M. 3		6	7	5	4	6			
	P.M. 4		6	6	5	5	5			

††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table D10. Color† scores for panelist#4 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	5	5	6	5	5	5	5	6	6
	P.M. 2	5	5	6	6	5	5	5	6	5
	P.M. 3	5	5	6	6	5	5	5	6	6
	P.M. 4	5	5	6	5	5	5	6	7	5
FX-100	P.M. 1		7	6	6	5	5	6	6	6
	P.M. 2		7	7	7	5	5	6	6	6
	P.M. 3		5	6	7	6	6	7	7	6
	P.M. 4		7	6	6	5	7	7	5	5
R-2000	P.M. 1		4	5	5	6	6	4	4	6
	P.M. 2		4	4	5	6	5	4	5	5
	P.M. 3		7	5	7	7	5	4	4	7
	P.M. 4		6	5	5	7	5	5	4	5

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.

Table D11. Discoloration†† scores for panelist#4 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	1	3	1	3	4	4	4	1	2
	P.M. 2	1	1	3	2	3	2	3	1	2
	P.M. 3	1	3	4	4	3	1	5	5	3
	P.M. 4	1	2	1	1	5	2	1	3	4
FX-100	P.M. 1		1	1	1	1	1	2	1	1
	P.M. 2		1	1	1	3	1	1	1	1
	P.M. 3		2	1	1	1	1	1	1	2
	P.M. 4		2	1	1	2	2	1	1	1
R-2000	P.M. 1		1	1	1	1	1	1	2	1
	P.M. 2		2	1	1	2	3	2	1	1
	P.M. 3		1	1	1	1	3	2	2	1
	P.M. 4		1	1	2	1	2	1	3	1

†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).

Table D12. Retail appearance[†††] scores for panelist#4 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	7	5	7	4	4	4	3	7	5
	P.M. 2	7	7	5	6	3	6	3	7	5
	P.M. 3	7	5	3	3	3	7	2	3	5
	P.M. 4	7	6	7	6	2	6	7	4	2
FX-100	P.M. 1		7	7	7	6	7	6	7	7
	P.M. 2		7	6	7	5	7	7	7	7
	P.M. 3		6	7	7	7	7	7	7	6
	P.M. 4		6	7	7	6	6	7	7	7
R-2000	P.M. 1		5	7	7	7	7	7	4	7
	P.M. 2		4	6	7	6	6	6	7	7
	P.M. 3		7	7	6	6	5	6	3	7
	P.M. 4		7	7	6	7	6	7	2	7

††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table D13. Color† scores for panelist#5 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type & replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	6	6	6	6	6	5	7	7	7
	P.M. 2	6	6	6	6	6	5	6	6	6
	P.M. 3	6	6	6	6	6	5	0	7	6
	P.M. 4	6	6	6	6	6	5	6	7	6
FX-100	P.M. 1		6	7	6	6	6	6	6	7
	P.M. 2		6	7	6	6	6	6	6	6
	P.M. 3		6	7	6	6	6	7	6	6
	P.M. 4		6	7	6	6	6	7	6	6
R-2000	P.M. 1		6	6	6	6	6	6	5	6
	P.M. 2		6	6	6	6	6	6	5	6
	P.M. 3		7	6	7	6	6	6	5	6
	P.M. 4		7	6	6	6	6	6	5	6

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.

Table D14. Discoloration†† scores for panelist#5 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type and replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	1	3	2	3	4	3	5	2	3
	P.M. 2	1	2	5	4	3	2	4	1	4
	P.M. 3	1	4	4	5	3	1	7	6	4
	P.M. 4	1	4	3	4	4	3	3	6	5
FX-100	P.M. 1		1	1	1	1	1	1	1	2
	P.M. 2		1	2	1	1	2	1	1	2
	P.M. 3		2	2	2	1	3	1	1	1
	P.M. 4		2	1	1	1	4	1	1	2
R-2000	P.M. 1		1	2	2	2	2	1	2	2
	P.M. 2		2	2	2	2	1	1	3	1
	P.M. 3		1	1	1	1	1	1	2	1
	P.M. 4		1	1	2	1	1	1	2	1

†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).

Table D15. Retail appearance[†††] scores for panelist#5 for beef (*psoas major*, PM) steaks stored under 100% N_2 atmosphere for up to 8 days (Transient discoloration study).

Treatment	Meat-type & replicate #	Day								
		0	1	2	3	4	5	6	7	8
Control	P.M. 1	7	5	6	4	3	5	3	5	4
	P.M. 2	7	6	2	3	4	6	3	6	3
	P.M. 3	7	4	2	2	4	6	1	2	2
	P.M. 4	7	4	4	2	3	4	3	2	2
FX-100	P.M. 1		7	7	6	7	7	7	7	5
	P.M. 2		7	6	6	7	5	7	7	5
	P.M. 3		6	6	5	7	5	6	7	6
	P.M. 4		6	7	6	7	4	6	7	6
R-2000	P.M. 1		7	6	6	5	6	7	6	5
	P.M. 2		6	5	5	5	7	7	5	6
	P.M. 3		6	6	6	6	7	7	6	7
	P.M. 4		6	6	5	7	7	7	6	7

† Color scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red.
†† Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
††† Retail acceptability scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

APPENDIX E

Table E1. Estimation of chemical states of myoglobin on the surface of beef (*psoas major*, PM) steaks using reflectance data as obtained by reflectance spectrophotometer (Transient discoloration study).

Treat	Day	Meat-type & replicate #	Reflectance values at wavelength (nm) of																				Color**			% of chemical states of myoglobin		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met-	deoxy-	oxy-
Control	0	pm1	14.1	13.4	12.2	11.5	12.3	14.2	16.5	17.2	16.0	13.6	14.2	13.7	21.2	28.4	32.2	34.6	36.6	38.3	39.3	39.2	49.9	18.7	9.0	5.5	0.0	94.5
	0	pm2	15.1	14.2	12.7	11.9	12.9	15.1	17.6	18.5	17.2	14.5	15.1	14.6	23.2	30.8	34.6	37.4	39.4	41.0	41.9	41.8	51.5	19.6	9.7	1.8	0.0	98.2
	0	pm3	15.1	14.3	13.0	12.2	13.1	15.1	17.1	17.9	16.8	14.4	15.0	14.4	22.6	29.7	33.2	36.1	38.4	40.0	40.9	40.8	51.0	18.9	9.1	6.8	0.0	93.2
	0	pm4	14.8	14.1	12.5	11.6	12.8	15.2	17.6	18.5	17.2	14.5	15.1	14.5	23.1	30.4	34.0	36.2	37.7	39.0	39.7	39.5	51.4	19.0	9.6	0.0	0.0	100.0
Control	1	pm1	11.9	10.9	8.8	7.8	9.1	11.7	14.6	15.5	14.0	10.8	11.6	11.0	20.4	28.2	31.9	33.9	35.4	36.6	37.2	36.7	47.5	22.6	11.8	0.0	4.0	96.0
	1	pm2	12.2	11.3	9.3	8.3	9.6	12.2	15.1	15.9	14.5	11.4	12.1	11.5	20.6	28.3	32.1	34.2	35.9	37.3	38.0	37.7	48.1	21.8	11.3	0.0	2.8	97.2
	1	pm3	14.6	13.2	11.6	11.1	13.1	15.7	17.3	17.4	16.9	15.2	16.6	16.0	23.6	27.8	29.9	35.4	40.8	42.9	43.5	43.1	51.6	16.1	9.8	43.7	0.0	56.3
	1	pm4	11.5	10.6	9.1	8.3	9.4	11.6	14.1	14.7	13.5	11.0	11.7	11.2	19.3	26.3	29.9	32.8	35.1	36.7	37.6	37.5	46.9	21.1	10.9	0.0	3.1	96.9
FX-100	1	pm1	12.6	11.9	10.7	10.1	10.7	12.7	15.1	15.4	13.9	12.0	12.2	12.0	17.6	23.9	27.5	29.6	31.6	33.4	34.5	34.4	46.6	17.0	7.4	7.4	27.0	65.7
	1	pm2	10.4	9.9	8.8	8.3	8.9	10.3	12.0	12.6	11.7	9.8	10.3	9.9	16.5	22.8	26.2	28.0	29.6	31.0	31.8	31.7	44.1	19.8	9.7	5.3	0.0	94.7
	1	pm3	14.1	13.3	12.0	11.3	12.0	13.8	15.9	16.7	15.6	13.2	13.7	13.3	21.3	28.7	32.4	34.6	36.3	37.7	38.5	38.2	49.6	19.7	9.5	4.3	0.0	95.8
	1	pm4	13.9	13.2	12.0	11.4	12.0	13.7	15.6	16.2	15.2	13.1	13.6	13.2	20.2	26.9	30.5	32.5	34.2	35.7	36.6	36.4	48.8	18.3	8.6	10.0	0.0	90.1
R-2000	1	pm1	12.1	11.4	9.5	8.7	9.9	12.7	15.5	16.7	15.2	11.8	12.6	11.9	23.1	31.6	35.6	37.7	39.2	40.5	41.1	40.7	49.7	24.1	12.9	0.0	0.0	100.0
	1	pm2	12.0	11.1	9.2	8.2	9.6	12.4	15.3	16.5	15.0	11.6	12.5	11.7	23.0	31.6	35.7	37.8	39.3	40.6	41.3	41.1	49.5	24.6	13.4	0.0	0.0	100.0
	1	pm3	14.0	13.2	12.0	11.3	12.1	14.3	16.9	17.1	15.5	13.5	13.7	13.6	19.1	25.7	29.6	32.2	34.7	36.9	38.4	38.7	48.7	16.4	7.1	9.4	29.3	61.3
	1	pm4	11.2	10.6	9.5	8.9	9.7	11.6	14.0	14.7	13.5	11.2	11.7	11.3	18.6	25.6	29.5	31.6	33.5	35.1	36.2	36.1	46.7	20.2	10.2	1.3	0.0	98.7
Control	2	pm1	11.1	10.3	8.9	8.2	8.8	10.7	13.1	13.5	12.1	9.9	10.3	10.0	16.2	22.7	26.2	28.2	30.0	31.8	32.8	32.8	44.2	19.2	8.6	0.0	28.3	71.7
	2	pm2	13.0	11.8	10.7	10.3	11.5	13.4	14.7	14.8	14.3	12.9	13.8	13.4	19.9	23.8	25.6	30.4	35.3	37.3	37.9	37.4	47.9	15.7	8.7	39.4	0.0	60.6
	2	pm3	10.5	9.8	8.5	7.9	8.9	11.2	13.7	14.1	12.7	10.6	11.0	10.7	17.3	23.9	27.5	30.3	32.9	34.9	36.1	36.2	45.4	19.5	9.6	1.2	18.1	80.8
	2	pm4	10.4	9.7	8.4	7.7	8.5	10.6	13.2	13.5	12.0	9.9	10.2	9.9	16.1	22.6	26.2	28.3	30.3	32.1	33.2	33.2	44.1	19.3	8.7	0.0	31.7	68.3
FX-100	2	pm1	13.5	12.8	10.4	9.1	10.8	14.1	17.3	18.2	16.6	13.2	14.0	13.3	23.0	30.7	34.5	36.7	38.7	40.6	41.7	41.8	50.6	20.9	11.1	0.0	5.7	94.3
	2	pm2	12.5	11.9	11.0	10.4	10.8	12.0	13.4	13.9	13.1	11.5	11.9	11.6	17.5	23.5	26.6	28.4	30.1	31.5	32.3	32.2	45.9	17.5	8.0	16.7	0.0	83.3
	2	pm3	13.0	12.5	11.6	11.1	11.6	13.0	14.8	15.3	14.4	12.6	13.0	12.7	18.7	24.9	28.4	30.7	32.9	34.7	35.9	36.0	47.6	17.2	8.0	15.6	0.0	84.4
	2	pm4	12.3	11.6	10.5	9.9	10.4	11.9	13.7	14.4	13.5	11.5	12.0	11.6	18.6	25.3	28.7	30.7	32.4	33.8	34.6	34.4	46.7	19.4	9.5	9.5	0.0	90.5
R-2000	2	pm1	12.5	11.7	9.6	8.5	9.9	12.4	14.9	15.9	14.6	11.6	12.4	11.7	21.5	29.0	32.6	34.3	35.5	36.1	36.2	35.3	48.5	22.1	11.7	0.0	0.0	100.0
	2	pm2	12.0	11.2	9.3	8.3	9.5	12.0	14.7	15.7	14.4	11.1	12.0	11.2	22.1	30.6	34.6	36.7	38.5	39.9	40.6	40.3	48.7	24.6	13.0	0.0	0.0	100.0
	2	pm3	11.1	10.4	8.8	8.1	9.1	11.5	14.0	15.0	13.7	10.8	11.5	10.9	20.2	28.0	32.0	34.1	35.9	37.3	38.1	37.8	47.4	22.9	12.1	0.0	0.0	100.0
	2	pm4	13.8	13.2	11.7	10.8	12.0	14.3	16.6	17.5	16.3	13.5	14.2	13.6	22.1	29.0	32.5	34.3	35.7	36.9	37.4	37.2	50.1	19.0	9.6	0.0	0.0	100.0
Control	3	pm1	13.5	12.2	11.0	10.8	12.6	14.9	16.4	16.4	15.8	14.2	15.1	14.7	21.1	25.5	27.7	32.1	35.9	37.5	38.0	37.5	49.6	15.3	8.3	35.8	4.3	59.9
	3	pm2	10.9	10.3	9.0	8.3	9.1	11.0	13.3	13.8	12.4	10.2	10.6	10.2	16.6	23.0	26.6	28.6	30.3	31.9	32.9	32.9	44.6	19.0	8.6	0.0	18.3	81.7

Treat	Day	Meat-type & replicate #	Reflectance values at wavelength (nm) of																				Color**			% of chemical states of myoglobin		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met-	deoxy-	oxy-
	3	pm3	13.5	12.6	11.4	11.0	12.3	14.7	16.7	16.9	15.9	14.2	14.9	14.6	20.8	25.9	28.5	32.9	37.2	39.5	40.5	40.3	49.7	15.6	8.4	30.7	7.6	61.7
	3	pm4	14.1	13.0	12.0	11.5	12.6	14.5	16.2	16.5	15.6	13.9	14.6	14.1	20.2	25.1	27.8	31.5	34.6	36.3	37.1	36.9	49.1	15.3	7.5	24.5	0.9	74.6
FX-100	3	pm1	14.4	13.6	12.2	11.4	12.1	13.9	16.1	16.6	15.4	13.2	13.7	13.3	20.3	27.3	31.1	33.5	35.5	37.3	38.4	38.3	49.1	18.5	8.5	7.1	5.9	87.0
	3	pm2	13.7	12.9	11.6	10.9	11.6	13.2	15.1	15.8	14.8	12.6	13.2	12.7	20.5	27.8	31.4	33.4	35.2	37.0	38.1	38.0	48.7	19.9	9.5	9.2	0.0	90.8
	3	pm3	11.8	11.0	9.6	8.9	9.7	11.7	14.1	14.7	13.4	11.0	11.5	11.2	18.5	25.7	29.6	31.8	33.6	35.5	36.7	36.9	46.6	20.4	10.0	0.0	8.4	91.6
	3	pm4	13.7	13.0	11.9	11.3	12.0	13.7	15.6	16.3	15.2	13.1	13.5	13.1	20.3	27.3	30.9	33.4	35.4	37.3	38.5	38.5	48.9	18.7	8.8	8.9	0.0	91.1
R-2000	3	pm1	11.4	10.6	8.9	8.0	9.1	11.5	14.2	15.0	13.5	10.6	11.2	10.6	19.7	27.5	31.3	33.5	35.2	36.9	37.9	37.8	46.9	22.7	11.3	0.0	10.4	89.6
	3	pm2	12.7	12.0	9.9	8.9	10.2	13.1	16.1	17.1	15.5	12.2	13.0	12.4	22.6	31.2	35.4	37.7	39.5	41.4	42.5	42.4	49.9	23.2	12.2	0.0	1.6	98.4
	3	pm3	13.0	12.3	10.1	9.0	10.8	14.3	17.9	18.6	16.9	13.5	14.3	13.7	23.0	31.0	35.0	37.3	39.1	40.8	41.7	41.6	50.9	20.6	11.2	0.0	12.7	87.3
	3	pm4	14.9	14.0	11.7	10.7	12.1	15.3	18.5	19.6	18.0	14.3	15.2	14.4	25.6	34.3	38.5	40.7	42.3	43.7	44.5	44.2	52.7	22.4	11.7	0.0	0.0	100.0
Control	4	pm1	15.1	14.0	12.3	11.5	12.9	15.3	17.6	18.1	16.9	14.6	15.3	14.8	22.4	28.8	32.2	35.7	38.6	40.5	41.5	41.4	51.0	17.8	8.9	11.2	4.2	84.6
	4	pm2	12.3	11.6	10.3	9.6	10.4	12.8	15.6	16.2	14.5	12.1	12.5	12.2	19.0	26.6	30.9	33.5	35.5	37.4	38.7	38.9	47.8	19.5	9.2	0.0	20.8	79.2
	4	pm3	13.1	12.4	11.0	10.2	11.2	13.6	16.5	17.0	15.3	13.0	13.3	13.1	19.8	27.0	31.0	33.6	35.7	37.6	38.9	39.0	48.8	18.4	8.7	2.3	22.0	75.8
	4	pm4	14.6	13.8	12.3	11.5	12.6	15.0	17.5	18.2	16.8	14.3	14.8	14.4	22.0	29.1	33.0	35.7	37.7	39.4	40.4	40.3	50.8	18.4	9.0	5.5	5.5	89.1
FX-100	4	pm1	13.0	12.2	10.9	10.1	10.9	12.7	14.9	15.6	14.3	12.1	12.5	12.1	19.1	25.7	29.2	31.3	32.7	34.2	35.0	34.8	47.5	18.5	8.7	1.8	3.5	94.7
	4	pm2	11.3	10.7	9.2	8.5	9.5	11.6	14.0	14.8	13.5	10.9	11.5	11.0	18.9	25.8	29.6	31.7	33.2	34.6	35.5	35.3	46.6	20.6	10.3	0.0	0.4	99.6
	4	pm3	13.7	12.9	11.8	11.2	11.8	14.1	16.9	17.1	15.3	13.3	13.4	13.3	19.0	26.1	30.3	33.0	35.3	37.5	39.0	39.3	48.6	17.3	7.2	6.6	38.7	54.7
	4	pm4	14.1	13.2	11.8	11.0	11.9	14.6	17.6	17.9	16.1	13.8	14.1	13.9	20.3	27.5	31.6	34.5	36.8	38.9	40.3	40.5	49.7	17.7	8.0	4.0	31.5	64.5
R-2000	4	pm1	14.6	13.7	12.3	11.5	12.4	14.5	17.0	17.6	16.1	13.8	14.2	13.8	20.8	27.9	31.9	34.4	36.2	37.9	39.0	39.0	49.8	18.1	8.3	4.1	11.7	84.2
	4	pm2	13.7	13.0	11.2	10.4	11.5	14.0	16.8	17.5	16.1	13.3	13.9	13.4	21.5	29.1	33.2	35.8	37.8	39.7	40.9	40.8	50.0	19.8	9.9	0.0	5.3	94.7
	4	pm3	16.4	15.8	13.4	12.1	14.0	17.6	21.1	21.9	20.3	16.8	17.6	16.9	26.9	34.4	37.9	40.3	41.9	43.2	43.8	43.4	54.6	18.7	10.1	0.0	2.3	97.7
	4	pm4	14.5	13.8	12.3	11.5	12.4	14.6	17.2	17.8	16.3	13.8	14.3	13.9	21.2	28.5	32.4	34.8	36.7	38.4	39.4	39.2	54.6	18.7	10.1	3.2	13.4	83.3
Control	5	pm1	14.0	13.3	11.9	11.3	12.2	14.4	16.8	17.5	16.2	13.8	14.4	13.9	21.8	28.9	32.5	35.4	37.6	39.4	40.3	40.3	50.3	18.9	9.4	6.2	0.0	93.8
	5	pm2	16.5	15.7	14.4	13.7	14.6	16.5	18.5	19.3	18.1	15.8	16.3	15.8	23.8	31.1	34.8	37.2	38.9	40.4	41.2	41.0	52.5	18.1	8.5	9.1	0.0	90.9
	5	pm3	12.0	11.3	10.1	9.6	10.4	12.8	15.4	15.8	14.4	12.2	12.6	12.3	18.6	25.6	29.5	32.4	34.8	36.9	38.2	38.4	47.6	18.4	8.8	5.1	19.7	75.2
	5	pm4	15.3	14.6	13.2	12.4	13.4	15.6	17.9	18.7	17.5	15.0	15.5	15.0	23.3	30.7	34.5	36.9	38.7	40.4	41.4	41.3	51.8	18.9	9.3	5.2	0.0	94.8
FX-100	5	pm1	15.4	14.5	12.5	11.4	12.7	15.1	17.8	18.5	17.2	14.3	15.1	14.4	23.2	30.7	34.5	36.7	38.4	39.8	40.7	40.5	51.4	19.5	9.7	0.0	0.0	100.0
	5	pm2	13.5	12.7	11.1	10.2	11.2	13.5	16.1	16.8	15.5	12.9	13.5	13.0	20.8	28.2	31.9	34.2	36.1	37.7	38.8	38.8	49.2	19.5	9.8	0.0	0.2	99.8
	5	pm3	13.6	13.0	11.9	11.3	11.9	13.5	15.3	15.9	14.8	12.9	13.3	13.0	19.4	26.0	29.5	31.7	33.6	35.5	36.6	36.7	48.3	17.7	8.1	12.3	0.0	87.7
	5	pm4	14.1	13.5	12.3	11.6	12.3	14.2	16.2	16.8	15.6	13.6	14.0	13.7	20.3	26.7	30.0	32.5	34.5	36.4	37.5	37.4	49.2	17.2	8.1	12.2	1.0	86.8
R-2000	5	pm1	14.1	13.3	11.8	11.0	11.9	14.0	16.3	16.8	15.5	13.3	13.7	13.4	20.2	26.9	30.6	33.0	35.0	36.7	37.8	37.7	49.0	17.8	8.4	6.1	9.1	84.8
	5	pm2	13.1	12.3	10.6	9.8	10.8	13.0	15.3	16.1	14.9	12.2	12.8	12.3	21.0	28.4	31.9	33.9	35.2	36.4	37.1	36.8	48.7	20.8	10.3	0.0	0.0	100.0
	5	pm3	15.1	14.4	12.6	11.7	12.8	15.2	17.7	18.5	17.2	14.4	15.1	14.4	23.4	30.9	34.6	36.7	38.3	39.6	40.3	40.0	51.5	19.6	9.7	0.0	0.0	100.0
	5	pm4	14.4	13.7	12.2	11.4	12.3	14.3	16.5	17.2	15.9	13.5	14.0	13.5	21.0	27.4	30.9	32.8	34.2	35.4	36.0	35.6	49.5	17.8	8.3	2.7	1.6	95.7

Treat	Day	Meat-type & replicate #	Reflectance values at wavelength (nm) of																				Color**			% of chemical states of myoglobin		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met-	deoxy-	oxy-
Control	6	pm1	14.8	13.9	12.6	11.9	13.1	15.3	17.4	17.9	16.9	14.7	15.3	14.9	22.1	28.4	31.5	35.2	38.8	40.8	41.8	41.6	50.9	17.3	8.6	15.5	0.0	84.5
	6	pm2	13.1	12.4	10.7	9.9	11.1	13.7	16.5	17.4	15.9	13.0	13.7	13.1	22.0	29.7	33.6	36.1	38.3	40.0	41.1	41.1	49.9	20.6	10.6	0.0	0.0	100.0
	6	pm3	15.4	14.4	13.2	12.7	13.9	16.0	17.4	17.6	16.9	15.4	16.1	15.7	22.1	26.1	27.9	32.8	38.3	40.8	41.7	41.5	50.8	14.2	7.4	32.6	0.0	67.4
	6	pm4	14.1	13.4	12.0	11.3	12.2	14.5	16.9	17.7	16.3	13.8	14.3	13.9	22.0	29.7	33.6	35.9	38.2	40.1	41.4	41.6	50.5	19.6	9.6	1.4	1.0	97.6
FX-100	6	pm1	15.2	14.6	13.1	12.2	13.4	15.8	18.4	19.1	17.7	15.1	15.6	15.1	23.2	30.5	34.3	36.5	38.5	40.3	41.3	41.3	51.8	18.3	8.9	2.1	0.9	97.1
	6	pm2	13.9	13.3	12.2	11.5	12.2	13.9	16.0	16.6	15.3	13.2	13.6	13.2	19.6	26.2	30.1	32.4	34.4	36.3	37.4	37.4	48.7	17.4	7.8	7.5	5.7	86.8
	6	pm3	13.5	13.1	12.1	11.5	12.1	13.8	16.0	16.5	15.2	13.3	13.6	13.3	19.6	26.3	30.1	32.5	34.6	36.5	37.7	37.7	48.7	17.5	7.9	10.5	5.9	83.7
	6	pm4	13.3	12.8	11.9	11.3	11.8	13.7	15.9	16.0	14.6	13.0	13.1	13.0	17.6	23.5	27.2	29.6	31.9	33.9	35.2	35.3	47.4	15.1	6.2	15.6	28.8	55.6
R-2000	6	pm1	13.9	13.2	11.2	10.3	11.6	14.2	16.9	17.8	16.4	13.3	14.0	13.4	22.9	30.8	34.6	36.7	38.3	39.6	40.2	39.8	50.6	21.1	10.7	0.0	0.0	100.0
	6	pm2	13.9	13.1	11.0	10.0	11.4	14.2	17.0	18.0	16.6	13.3	14.1	13.4	23.9	32.0	35.8	37.9	39.5	40.6	41.2	40.7	51.0	22.1	11.5	0.0	0.0	100.0
	6	pm3	14.8	14.1	11.9	10.9	12.3	15.2	18.1	19.2	17.7	14.3	15.1	14.4	25.4	33.6	37.4	39.5	41.1	42.3	42.9	42.5	52.4	21.9	11.4	0.0	0.0	100.0
	6	pm4	16.5	15.7	13.9	13.0	14.0	16.1	18.4	19.2	18.0	15.2	15.8	15.2	24.5	31.7	35.3	37.2	38.6	39.7	40.1	39.6	52.4	19.3	9.1	0.0	0.0	100.0
Control	7	pm1	14.2	13.5	12.2	11.5	12.3	14.4	16.9	17.5	16.1	13.8	14.1	13.8	20.5	27.6	31.7	34.1	35.9	37.7	38.9	38.9	49.7	17.8	8.2	4.3	10.4	85.4
	7	pm2	13.2	12.5	11.2	10.5	11.4	13.8	16.5	17.1	15.5	13.1	13.5	13.2	20.3	27.8	31.8	34.5	36.7	38.8	40.0	40.1	49.2	19.0	9.0	1.3	16.4	82.3
	7	pm3	14.5	13.4	12.3	11.9	13.0	14.9	16.3	16.4	15.9	14.4	15.1	14.7	20.8	24.6	26.2	31.5	37.2	39.7	40.5	40.2	49.4	14.2	7.5	34.0	0.0	66.0
	7	pm4	15.2	14.3	12.8	12.2	13.9	16.4	18.2	18.6	17.7	15.7	16.6	16.0	23.4	28.3	30.5	34.7	38.9	41.1	42.0	41.9	51.8	15.5	8.4	24.9	0.0	75.2
FX-100	7	pm1	13.2	12.5	11.3	10.7	11.4	13.4	15.7	16.4	15.1	12.8	13.3	12.9	20.0	27.2	31.2	33.8	36.1	38.2	39.6	39.9	48.7	19.0	9.1	5.3	1.6	93.2
	7	pm2	13.1	12.4	10.4	9.4	10.8	13.5	16.6	17.4	15.9	12.9	13.6	13.0	21.7	29.4	33.3	35.6	37.4	39.1	40.2	40.2	49.7	20.5	10.7	0.0	4.2	95.8
	7	pm3	13.9	13.2	12.0	11.3	12.1	14.0	16.2	16.9	15.7	13.4	13.9	13.5	20.9	28.0	31.8	34.1	35.9	37.7	38.9	38.9	49.5	18.8	9.1	7.4	0.0	92.6
	7	pm4	13.6	12.9	11.5	10.7	11.7	13.9	16.5	17.2	15.7	13.2	13.7	13.2	20.7	28.0	31.9	34.2	36.0	37.8	38.8	38.8	49.4	18.9	9.0	0.0	6.9	93.2
R-2000	7	pm1	15.9	14.9	12.6	11.5	12.9	15.9	18.9	20.0	18.4	14.8	15.7	14.9	26.0	34.9	39.0	41.3	42.9	44.4	45.2	44.8	53.3	22.2	11.3	0.0	0.0	100.0
	7	pm2	14.2	13.3	11.6	10.7	11.7	14.0	16.3	17.1	15.8	13.1	13.7	13.1	21.6	28.9	32.4	34.6	36.2	37.7	38.6	38.4	49.6	19.8	9.5	0.0	0.9	99.1
	7	pm3	15.3	14.6	12.7	11.7	13.0	15.8	18.5	19.5	18.0	14.8	15.5	14.8	25.1	33.5	37.6	40.0	41.8	43.4	44.3	43.9	52.7	21.3	10.6	0.0	0.0	100.0
	7	pm4	12.0	11.1	8.8	7.7	9.2	12.2	15.3	16.3	14.7	11.2	12.0	11.2	22.0	30.4	34.2	36.3	37.9	39.4	40.2	39.9	48.7	24.0	12.6	0.0	4.9	95.1
Control	8	pm1	16.7	15.6	13.3	12.1	13.8	16.7	19.7	20.0	18.5	15.8	16.4	15.9	23.2	29.7	33.1	35.4	37.1	38.6	39.5	39.4	52.2	16.2	7.9	3.9	19.7	76.4
	8	pm2	12.9	11.9	10.4	9.7	10.8	13.0	15.0	15.6	14.5	12.2	12.9	12.5	19.9	25.8	28.9	31.9	34.5	36.1	36.8	36.5	47.9	18.4	9.3	10.7	4.1	85.2
	8	pm3	14.3	13.5	12.0	11.1	12.1	14.3	16.6	17.4	16.0	13.5	14.0	13.5	21.0	27.6	31.3	33.3	34.8	36.2	37.0	36.8	49.6	18.0	8.5	0.5	2.2	97.4
	8	pm4	14.9	14.1	12.3	11.5	13.0	15.6	17.9	18.6	17.3	14.7	15.4	14.8	23.3	29.7	32.9	35.7	37.8	39.2	39.8	39.5	51.4	18.1	9.2	5.7	0.9	93.5
FX-100	8	pm1	11.5	10.9	9.9	9.3	9.9	11.6	13.6	14.2	13.1	11.1	11.5	11.1	17.3	23.5	27.0	29.0	30.7	32.3	33.4	33.4	45.6	18.1	8.5	5.2	2.6	92.2
	8	pm2	16.9	16.4	14.2	13.0	14.7	17.8	20.8	21.8	20.5	17.1	18.0	17.2	27.5	35.4	39.1	41.3	42.8	44.2	45.0	44.6	55.1	19.3	10.5	0.0	0.0	100.0
	8	pm3	13.6	13.1	12.1	11.5	12.2	13.8	15.6	16.2	15.2	13.2	13.6	13.2	19.5	25.8	29.3	31.4	33.0	34.6	35.6	35.6	48.5	16.9	7.8	11.2	0.0	88.8
	8	pm4	16.4	15.6	13.9	12.9	13.9	16.1	18.4	19.3	18.1	15.3	16.0	15.4	24.9	32.7	36.2	38.2	39.5	40.8	41.4	41.0	52.7	19.9	9.7	1.1	0.0	98.9
R-2000	8	pm1	14.4	13.8	12.4	11.6	12.5	14.8	17.2	18.0	16.7	14.2	14.7	14.3	21.9	29.2	33.1	35.5	37.4	39.2	40.3	40.3	50.7	18.6	9.2	5.0	0.0	95.0
	8	pm2	14.5	13.8	12.3	11.5	12.4	14.5	16.8	17.5	16.2	13.7	14.2	13.7	21.2	27.8	31.5	33.4	34.8	36.2	36.9	36.6	49.8	17.9	8.3	1.2	3.9	94.9

Treat	Day	Meat-type & replicate #	Reflectance values at wavelength (nm) of																				Color**			% of chemical states of myoglobin		
			360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740	L	A	B	met-	deoxy-	oxy-
	8	pm3	14.3	13.8	12.4	11.6	12.5	14.6	16.8	17.5	16.3	13.9	14.4	13.9	21.6	28.7	32.4	34.7	36.5	38.3	39.3	39.2	50.2	18.6	8.9	4.0	0.0	96.0
	8	pm4	15.0	14.3	12.7	11.8	12.7	14.9	17.1	17.8	16.4	13.9	14.3	13.8	21.3	28.0	31.6	33.6	35.0	36.3	36.9	36.5	49.9	17.8	7.9	0.0	9.3	90.7

** Hunterlab scale.

APPENDIX F

Table F1 Visual† scores for panelist #1 for beef (*psoas major*, P.M.) (shelf-life study).

	BAG #, MEAT-TYPE & REPLICATE #	WEEK 0					WEEK 1					WEEK 2					WEEK 3				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	7	7	8		6	7	0				5				6	7	7	7	7
	#1 P. M. 2	6	6	6	7		6	0	0				5				6	7	7	7	7
	#1 P. M. 3	6	7	7	8		5						6				7	6	6	6	6
	#1 P. M. 4	5					6	6	0								7				
	#2 P. M. 1	6	7	7	8		6	0	0				6				7	7	7	7	7
	#2 P. M. 2	5	6	7	8		5	6	0				6				7	6	6	6	7
	#2 P. M. 3	6	7	6	8		6						7				6	7	6	6	7
	#2 P. M. 4	6					6	6	0								7				
Discoloration	#1 P. M. 1	1	1	1	2		1	6	7				2				1	3	5	6	6
	#1 P. M. 2	1	1	1	2		1	7	7				1				1	3	5	6	6
	#1 P. M. 3	1	1	1	2		1						2				1	2	4	5	6
	#1 P. M. 4	1					1	6	7								1				
	#2 P. M. 1	1	1	1	2		1	7	7				3				1	3	5	6	6
	#2 P. M. 2	1	1	1	2		1	5	7				2				1	2	5	6	6
	#2 P. M. 3	1	1	1	2		1						2				1	2	4	5	5
	#2 P. M. 4	1					1	5	7								1				
Acceptance	#1 P. M. 1	7	6	7	7		6	1	1				5				7	4	2	1	1
	#1 P. M. 2	7	7	7	7		6	1	1				5				7	3	2	1	1
	#1 P. M. 3	7	7	7	7		7						5				7	5	3	2	1
	#1 P. M. 4	7					6	1	1								7				
	#2 P. M. 1	7	7	7	7		6	1	1				4				7	4	2	1	1
	#2 P. M. 2	7	7	7	7		7	2	1				5				7	5	2	2	1
	#2 P. M. 3	7	7	7	7		7						5				7	5	3	2	2
	#2 P. M. 4	7					6	2	1								7				

Table F1 Visual† scores for panelist #1for beef (*psoas major*, P.M.) (shelf-life study).

	BAG#, MEAT-TYPE, & REPLICATE #	WEEK 4					WEEK 5					WEEK 6					WEEK 7				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	5	6	6	7	7	5	6	6	6	6	6	6	6	6	0	6	6	7	7	7
	#1 P. M. 2	5	6	6	6	6	5	6	6	6	6	6	6	6	6	7	6	6	7	7	7
	#1 P. M. 3	5	6	6	6	6	5	7	7	7	7	5	5	5	5	5	6	5	6	7	7
	#1 P. M. 4	5					5					6					6				
	#2 P. M. 1	5	7	7	7	7	6	7	7	7	7	7	6	7	7	7	6	6	6	6	6
	#2 P. M. 2	5	7	7	7	7	6	6	6	7	7	5	6	6	6	7	6	5	6	6	6
	#2 P. M. 3	5	7	6	6	6	5	6	6	6	7	6	7	6	6	6	6	5	6	6	6
	#2 P. M. 4	6					5					6					6				
Discoloration	#1 P. M. 1	3	1	4	5	6	1	1	4	4	6	1	3	4	6	7	1	2	3	6	4
	#1 P. M. 2	3	2	3	4	5	1	1	3	4	5	1	2	3	4	6	1	2	3	5	5
	#1 P. M. 3	2	2	4	5	6	1	3	5	6	6	1	1	3	4	4	1	2	3	5	4
	#1 P. M. 4	3					1					1					1				
	#2 P. M. 1	2	3	5	6	6	1	2	5	6	6	1	3	5	5	6	1	2	2	4	3
	#2 P. M. 2	2	3	5	6	6	1	2	3	4	5	1	3	4	4	6	1	2	3	5	4
	#2 P. M. 3	2	2	4	5	5	1	3	4	4	5	1	3	4	4	6	1	2	2	3	3
	#2 P. M. 4	2					1					1					1				
Acceptance	#1 P. M. 1	6	6	4	2	1	7	6	4	3	2	7	4	3	1	1	6	4	3	1	2
	#1 P. M. 2	6	5	4	3	2	7	6	4	3	3	7	5	3	2	2	6	3	3	2	2
	#1 P. M. 3	6	5	3	3	1	7	3	2	1	1	6	4	4	2	2	6	3	3	2	2
	#1 P. M. 4	6					7					7					6				
	#2 P. M. 1	6	4	2	2	1	7	4	3	1	1	6	4	2	2	2	6	4	4	3	3
	#2 P. M. 2	6	4	2	3	1	7	5	3	3	2	7	4	3	2	2	6	4	3	2	2
	#2 P. M. 3	6	5	4	4	2	7	4	3	3	2	6	4	3	3	2	6	4	5	4	3
	#2 P. M. 4	6					7					6					6				

Table F1 Visual† scores for panelist #1 for beef (*psoas major*, P.M.) (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8					WEEK 9					WEEK 10				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	6	7	7	7	5	5	6	6		6	6	6	6	6
	#1 P. M. 2	6	6	7	7	7	5	5	5	6		5	6	6	7	7
	#1 P. M. 3	6	6	6	6	7	5	5	6	6		6	6	6	6	6
	#1 P. M. 4	6					5					6				
	#2 P. M. 1	5	6	6	7	7	5	6	5	6		5	5	6	6	6
	#2 P. M. 2	6	6	6	7	6	5	5	6	7		5	5	5	6	6
	#2 P. M. 3	6	7	7	7	7	5	6	6	6		5	5	6	6	7
	#2 P. M. 4	6					5					6				
Discoloration	#1 P. M. 1	2	4	5	7	7	1	2	4	5		1	4	5	5	6
	#1 P. M. 2	1	2	2	6	3	1	2	4	5		1	5	6	6	6
	#1 P. M. 3	1	2	3	4	4	1	2	6	6		1	4	4	5	5
	#1 P. M. 4	2					1					1				
	#2 P. M. 1	1	4	5	6	6	1	1	2	5		1	2	3	4	5
	#2 P. M. 2	1	2	2	4	4	1	1	3	4		1	2	3	3	4
	#2 P. M. 3	1	2	2	4	4	1	1	3	4		1	2	3	3	5
	#2 P. M. 4	1					1					1				
Acceptance	#1 P. M. 1	5	3	2	1	1	7	6	5	2		6	3	2	2	2
	#1 P. M. 2	6	5	4	2	2	7	6	5	2		6	2	2	1	1
	#1 P. M. 3	6	5	3	2	2	7	5	3	1		7	3	3	2	2
	#1 P. M. 4	5					7					7				
	#2 P. M. 1	6	3	2	1	1	7	7	6	2		6	5	4	3	2
	#2 P. M. 2	6	5	4	3	2	7	6	4	3		7	5	5	4	3
	#2 P. M. 3	6	5	3	3	2	7	7	5	3		7	5	5	4	2
	#2 P. M. 4	6					7					6				

† Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7=100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table F2 Odor†† scores for panelist #1 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0		WEEK 1		WEEK 2		WEEK 3	
DAY		0	4	0	2	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1		2	1			1	3
	#1 P. M. 2	1		2	2			1	2
	#1 P. M. 3	1		2				1	2
	#1 P. M. 4	1		1	1			1	
	#2 P. M. 1	1		1	1			1	3
	#2 P. M. 2	1		1	1			1	2
	#2 P. M. 3	1		1				1	2
	#2 P. M. 4	1		1	2			1	
Acceptability	#1 P. M. 1	1		2	1			1	3
	#1 P. M. 2	1		2	3			1	2
	#1 P. M. 3	1		2				1	2
	#1 P. M. 4	1		1	1			1	
	#2 P. M. 1	1		1	1			1	3
	#2 P. M. 2	1		1	1			1	2
	#2 P. M. 3	1		1				1	2
	#2 P. M. 4	1		1	3			1	
Description	#1 P. M. 1	.		2	.			.	3
	#1 P. M. 2	.		2	2			.	3
	#1 P. M. 3	.		2				.	3
	#1 P. M. 4	.		.	.			.	
	#2 P. M. 1	.		.	.			.	4
	#2 P. M. 2	.		.	.			.	4
	#2 P. M. 3	.		.				.	4
	#2 P. M. 4	.		.	2			.	

Table F2 Odor†† scores for panelist #1 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4		WEEK 5		WEEK 6		WEEK 7	
DAY		0	4	0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	2	2	1	2	1	4	2	2
	#1 P.M. 2	1	2	1	2	1	3	2	2
	#1 P.M. 3	1	2	1	2	1	3	2	2
	#1 P.M. 4	2		1		1		1	
	#2 P.M. 1	1	3	1	2	1	3	1	1
	#2 P.M. 2	2	3	1	2	1	3	2	2
	#2 P.M. 3	1	2	1	2	1	3	1	2
	#2 P.M. 4	1		1		1		1	
Acceptability	#1 P.M. 1	4	2	1	3	1	4	3	2
	#1 P.M. 2	1	3	1	2	1	3	2	2
	#1 P.M. 3	1	2	1	2	1	3	2	2
	#1 P.M. 4	4		1		1		1	
	#2 P.M. 1	1	4	1	2	1	3	1	2
	#2 P.M. 2	2	4		2	1	3	2	2
	#2 P.M. 3	1	2		2	1	3	1	2
	#2 P.M. 4	1				1		1	
Description	#1 P. M. 1	2	stale		2		2	4	2
	#1 P. M. 2	1	stale		stale		2	2	2
	#1 P. M. 3	1	stale		stale		2	2	4
	#1 P. M. 4	2							
	#2 P. M. 1	1	3		4		2		
	#2 P. M. 2	2	3		4		2	2	2
	#2 P. M. 3	1	stale		stale		2		2
	#2 P. M. 4	1							

Table F2 Odor†† scores for panelist #1 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8		WEEK 9		WEEK 10	
DAY		0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	2	4	2	2	2	3
	#1 P. M. 2	2	2	1	2	2	3
	#1 P. M. 3	2	3	1	3	2	2
	#1 P. M. 4	2		1		2	
	#2 P. M. 1	3	4	1	3	2	2
	#2 P. M. 2	2	3	1	3	2	2
	#2 P. M. 3	2	2	2	3	1	2
	#2 P. M. 4	2		1		1	
Acceptability	#1 P. M. 1	2	5	2	3	2	4
	#1 P. M. 2	2	2	1	3	2	4
	#1 P. M. 3	2	4	1	4	2	3
	#1 P. M. 4	2		1		1	
	#2 P. M. 1	4	4	1	4	1	3
	#2 P. M. 2	2	3	1	4	1	3
	#2 P. M. 3	2	2	2	4	1	3
	#2 P. M. 4	2		1		1	
Description	#1 P. M. 1	2	4	2	2	2	4
	#1 P. M. 2	2	2		2	4	stle
	#1 P. M. 3	2	4		6	2	stle
	#1 P. M. 4	4				4	
	#2 P. M. 1	3	4		2	4	stle
	#2 P. M. 2	4	2		2	4	stle
	#2 P. M. 3	4	2	2	2		stle
	#2 P. M. 4	4					

†† Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable. Odor description scores were assessed using a six point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other.

Table F3 Flavor††† scores for panelist #1 for beef (*psoas major*, P.M.) steaks (shelf-life study).

		Flavour		Off Flavour Intensity		Comments	
		Green	Red	Green	Red	Green	Red
WEEK 0	DAY 0	6	6	1	1	v. good	v. good
	DAY 4						
WEEK 1	DAY 0	6	6	1	1	.	.
	DAY 2	5	4	2	2	v. good	more bland
WEEK 2	DAY 0						
	DAY 4						
WEEK 3	DAY 0	5	6	2	1	sour/liver	.
	DAY 4	3	3	3	3	sour/metal-lic	sour/metal-lic
WEEK 4	DAY 0	4	5	3	2	off	-
	DAY 4	2	3	3	2	sour,putrd	sour,putrd
WEEK 5	DAY 0	6	6	2	1	livery	v. good
	DAY 4	2	2	3	3	sour	bloody
WEEK 6	DAY 0	4	3	2	3	bloody	sour
	DAY 4	2	1	4	4	sour	putrid
WEEK 7	DAY 0	3	4	3	3	sour	sour
	DAY 4	1	1	4	4	bitter/met-allic	bitter/met-allic
WEEK 8	DAY 0	2	3	4	3	sour,met-allic	sour, met-allic
	DAY 4	1	3	4	2	livery	sour
WEEK 9	DAY 0	4	4	2	3	livery	livery
	DAY 4	1	1	3	4		bad
WEEK 10	DAY 0	1	1	4	4	bloody	bloody
	DAY 4	2	2	4	4	rotten, metallic	livery, metallic

††† The flavor was assessed using a six point descriptive scale: 6=Desirable, 5=Moderately desirable, 4=Slightly desirable, 3=Slightly undesirable, 2=Moderately undesirable, 1=Undesirable. Off flavor intensity was assessed using a four point descriptive scale: 4=Prevalent off flavor, 3=Moderate off flavor, 2=Slight off flavor, 1=No off flavor.

Table F4. Visual† score for panelist #2 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0					WEEK 1					WEEK 2					WEEK 3				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	6	7	7	7	5	5	0			5	6	7	6	6	6	6	7	6	6
	#1 P. M. 2	6	6	7	7	7	5	5	0	6		5	6	7	6	6	5	6	7	6	6
	#1 P. M. 3	6	6	7	7	7	5					5	6	7	6	6	5	6	7	6	6
	#1 P. M. 4	6					5	5	7	6		5					5				
	#2 P. M. 1	6	6	7	7	7	5	0	0			5	7	7	6	7	6	6	7	6	6
	#2 P. M. 2	6	6	7	7	7	5	5	6	6		6	7	7	6	7	6	6	7	6	6
	#2 P. M. 3	6	6	7	7	7	5					6	7	7	6	7	5	6	7	6	6
	#2 P. M. 4	6					5	5	6	6		6					5				
Discoloration	#1 P. M. 1	1	1	1	4	6	1	6	7			1	1	5	5	6	1	3	4	5	6
	#1 P. M. 2	1	1	1	1	6	1	6	7	6		1	1	5	3	6	1	2	3	5	6
	#1 P. M. 3	1	1	1	1	6	1					1	3	6	6	6	1	2	3	5	6
	#1 P. M. 4	1					2	6	6	6		1					1				
	#2 P. M. 1	1	1	1	4	5	1	7	7			1	4	5	5	6	1	2	3	4	6
	#2 P. M. 2	1	1	1	5	5	1	4	4	5		1	1	6	6	6	1	2	2	6	6
	#2 P. M. 3	1	1	1	4	6	1					1	5	6	6	6	1	1	2	3	6
	#2 P. M. 4	1					2	4	5	6		1					1				
Acceptance	#1 P. M. 1	6	5	4	5	2	7	2	2			7	6	4	3	2	6	5	3	2	1
	#1 P. M. 2	6	5	4	5	2	7	2	2	2		7	6	4	3	2	7	5	3	2	2
	#1 P. M. 3	6	5	4	5	2	7					7	5	3	2	2	7	6	4	3	2
	#1 P. M. 4	6					5	2	2	2		7					7				
	#2 P. M. 1	6	5	4	5	2	7	2	2			7	4	3	2	2	6	5	4	3	2
	#2 P. M. 2	6	5	4	5	2	7	3	2	3		7	4	3	1	2	6	5	4	3	2
	#2 P. M. 3	6	5	4	5	2	7					7	3	3	1	2	7	6	4	3	2
	#2 P. M. 4	6					5	3	2	2		7					7				

Table F4. Visual† score for panelist #2 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4					WEEK 5					WEEK 6					WEEK 7				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	5	6	6	6	7	5	6	7	7	7	5	6	7	7	0	5	6	7		7
	#1 P. M. 2	4	6	6	6	7	5	6	7	7	8	5	6	7	7	7	5	7	8		7
	#1 P. M. 3	4	6	6	6	7	5	7	7	7	8	5	6	6	6	7	5	6	7		8
	#1 P. M. 4	6					5					5					5				
	#2 P. M. 1	6	7	7	7	7	5	7	7	7	8	5	6	7	7	7	5	6	6		7
	#2 P. M. 2	6	7	7	7	7	5	6	7	7	8	5	6	7	7	7	5	6	6		7
	#2 P. M. 3	5	7	7	7	7	5	6	7	7	8	5	6	7	7	7	5	6	6		6
	#2 P. M. 4	6					5					5					5				
Discoloration	#1 P. M. 1	1	3	3	5	6	1	1	2	4	5	1	3	3	5	7	1	1	6		5
	#1 P. M. 2	1	2	2	3	6	1	1	2	4	5	1	3	3	4	6	1	1	5		6
	#1 P. M. 3	1	3	3	5	6	1	1	6	6	6	1	3	1	3	4	1	2	5		5
	#1 P. M. 4	1					1					1					1				
	#2 P. M. 1	1	1	1	6	6	1	1	5	6	6	1	3	2	4	4	1	1	3		4
	#2 P. M. 2	1	3	1	6	6	1	1	4	4	5	1	3	4	5	5	1	2	4		5
	#2 P. M. 3	1	1	1	6	6	1	1	4	5	5	1	3	3	4	5	1	1	3		4
	#2 P. M. 4	1					1					1					1				
Acceptance	#1 P. M. 1	7	6	4	3	2	7	5	6	5	3	7	5	5	3	1	7	6	1		2
	#1 P. M. 2	6	6	4	3	2	7	5	6	5	3	7	5	5	3	1	7	5	2		1
	#1 P. M. 3	6	6	4	3	2	7	4	3	2	2	7	5	6	5	3	7	6	2		2
	#1 P. M. 4	5					7					7					7				
	#2 P. M. 1	5	5	5	3	2	7	4	4	2	2	7	5	5	4	3	7	6	3		2
	#2 P. M. 2	5	5	4	3	2	7	5	5	3	2	7	5	5	4	1	7	5	3		2
	#2 P. M. 3	7	5	5	4	2	7	5	5	2	2	7	5	5	4	1	7	6	5		2
	#2 P. M. 4	5					7					7					7				

Table F4. Visual† score for panelist #2 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8					WEEK 9					WEEK 10				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	7				0	5			8		5				6
	#1 P. M. 2	7				5	5			7		5				0
	#1 P. M. 3	7				5	5			8		6				6
	#1 P. M. 4	7					5					6				
	#2 P. M. 1	7				6	5			8		5				6
	#2 P. M. 2	7				6	5			8		5				6
	#2 P. M. 3	7				6	5			8		5				6
	#2 P. M. 4	7					5					6				
Discoloration	#1 P. M. 1	1				7	1			2		1				5
	#1 P. M. 2	1				5	1			5		1				7
	#1 P. M. 3	1				4	1			6		1				4
	#1 P. M. 4	2					1					1				
	#2 P. M. 1	1				6	1			2		1				6
	#2 P. M. 2	1				5	1			4		1				5
	#2 P. M. 3	1				4	1			4		1				5
	#2 P. M. 4	1					1					1				
Acceptance	#1 P. M. 1	6				1	7			3		7				2
	#1 P. M. 2	6				2	7			2		7				1
	#1 P. M. 3	6				2	7			2		6				3
	#1 P. M. 4	4					7					6				
	#2 P. M. 1	6				1	7			3		7				2
	#2 P. M. 2	6				2	7			3		7				2
	#2 P. M. 3	6				2	7			3		7				2
	#2 P. M. 4	6					7					6				

† Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table F5. Odor†† scores for panelist #2 (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0		WEEK 1		WEEK 2		WEEK 3	
DAY		0	4	0	2	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	1	1	1	1	1	1	1
	#1 P. M. 2	1	1	1	1	1	2	1	2
	#1 P. M. 3	1	2	1		1	1	1	2
	#1 P. M. 4	1		1	1	1		1	
	#2 P. M. 1	1	1	2	1	1	1	1	2
	#2 P. M. 2	1	2	1	1	1	2	1	1
	#2 P. M. 3	1	1	1		2	1	1	1
	#2 P. M. 4	1		1	1	1		1	
Acceptability	#1 P. M. 1	1	1	1	1	1	1	1	1
	#1 P. M. 2	1	1	1	1	1	2	1	1
	#1 P. M. 3	1	1	1		1	1	1	1
	#1 P. M. 4	1		1	1	1		1	
	#2 P. M. 1	1	1	1	1	1	1	1	1
	#2 P. M. 2	1	1	1	1	1	2	1	1
	#2 P. M. 3	1	1	1		1	1	1	1
	#2 P. M. 4	1		1	1	1		1	
Description	#1 P. M. 1	.	.	.	.	.	.	.	.
	#1 P. M. 2	.	.	.	.	.	2	.	2
	#1 P. M. 3	.	2	.		.	.	.	2
	#1 P. M. 4	.		.	.	.		.	
	#2 P. M. 1	.	.	2	.	.	.	.	2
	#2 P. M. 2	.	2	.	.	.	2	.	.
	#2 P. M. 3	.	.	.		2	.	.	.
	#2 P. M. 4	.		.	.	.		.	

Table F5. Odor†† scores for panelist #2 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4		WEEK 5		WEEK 6		WEEK 7	
DAY		0	4	0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	1	1	1	2	3	2	3
	#1 P. M. 2	1	1	1	1	1	2	1	3
	#1 P. M. 3	1	1	1	1	1	2	1	3
	#1 P. M. 4	1		1		2		1	
	#2 P. M. 1	1	1	1	2	1	3	1	
	#2 P. M. 2	1	2	1	2	1	3	2	2
	#2 P. M. 3	1	1	1	2	1	3	1	3
	#2 P. M. 4	1		1		1		2	3
Acceptability	#1 P. M. 1	1	1	1	1	1	2	3	4
	#1 P. M. 2	1	1	1	1	1	1	1	4
	#1 P. M. 3	1	1	1	1	1	1	1	4
	#1 P. M. 4	1		1		1		1	
	#2 P. M. 1	1	1	1	1	1	2	1	3
	#2 P. M. 2	1	2	1	1	1	2	4	5
	#2 P. M. 3	1	1	1	1	1	2	1	4
	#2 P. M. 4	1		1		1		3	
Description	#1 P. M. 1	-				2	2	6	2
	#1 P. M. 2	-					2		2
	#1 P. M. 3	-				2	2		2
	#1 P. M. 4	-							
	#2 P. M. 1	-			2		2		2
	#2 P. M. 2	-	2		2		2	2	2
	#2 P. M. 3	-			2		2		2
	#2 P. M. 4	-						2	

Table F5. Odor†† scores for panelist #2 (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8		WEEK 9		WEEK 10	
DAY		0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	2	4	1	3	2	3
	#1 P. M. 2	2	2	1	2	2	3
	#1 P. M. 3	2	3	2	4	3	3
	#1 P. M. 4	3		2		2	
	#2 P. M. 1	2	3	1	2	1	2
	#2 P. M. 2	2	2	2	3	1	2
	#2 P. M. 3	2	1	1	3	1	3
	#2 P. M. 4	2		1		1	
Acceptability	#1 P. M. 1	3	5	1	3	2	4
	#1 P. M. 2	3	4	1	4	2	4
	#1 P. M. 3	3	5	2	2	3	4
	#1 P. M. 4	4		2		2	
	#2 P. M. 1	3	5	1	4	1	4
	#2 P. M. 2	3	4	2	3	1	4
	#2 P. M. 3	3	1	1	3	1	4
	#2 P. M. 4	3		1		1	
Description	#1 P. M. 1	2	2			2	2
	#1 P. M. 2	2	2			6	2
	#1 P. M. 3	2	2			2	2
	#1 P. M. 4	2				2	
	#2 P. M. 1	2	2				2
	#2 P. M. 2	2	2				2
	#2 P. M. 3	2					2
	#2 P. M. 4	2					

†† Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable. Odor description scores were assessed using a six point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other.

Table F6. Flavor††† scores for panelist #2 (shelf-life study).

		Flavour		Off Flavour Intensity		Comments	
		Green	Red	Green	Red	Green	Red
WEEK 0	DAY 0	6	6	1	1	.	.
	DAY 4	6	5	1	1	.	.
WEEK 1	DAY 0	6	6	1	1	.	.
	DAY 2	4	5	2	2	bad flavor	sour
WEEK 2	DAY 0	5	6	1	1	.	.
	DAY 4	5	6	1	1	bland	.
WEEK 3	DAY 0	6	6	1	1	.	.
	DAY 4	6	5	1	2		sour
WEEK 4	DAY 0	4	5	2	1	stale	-
	DAY 4	5	5	2	1	sour	
WEEK 5	DAY 0	5	5	1	1	raw taste	raw taste
	DAY 4	3	4	3	3		
WEEK 6	DAY 0	5	5	2	1	sour	
	DAY 4	4	5	2	1	sour	
WEEK 7	DAY 0	5	3	1	3	v. good	
	DAY 4	1	1	4	4	v.bad	v.bad
WEEK 8	DAY 0	2	5	4	1		
	DAY 4	2	1	3	4	v.bad	v. bad
WEEK 9	DAY 0	4	4	2	2		
	DAY 4	1	3	4	3		
WEEK 10	DAY 0	4	1	2	4	livery	bloody
	DAY 4	1	2	4	3	bad	bad

††† The flavor was assessed using a six point descriptive scale: 6=Desirable, 5=Moderately desirable, 4=Slightly desirable, 3=Slightly undesirable, 2=Moderately undesirable, 1=Undesirable. Off flavor intensity was assessed using a four point descriptive scale: 4=Prevalent off flavor, 3=Moderate off flavor, 2=Slight off flavor, 1=No off flavor.

Table F7. Visual† scores for panelist #3 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0					WEEK 1					WEEK 2					WEEK 3				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	6	8	8	8						5	6	6	6	6		7	6	7	6
	#1 P. M. 2	6	5	7	7	7						5	6	6	6	6		6	6	6	6
	#1 P. M. 3	6	5	8	7	8						5	6	6	6	6		6	6	6	6
	#1 P. M. 4	5										5									
	#2 P. M. 1	6	6	8	7	7						5	6	7	6	0		6	6	6	6
	#2 P. M. 2	6	6	8	6	6						6	6	6	6	0		6	6	6	6
	#2 P. M. 3	6	5	7	6	7						6	6	6	6	0		6	6	6	6
	#2 P. M. 4	5										6									
Discoloration	#1 P. M. 1	1	1	2	2	3						1	1	2	6	4		2	3	2	5
	#1 P. M. 2	1	1	2	2	4						2	2	3	6	5		2	3	3	5
	#1 P. M. 3	1	1	2	2	3						2	1	3	6	6		1	1	3	4
	#1 P. M. 4	1										2									
	#2 P. M. 1	1	1	2	3	2						4	1	3	6	7		1	1	2	6
	#2 P. M. 2	1	1	2	3	6						4	2	6	6	7		2	1	2	5
	#2 P. M. 3	1	1	2	3	3						2	3	6	6	7		2	2	2	6
	#2 P. M. 4	1										2									
Acceptance	#1 P. M. 1	6	6	3	3	2						7	6	6	4	4		4	4	4	2
	#1 P. M. 2	7	7	4	4	3						6	6	5	4	3		5	5	4	2
	#1 P. M. 3	7	7	3	4	2						7	6	5	4	2		6	6	4	3
	#1 P. M. 4	7										7									
	#2 P. M. 1	6	6	3	3	4						4	6	4	3	2		6	6	5	2
	#2 P. M. 2	7	6	3	4	2						4	5	4	2	2		5	6	5	3
	#2 P. M. 3	6	6	4	4	3						5	4	3	2	2		5	5	5	2
	#2 P. M. 4	7										6									

Table F7. Visual† scores for panelist #3 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4					WEEK 5					WEEK 6					WEEK 7				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	6	6	6	6	5	6	6	6	7	6	6	6	6	0	5	7	7		7
	#1 P. M. 2	6	6	6	6	7	5	6	5	6	6	5	6	5	6	6	6	7	8		8
	#1 P. M. 3	6	6	6	6	6	6	7	6	6	7	5	5	6	6	6	5	7	7		7
	#1 P. M. 4	6					6					6					5				
	#2 P. M. 1	6	6	6	6	7	5	7	6	0	0	6	6	6	6	0	5	5	6		6
	#2 P. M. 2	6	6	7	7	7	5	6	6	5	6	5	6	6	6	6	5	6	6		7
	#2 P. M. 3	6	6	6	6	6	5	6	5	6	6	5	6	6	6	6	5	6	6		6
	#2 P. M. 4	6					5					5					5				
Discoloration	#1 P. M. 1	2	2	2	6	6	1	1	1	2	3	1	3	6	6	7	1	2	3		1
	#1 P. M. 2	2	2	2	4	6	1	2	2	2	3	1	3	5	6	6	1	2	3		3
	#1 P. M. 3	2	1	2	4	6	1	2	2	4	4	2	3	4	4	6	1	3	3		4
	#1 P. M. 4	5					1					2					2				
	#2 P. M. 1	1	3	3	4	6	2	2	2	7	7	1	2	6	6	7	1	6	4		3
	#2 P. M. 2	3	4	3	4	6	1	1	2	6	6	1	2	6	6	6	3	2	3		3
	#2 P. M. 3	2	2	2	4	6	2	2	6	6	6	1	3	6	6	4	1	2	3		5
	#2 P. M. 4	3					1					2					1				
Acceptance	#1 P. M. 1	6	6	5	3	2	7	6	5	5	2	7	5	3	2	2	7	4	5		5
	#1 P. M. 2	6	6	5	5	2	7	6	5	5	3	7	5	4	2	2	7	4	4		3
	#1 P. M. 3	6	7	5	5	2	6	4	4	4	2	6	5	5	3	2	7	3	5		2
	#1 P. M. 4	3					6					5					6				
	#2 P. M. 1	7	5	5	5	2	6	5	4	3	2	6	6	3	2	2	7	3	5		5
	#2 P. M. 2	5	4	5	4	2	7	6	5	3	2	7	6	3	2	2	5	5	4		4
	#2 P. M. 3	6	5	4	5	2	7	5	3	3	2	7	5	3	2	3	7	5	5		4
	#2 P. M. 4	5					7					6					7				

Table F7. Visual† scores for panelist #3 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8					WEEK 9					WEEK 10				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	5	6	0	0	0	6	5	6	7		6	6	5	5	0
	#1 P. M. 2	5	6	6	7	8	5	5	6	6		6	6	5	0	0
	#1 P. M. 3	5	6	6	6	7	5	6	7	6		6	6	6	6	8
	#1 P. M. 4	5					5					6				
	#2 P. M. 1	5	6	0	0	0	5	5	6	6		5	5	5	5	0
	#2 P. M. 2	5	6	6	0	7	6	6	7	7		5	5	6	5	7
	#2 P. M. 3	5	7	8	8	8	6	6	6	6		5	5	6	5	0
	#2 P. M. 4	5					5					5				
Discoloration	#1 P. M. 1	2	2	7	7	7	1	2	1	2		2	2	6	6	7
	#1 P. M. 2	1	2	4	4	3	2	1	2	4		2	4	6	7	7
	#1 P. M. 3	2	2	3	4	3	2	1	3	6		1	3	4	6	4
	#1 P. M. 4	2					2					1				
	#2 P. M. 1	1	5	7	7	7	1	2	2	1		1	5	4	6	7
	#2 P. M. 2	1	4	6	7	4	1	1	2	2		2	2	2	4	4
	#2 P. M. 3	1	2	1	3	2	1	1	3	5		1	3	2	5	7
	#2 P. M. 4	1					1					1				
Acceptance	#1 P. M. 1	6	5	2	2	1	6	6	6	4		5	6	4	2	2
	#1 P. M. 2	7	5	4	4	3	6	6	5	4		5	4	3	2	2
	#1 P. M. 3	6	5	4	4	3	6	6	4	2		6	5	4	3	3
	#1 P. M. 4	6					6					6				
	#2 P. M. 1	7	4	2	2	1	7	7	6	6		7	4	4	2	2
	#2 P. M. 2	7	4	3	2	2	6	6	5	4		6	6	6	4	4
	#2 P. M. 3	7	4	3	3	3	6	6	5	3		7	5	6	3	2
	#2 P. M. 4	7					7					7				

† Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table F8. Odor[††] scores for panelist #3 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0		WEEK 1		WEEK 2		WEEK 3	
DAY		0	4	0	2	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	2			2	2		2
	#1 P. M. 2	1	2			1	1		2
	#1 P. M. 3	1	2			2	2		2
	#1 P. M. 4	1				1			
	#2 P. M. 1	1	2			1	1		2
	#2 P. M. 2	1	2			2	1		1
	#2 P. M. 3	1	2			1	2		1
	#2 P. M. 4	1				2			
Acceptability	#1 P. M. 1	1	1			1	2		1
	#1 P. M. 2	1	2			1	1		1
	#1 P. M. 3	1	2			1	2		1
	#1 P. M. 4	1				1			
	#2 P. M. 1	1	2			1	1		1
	#2 P. M. 2	1	1			1	1		1
	#2 P. M. 3	1	2			1	1		1
	#2 P. M. 4	1				1			
Description	#1 P. M. 1	.	6 stale			6 stale	6 stale		6 stale
	#1 P. M. 2	.	6 stale			.	.		6 stale
	#1 P. M. 3	.	6 stale			6 stale	6 stale		6 stale
	#1 P. M. 4	.				.			
	#2 P. M. 1	.	6 stale			.	.		6 stale
	#2 P. M. 2	.	6 stale			6 stale	.		.
	#2 P. M. 3	.	6 stale			.	6 stale		.
	#2 P. M. 4	.				6 stale			

Table F8. Odor[††] scores for panelist #3 (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4		WEEK 5		WEEK 6		WEEK 7	
DAY		0	4	0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	1	1	2	1	3	1	2
	#1 P. M. 2	1	2	1	2	1	1	1	2
	#1 P. M. 3	1	1	1	1	1	2	1	1
	#1 P. M. 4	1		1		1		2	
	#2 P. M. 1	1	1	1	2	1	3	1	2
	#2 P. M. 2	1	2	1	1	1	2	1	1
	#2 P. M. 3	1	1	1	1	1	2	1	2
	#2 P. M. 4	1		1		1		1	
Acceptability	#1 P. M. 1	1	1	1	2	1	3	1	2
	#1 P. M. 2	1	1	1	2	1	1	1	2
	#1 P. M. 3	1	1	1	1	1	2	1	1
	#1 P. M. 4	1		1		1		1	
	#2 P. M. 1	1	1	1	2	1	3	1	1
	#2 P. M. 2	1	2	1	1	1	2	1	1
	#2 P. M. 3	1	1	1	1	1	2	1	1
	#2 P. M. 4	1		1		1		1	
Description	#1 P. M. 1	-			6stale		stale		stale
	#1 P. M. 2	-	6stale		6stale				stale
	#1 P. M. 3	-					stale		
	#1 P. M. 4	-						2	
	#2 P. M. 1	-			6stale		stale		sour
	#2 P. M. 2	-	6stale				stale		
	#2 P. M. 3	-					stale		sour
	#2 P. M. 4	-							

Table F8. Odor†† scores for panelist #3 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8		WEEK 9		WEEK 10	
DAY		0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	4	1	2	1	3
	#1 P. M. 2	1	2	2	2	1	1
	#1 P. M. 3	1	2	1	1	1	2
	#1 P. M. 4	1		1		2	
	#2 P. M. 1	2	3	1	1	1	2
	#2 P. M. 2	1	1	1	1	1	2
	#2 P. M. 3	2	3	2	1	1	2
	#2 P. M. 4	1		1		1	
Acceptability	#1 P. M. 1	1	5	1	1	1	3
	#1 P. M. 2	1	1	1	1	1	1
	#1 P. M. 3	1	1	1	1	1	1
	#1 P. M. 4	1		1		1	
	#2 P. M. 1	1	2	1	1	1	1
	#2 P. M. 2	1	1	1	1	1	1
	#2 P. M. 3	2	1	1	1	1	1
	#2 P. M. 4	1		1		1	
Description	#1 P. M. 1		sour		stale		stale
	#1 P. M. 2		sweet	sour	stale		
	#1 P. M. 3		sweet				stale
	#1 P. M. 4	stale				stale	
	#2 P. M. 1		stale				stale
	#2 P. M. 2	stale					stale
	#2 P. M. 3		stale	sour			stale
	#2 P. M. 4						

†† Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable. Odor description scores were assessed using a six point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other.

Table F9. Flavor[†††] scores for panelist #3 (shelf-life study).

		Flavour		Off Flavour Intensity		Comments	
		Green	Red	Green	Red	Green	Red
WEEK 0	DAY 0	6	6	1	1	.	.
	DAY 4	6	6	1	1	.	.
WEEK 1	DAY 0						
	DAY 4						
WEEK 2	DAY 0	6	6	1	1	.	.
	DAY 4	6	6	1	1	.	.
WEEK 3	DAY 0						
	DAY 4	4	2	2	3	bitter, metallic	bitter,metallic
WEEK 4	DAY 0	5	6	2	1	livery	
	DAY 4	6	6	1	1		
WEEK 5	DAY 0	6	6	1	1		
	DAY 4	6	6	2	1		sour
WEEK 6	DAY 0	6	6	1	1		
	DAY 4	6	4	1	3		stale
WEEK 7	DAY 0	6	6	1	1		
	DAY 4	6	6	2	1	astringent	
WEEK 8	DAY 0	6	6	1	1		
	DAY 4	6	6	1	1		
WEEK 9	DAY 0	6	6	2	2	metallic	sour
	DAY 4	6	6	1	1		
WEEK 10	DAY 0	6	4	1	3		livery
	DAY 4	6	6	1	1		

††† The flavor was assessed using a six point descriptive scale: 6=Desirable, 5=Moderately desirable, 4=Slightly desirable, 3=Slightly undesirable, 2=Moderately undesirable, 1=Undesirable. Off flavor intensity was assessed using a four point descriptive scale: 4=Prevalent off flavor, 3=Moderate off flavor, 2=Slight off flavor, 1=No off flavor.

Table F10. Visual† scores for panelist #4 for beef (*psoas major*, P.M.) (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0					WEEK 1					WEEK 2					WEEK 3				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	6	7	7	6	5	8	0			5	5	5	5	6	6	7	6	6	5
	#1 P. M. 2	5	5	6	6	5	5	4	0	0		5	5	5	6	6	5	7	6	5	5
	#1 P. M. 3	6	6	7	5	7	5					5	5	6	7	0	5	6	6	5	5
	#1 P. M. 4	5					5	5	5	6		6					5				
	#2 P. M. 1	6	6	7	7	6	5	0	0			5	6	6	6	0	6	7	7	6	6
	#2 P. M. 2	5	6	6	6	5	5	5	5	5		6	7	7	6	7	6	6	6	5	5
	#2 P. M. 3	6	6	6	6	6	4					6	7	6	0	0	5	6	5	5	5
	#2 P. M. 4	6					5	5	5	6		6					5				
Discoloration	#1 P. M. 1	1	1	1	2	3	2	6	7			1	2	3	5	5	1	2	4	5	6
	#1 P. M. 2	1	1	1	1	4	1	6	7	7		1	1	1	4	5	1	2	3	6	5
	#1 P. M. 3	1	1	1	2	5	1					1	1	5	6	7	1	1	3	5	6
	#1 P. M. 4	1					1	6	6	6		1					1				
	#2 P. M. 1	1	1	1	3	4	2	7	7			1	4	4	6	7	2	1	4	4	5
	#2 P. M. 2	1	1	6	6	6	2	3	3	5		1	2	2	6	6	2	2	2	6	6
	#2 P. M. 3	1	1	1	3	5	2					1	5	6	7	7	1	1	3	3	5
	#2 P. M. 4	1					2	1	6	6		1					1				
Acceptance	#1 P. M. 1	7	7	6	5	4	6	2	1			7	6	5	2	2	7	6	3	2	1
	#1 P. M. 2	7	7	7	7	4	7	1	1	1		7	7	7	2	2	7	6	7	3	2
	#1 P. M. 3	7	7	7	5	3	7					7	7	3	2	1	7	7	7	2	2
	#1 P. M. 4	7					6	1	1	2		7					7				
	#2 P. M. 1	7	7	6	4	3	6	1	1			7	5	4	2	1	6	7	5	3	2
	#2 P. M. 2	6	7	2	2	2	6		3	2		7	6	6	2	1	6	6	6	2	1
	#2 P. M. 3	7	7	7	4	3	6	4				7	4	1	1	1	7	7	6	4	3
	#2 P. M. 4	6					6	4	1	1		6					7				

† Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table F11. Odor†† scores for panelist #4 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0		WEEK 1		WEEK 2		WEEK 3	
DAY		0	4	0	2	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	2	1	1	1	2	1	2
	#1 P. M. 2	1	2	1	2	1	2	1	2
	#1 P. M. 3	1	2	1		1	2	1	2
	#1 P. M. 4	1		1	1	1		1	
	#2 P. M. 1	1	2	1	1	1	1	1	2
	#2 P. M. 2	1	2	2	1	1	2	1	2
	#2 P. M. 3	1	2	1		2	2	1	2
	#2 P. M. 4	1		1	1	1		1	
Acceptability	#1 P. M. 1	1	2	1	1	1	2	1	3
	#1 P. M. 2	1	1	1	3	1	1	1	3
	#1 P. M. 3	1	1	1		1	2	1	2
	#1 P. M. 4	1		1	1	1		1	
	#2 P. M. 1	1	1	1	1	1	1	1	2
	#2 P. M. 2	1	2	2	1	1	2	1	1
	#2 P. M. 3	1	3	1		1	3	1	1
	#2 P. M. 4	1		1	1	1		1	
Description	#1 P. M. 1	.	2	.	.	.	2	.	2
	#1 P. M. 2	.	3	.	4	.	6 stale	.	2
	#1 P. M. 3	.	3	.		.	3	.	2
	#1 P. M. 4	.		.	.	.		.	
	#2 P. M. 1	.	6 stale	.	.	.	.	.	6 stale
	#2 P. M. 2	.	2	2	.	.	4	.	2
	#2 P. M. 3	.	4	.		2	6	.	6 stale
	#2 P. M. 4	.		.	.	.	.	.	

†† Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable. Odor description scores were assessed using a six point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other.

Table F12. Flavor[†††] scores for panelist #4 for beef (*psoas major*, P.M.) steaks (shelf-life study).

		Flavour		Off Flavour Intensity		Comments	
		Green	Red	Green	Red	Green	Red
WEEK 0	DAY 0	6	2	5	1	v. Sour	raw flavour
	DAY 4	6	6	1	2	.	Sour
WEEK 1	DAY 0	5	5	1	1	1	1
	DAY 2	6	6	1	1	.	.
WEEK 2	DAY 0	6	6	1	1	.	.
	DAY 4	2	5	3	1	sour/burnt	raw flavour
WEEK 3	DAY 0	6	5	1	1	.	.
	DAY 4	5	1	5	1	.	metallic, dirty taste

††† The flavor was assessed using a six point descriptive scale: 6=Desirable, 5=Moderately desirable, 4=Slightly desirable, 3=Slightly undesirable, 2=Moderately undesirable, 1=Undesirable. Off flavor intensity was assessed using a four point descriptive scale: 4=Prevalent off flavor, 3=Moderate off flavor, 2=Slight off flavor, 1=No off flavor.

Table F13. Visual† scores for panelist #5 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0					WEEK 1					WEEK 2					WEEK 3				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	6	7	7	7	6	0	0			5	6	6	6	7	5	6	6	7	7
	#1 P. M. 2	6	6	7	7	7	6	0	0	8		6	5	6	6	7	5	6	6	7	7
	#1 P. M. 3	6	6	7	7	7	6					5	6	6	6	7	5	5	6	6	6
	#1 P. M. 4	6					6	7	8	8		5					5				
	#2 P. M. 1	6	6	7	7	6	6	0	0			5	6	6	6	7	6	5	6	6	6
	#2 P. M. 2	6	6	7	7	6	6	7	8	8		6	6	6	6	7	6	6	6	6	6
	#2 P. M. 3	6	6	7	7	6	6					6	6	7	7	8	5	6	6	6	7
	#2 P. M. 4	6					6	7	8	8		6					5				
Discoloration	#1 P. M. 1	1	1	1	1	4	1	7	7			1	1	1	2	3	1	1	3	4	5
	#1 P. M. 2	1	1	1	1	4	2	7	7	6		2	1	1	2	3	1	1	2	5	5
	#1 P. M. 3	1	1	1	1	5	2					1	1	2	4	4	1	1	2	4	4
	#1 P. M. 4	1					1	6	6	6		1					1				
	#2 P. M. 1	1	1	1	3	6	1	7	7			1	1	2	2	4	1	1	2	4	5
	#2 P. M. 2	1	1	1	3	6	1	6	7	6		1	2	2	3	6	1	1	1	3	5
	#2 P. M. 3	1	1	1	2	6	1					2	3	5	5	6	1	1	2	3	4
	#2 P. M. 4	1					1	6	7	6		1					1				
Acceptance	#1 P. M. 1	7	7	5	6	3	7	1	1			7	7	6	6	5	7	7	4	4	4
	#1 P. M. 2	7	7	6	6	3	6	1	1	1		6	7	7	6	5	7	7	6	4	4
	#1 P. M. 3	7	7	5	6	2	6					7	7	5	5	4	7	7	6	5	5
	#1 P. M. 4	7					7	2	1	1		7					7				
	#2 P. M. 1	7	7	5	4	1	7	1	1			7	7	5	6	4	7	7	6	5	3
	#2 P. M. 2	7	7	5	4	1	7	2	1	1		7	5	6	5	3	7	7	7	6	3
	#2 P. M. 3	7	7	5	5	1	7					6	4	4	4	2	7	6	6	6	4
	#2 P. M. 4	7					7	2	1	1		7					7				

Table F13. Visual† scores for panelist #5 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4					WEEK 5					WEEK 6					WEEK 7				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	5	5	6	6	6	5	5	5	6	7	5	6	7	7	8	6	6	6	7	8
	#1 P. M. 2	5	5	6	6	6	5	5	5	6	7	6	6	7	6	7	6	6	6	7	8
	#1 P. M. 3	5	5	6	6	6	5	6	7	8	0	6	6	6	6	7	6	6	6	7	8
	#1 P. M. 4	5					5					6					6				
	#2 P. M. 1	6	6	7	7	6	5	6	6	7	0	6	6	7	7	7	6	6	6	6	7
	#2 P. M. 2	6	6	7	7	6	5	5	6	7	8	6	6	6	7	7	6	6	6	6	7
	#2 P. M. 3	6	6	7	6	6	5	5	6	7	8	5	6	6	7	7	6	6	6	6	7
	#2 P. M. 4	6					5					5					6				
Discoloration	#1 P. M. 1	1	1	3	3	5	1	1	1	2	4	1	1	4	5	7	1	2	4	3	6
	#1 P. M. 2	1	1	2	3	5	1	1	1	2	4	1	2	3	5	6	1	2	4	4	6
	#1 P. M. 3	1	1	3	4	5	1	3	5	6	7	1	1	2	4	6	1	1	4	4	5
	#1 P. M. 4	1					1					1					1				
	#2 P. M. 1	1	1	3	4	5	1	3	3	4	7	1	2	4	5	6	1	1	3	2	6
	#2 P. M. 2	1	1	2	4	6	1	1	1	4	5	1	2	4	5	6	1	1	2	3	5
	#2 P. M. 3	1	1	3	3	4	1	1	3	5	5	1	2	4	5	6	1	1	1	2	5
	#2 P. M. 4	1					1					1					1				
Acceptance	#1 P. M. 1	7	7	5	5	3	7	7	7	5	3	7	6	4	5	2	7	6	4	3	2
	#1 P. M. 2	7	7	6	5	3	7	7	7	6	2	7	6	5	5	2	7	6	4	3	2
	#1 P. M. 3	7	7	5	5	4	7	6	3	2	1	7	6	6	6	2	7	6	4	3	2
	#1 P. M. 4	7					7					7					7				
	#2 P. M. 1	6	6	6	5	3	7	6	5	4	1	7	6	4	4	2	7	6	6	5	4
	#2 P. M. 2	6	6	5	5	2	7	7	6	5	3	7	6	4	4	2	7	6	6	4	2
	#2 P. M. 3	6	6	6	6	4	7	7	5	4	3	7	6	5	5	2	7	6	7	6	4
	#2 P. M. 4	6					7					7					7				

Table F13. Visual† scores for panelist #5 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8					WEEK 9					WEEK 10				
DAY		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Color Intensity	#1 P.M. 1	6	7	7	8	8	5	6	6	6		5	6	6	7	8
	#1 P. M. 2	6	6	6	6	7	5	6	6	6		5	6	6	7	0
	#1 P. M. 3	6	6	6	6	7	5	7	7	7		5	6	6	7	8
	#1 P. M. 4	6					5					5				
	#2 P. M. 1	6	6	7	8	8	5	6	6	6		5	6	6	6	8
	#2 P. M. 2	6	6	6	6	7	5	7	6	6		5	5	6	6	8
	#2 P. M. 3	6	6	6	6	7	5	6	6	6		5	5	6	6	8
	#2 P. M. 4	6					5					5				
Discoloration	#1 P. M. 1	2	3	4	5	6	1	1	1	2		1	1	2	4	5
	#1 P. M. 2	1	2	2	3	5	1	1	2	3		1	2	3	5	7
	#1 P. M. 3	1	2	2	3	6	1	2	3	5		1	2	3	3	5
	#1 P. M. 4	2					1					1				
	#2 P. M. 1	1	2	4	5	6	1	1	1	2		1	1	2	2	5
	#2 P. M. 2	1	1	2	3	6	1	2	2	3		1	1	2	2	5
	#2 P. M. 3	1	1	2	2	5	1	1	2	2		1	1	2	3	6
	#2 P. M. 4	1					1					1				
Acceptance	#1 P. M. 1	6	5	4	2	1	7	7	7	6		7	7	5	4	3
	#1 P. M. 2	7	6	6	5	3	7	7	6	5		7	6	4	3	1
	#1 P. M. 3	7	6	6	5	1	7	5	4	3		7	6	5	5	4
	#1 P. M. 4	5					7					7				
	#2 P. M. 1	7	6	5	3	1	7	7	6	6		7	7	6	5	3
	#2 P. M. 2	7	6	6	5	2	7	6	6	5		7	7	6	6	4
	#2 P. M. 3	7	6	6	6	3	7	7	6	6		7	7	6	5	2
	#2 P. M. 4	7					7					7				

† Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5= Slightly desirable, 6= Desirable, 7=Extremely desirable.

Table F14. Odor[††] scores for panelist #5 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 0		WEEK 1		WEEK 2		WEEK 3	
DAY		0	4	0	2	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	2	1	1	1	2	1	2
	#1 P. M. 2	1	2	1	1	1	2	1	2
	#1 P. M. 3	1	2	1		1	3	1	2
	#1 P. M. 4	1		1	1	1		1	
	#2 P. M. 1	1	3	1	2	1	2	1	2
	#2 P. M. 2	1	3	1	1	1	2	1	2
	#2 P. M. 3	1	3	1		1	3	1	2
	#2 P. M. 4	1		1	2	1		1	
Acceptability	#1 P. M. 1	1	3	1	1	1	2	1	3
	#1 P. M. 2	1	4	1	1	1	2	1	4
	#1 P. M. 3	1	4	1		1	3	1	4
	#1 P. M. 4	1		1	1	1		1	
	#2 P. M. 1	1	5	1	2	1	2	1	4
	#2 P. M. 2	1	5	1	1	1	2	1	4
	#2 P. M. 3	1	5	1		1	3	1	2
	#2 P. M. 4	1		1	2	1		1	
Description	#1 P. M. 1	.	4	.	.	.	2	.	2
	#1 P. M. 2	.	2	.	.	.	2	.	4
	#1 P. M. 3	.	2	.		.	2	.	4
	#1 P. M. 4	.		.	.	.		.	
	#2 P. M. 1	.	2	.	2	.	2	.	2
	#2 P. M. 2	.	2	.	.	.	2	.	2
	#2 P. M. 3	.	2	.		.	2	.	6
	#2 P. M. 4	.		.	2	.		.	

Table F14. Odor†† scores for panelist #5 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 4		WEEK 5		WEEK 6		WEEK 7	
DAY		0	4	0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	1	1	2	1	2	1	1
	#1 P. M. 2	1	2	1	1	1	2	1	2
	#1 P. M. 3	1	1	1	2	1	2	1	2
	#1 P. M. 4	1		1		1		1	
	#2 P. M. 1	1	1	1	2	1	2	1	2
	#2 P. M. 2	1	2	1	2	1	2	1	2
	#2 P. M. 3	1	1	1	2	1	2	1	2
	#2 P. M. 4	1		1		1		1	
Acceptability	#1 P. M. 1	1	1	1	2	1	2	1	1
	#1 P. M. 2	1	1	1	1	1	2	1	2
	#1 P. M. 3	1	1	1	2	1	2	1	2
	#1 P. M. 4	1		1		1		1	
	#2 P. M. 1	1	1	1	3	1	2	1	2
	#2 P. M. 2	1	2	1	3	1	2	1	2
	#2 P. M. 3	1	1	1	3	1	2	1	2
	#2 P. M. 4	1		1		1		1	
Description	#1 P. M. 1	-			2		2		
	#1 P. M. 2	-					2		2
	#1 P. M. 3	-			2		2		2
	#1 P. M. 4	-							
	#2 P. M. 1	-			4		2		2
	#2 P. M. 2	-			4		2		2
	#2 P. M. 3	-	stale		4		2		2
	#2 P. M. 4	-							

Table F14. Odor†† scores for panelist #5 for beef (*psoas major*, P.M.) steaks (shelf-life study).

	BAG #, MEAT-TYPE, & REPLICATE #	WEEK 8		WEEK 9		WEEK 10	
DAY		0	4	0	4	0	4
Off Odor Intensity Scale	#1 P.M. 1	1	2	1	1	1	2
	#1 P. M. 2	1	1	1	2	1	3
	#1 P. M. 3	1	2	1	3	1	2
	#1 P. M. 4	1		1		1	
	#2 P. M. 1	1	3	1	1	1	3
	#2 P. M. 2	1	2	1	1	1	3
	#2 P. M. 3	1	1	1	1	1	3
	#2 P. M. 4	1		1		1	
Acceptability	#1 P. M. 1	1	2	1	1	1	3
	#1 P. M. 2	1	1	1	2	1	3
	#1 P. M. 3	1	2	1	3	1	3
	#1 P. M. 4	1		1		1	
	#2 P. M. 1	1	3	1	1	1	3
	#2 P. M. 2	1	2	1	1	1	3
	#2 P. M. 3	1	1	1	1	1	3
	#2 P. M. 4	1		1		1	
Description	#1 P. M. 1		2				2
	#1 P. M. 2				2		4
	#1 P. M. 3		2		2		2
	#1 P. M. 4						
	#2 P. M. 1		2				4
	#2 P. M. 2		2				4
	#2 P. M. 3						2
	#2 P. M. 4						

†† Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable. Odor description scores were assessed using a six point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other.

APPENDIX G

APPENDIX G1: MEDIA PREPARATION

APT (All Purpose Tween):

- Weigh out the appropriate amount of APT agar and place it into a volumetric flask. Ensure that the volume of the flask is two times greater than that of the final solution.
- Measure and add the appropriate amount of filtered water to the flask.
- Place a metallic stirring rod in the flask.
- Heat and stir until the dilution is completely dissolved.
- Place tinfoil over the flask opening and autoclave.
- Pour the heated media into sterile petri plates.
- Invert and stack the plates to allow for slow cooling.
- Refrigerate once the media is solidified.

PEPTONE (0.1%):

- Weigh out and add the desired amount of peptone to a volumetric flask. Ensure that the volume of the flask is two times greater than that of the final solution.
- Add the appropriate amount of filtered water to the flask.
- Place a metal stirring rod into the flask.
- Heat and stir until completely dissolved.
- Pipette (using brinkmann dispenser) 10 ml or 90 ml into labeled plastic bottles, or 9 ml into glass disposable test tubes.
- Autoclave and refrigerate.

APPENDIX G2: STEPS OF MICROBIOLOGICAL ANALYSIS:

1) Remove the APT (All purpose Tween, DIFCO Laboratories, Detroit, MI) plates and 0.1% peptone bottles and test tubes approximately 2 h prior to analysis.
2) Sterilize the 10 cm^2 corer by dipping it into ethyl alcohol and flame until all the alcohol is burned off and the corer is cooled down.
3) Remove a 10 cm^2 sample by placing the alcohol sterilized circular corer perpendicular to the meat surface and twisting down until the top layer of the meat is cut through. Be sure not to cut through the whole thickness of the meat.
4) Using alcohol sterilized forceps and a disposable sterilized scalpel blade (Feather Safety Razor CO., Limited), cut and remove the core to release the 10 cm^2 circular sample.
5) Place the core into a stomacher bag (Seward Stomacher Bag) with 10 ml of 0.1% peptone solution and stomach for 120 s on high power, yielding a dilution of 10^0.
6) Using a disposable serological 1 ml pipette (Fisher Scientific, Edmonton, AB), transfer 1 ml from the stomacher bag into a glass test tube (Fisher Scientific, Pittsburgh, PA) containing 9 ml of 0.1% peptone solution (10^{-1} dilution).
7) Vortex the test tube.
8) Using a new disposable pipette, transfer 1 ml from the first test tube into another test tube (test tube #2) which is also filled with 9 ml of 0.1% peptone (10^{-2} dilution).
9) Repeat steps 6 and 7 until the desired dilutions are reached.
10) Label the APT plates and transfer 0.1 ml from the desired dilution tubes using the disposable pipettes onto the APT plate surface (ensure to flame the test tube end prior to withdrawing the sample). Using an alcohol sterilized glass rod (hockey stick), spread the sample in a circular motion around the plate. Try to have an even spread across the plate.
11) Invert the plate and incubate at 25 °C for 3 days.

Table G1 Enumeration of total meat organisms on beef (*psoas major*, P.M.) steak [sample #1] (shelf-life study).

Dilution factor	Sample	WEEK 0		WEEK 1		WEEK 2		WEEK 3		WEEK 4	
		day0	day4	day0	day2	day0	day4	day 0	day4	day0	day4
10^{0}	A	10	42	7	1	6	218	7	105	2	50
	B	23	39	13	<1	5	136	1	212	3	36
10^{-1}	A	1	7	2	2	2	32	<1	9	<1	<1
	B	1	8	6	10	<1	33	<1	14	<1	5
10^{-2}	A	<1	1	<1	<1	<1	3		1		<1
	B	<1	<1	3	1	<1	4		1		<1
10^{-3}	A	<1	<1	<1	1	<1	3		<1		<1
	B	<1	<1	<1	<1	<1	<1		<1		<1
10^{-4}	A		145	<1	<1		<1		<1		<1
	B		147	<1	<1		<1		<1		<1
10^{-5}	A		15				<1		<1		<1
	B		12				<1		<1		<1
10^{-6}	A		1								
	B		1								
10^{-7}	A										
	B										
10^{-8}	A										
	B										
10^{-9}	A										
	B										
10^{-10}	A										
	B										

Dilution factor	Sample	WEEK 5		WEEK 6		WEEK 7		WEEK 8		WEEK 9		WEEK 10	
		day0	day4	day0	day4	day0	day4	day 0	day4	day0	day4	day0	day4
10^{0}	A	1		1		TNC		2		2		2	
	B	4		1		TNC		1		1		1	
10^{-1}	A	<1	TNC	<1	7	185	27	<1	TNC	<1	110	<1	TNC
	B	<1	TNC	<1	5	182	22	<1	TNC	<1	90	<1	TNC
10^{-2}	A		65		3		<1		TNC		14		TNC
	B		64		<1		<1		TNC		10		TNC
10^{-3}	A		2		<1		<1		17		<1		18
	B		4		<1		<1		43		<1		45
10^{-4}	A		<1		<1		<1		<1		<1		<1
	B		<1		<1		<1		<1		<1		<1
10^{-5}	A		<1		<1		<1		<1		<1		<1
	B		<1		<1		<1		<1		<1		<1
10^{-6}	A												
	B												
10^{-7}	A												
	B												
10^{-8}	A												
	B												
10^{-9}	A												
	B												
10^{-10}	A												
	B												

ble G2 Enumeration of total meat organisms on beef (*psoas major*, P.M.) steak [sample #2] (shelf-life study).

Dilution factor	Sample	WEEK 0		WEEK 1		WEEK 2		WEEK 3		WEEK 4	
		day0	day4	day0	day2	day0	day4	day 0	day4	day0	day4
10^{0}	A	11	TNC	14	8	3	TNC	7	TNC	1	TNC
	B	19	TNC	12	11	2	TNC	49	TNC	6	TNC
10^{-1}	A	2	46	<1	<1	<1	TNC	4	TNC	<1	TNC
	B	1	67	<1	1	<1	TNC	<1	TNC	<1	TNC
10^{-2}	A	<1	30	<1	<1	<1	107		45		TNC
	B	<1	42	<1	<1	<1	184		38		TNC
10^{-3}	A	<1	4	<1	<1	<1	36		5		19
	B	<1	8	<1	<1	<1	35		6		25
10^{-4}	A		1	1	1		3		<1		5
	B		2	<1	<1		4		<1		3
10^{-5}	A		<1				1		<1		<1
	B		<1				<1		<1		<1
10^{-6}	A		<1								
	B		<1								
10^{-7}	A										
	B										
10^{-8}	A										
	B										
10^{-9}	A										
	B										
10^{-10}	A										
	B										

Dilution Factor	Sample	WEEK 5		WEEK 6		WEEK 7		WEEK 8		WEEK 9		WEEK 10	
		day0	day4	day0	day4	day0	day4	day 0	day4	day0	day4	day0	day4
10^{0}	A	11		11		2		18		3		<1	
	B	4		6		1		3		1		2	
10^{-1}	A	3	32	2	3	1	51	<1	1	<1	<1		TNC
	B	2	29	<1	2	<1	68	<1	2	<1	<1		TNC
10^{-2}	A		28		1		11		<1		<1		TNC
	B		4		<1		9		<1		<1		TNC
10^{-3}	A		21		<1		<1		<1		<1		24
	B		<1		<1		<1		<1		<1		50
10^{-4}	A		<1		<1		<1		<1		<1		<1
	B		<1		<1		<1		<1		<1		<1
10^{-5}	A		<1		<1		<1		<1		<1		<1
	B		<1		<1		<1		<1		<1		<1
10^{-6}	A												
	B												
10^{-7}	A												
	B												
10^{-8}	A												
	B												
10^{-9}	A												
	B												
10^{-10}	A												
	B												

APPENDIX H

Table H1 Reflectance data as obtained on the surfaces of beef (*psoas major*, p.m.) steaks after their storage in liquid-N_2 refrigerated container.

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color[1]			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm1	1.0	0.0	0.0	18.5	17.9	16.9	16.1	16.8	18.9	20.9	21.7	20.5	18.3	18.7	18.2	24.8	30.8	33.8	35.9	37.5	39.1	40.1	40.4	54.3	14.0	6.6	12.1
pm2	1.0	0.0	0.0	10.3	9.7	8.6	8.1	9.1	11.3	13.7	14.5	13.1	10.7	11.1	10.7	18.3	25.9	29.9	32.3	34.3	36.3	37.5	37.8	46.3	21.4	10.7	0.0
pm3	1.0	0.0	0.0	15.2	14.5	13.3	12.7	13.3	15.1	17.2	17.9	16.7	14.4	14.9	14.5	21.7	29.0	32.9	35.3	37.3	39.1	40.3	40.4	50.7	18.3	8.3	8.5
pm4	1.0	0.0	0.0	14.0	13.3	12.0	11.3	12.2	14.6	17.3	18.2	16.7	13.9	14.6	14.0	23.0	31.2	35.2	38.2	40.6	42.6	43.8	43.9	51.2	20.8	10.4	0.0
pm1	2.0	0.0	0.0	14.9	14.2	12.9	12.2	12.9	14.9	17.2	17.9	16.6	14.1	14.6	14.2	21.7	29.3	33.4	35.8	37.9	39.7	40.9	41.0	50.6	18.9	8.8	4.0
pm2	2.0	0.0	0.0	11.2	10.4	8.8	8.0	9.2	11.9	14.8	15.6	14.1	11.1	11.8	11.2	20.1	28.1	32.2	35.3	37.8	39.8	40.9	41.1	47.7	22.5	11.7	0.0
pm3	2.0	0.0	0.0	9.0	8.5	7.2	6.6	7.4	9.5	12.0	12.6	11.1	8.8	9.2	8.8	15.8	23.3	27.4	29.9	32.0	34.1	35.4	35.6	43.3	22.4	10.8	0.0
pm4	2.0	0.0	0.0	11.1	10.4	9.0	8.4	9.3	11.6	14.2	15.0	13.5	10.9	11.4	11.0	18.9	26.6	30.7	33.1	35.2	37.1	38.2	38.3	43.3	22.4	10.8	0.0
pm1	1.0	0.0	24.0	15.8	14.8	13.6	13.0	14.1	16.4	18.2	18.7	18.0	15.9	16.7	16.1	23.6	27.9	29.4	34.0	38.5	40.3	41.0	40.6	51.8	14.8	8.1	21.5
pm2	1.0	0.0	24.0	14.4	13.5	12.3	11.7	12.7	14.6	16.2	16.6	15.9	13.9	14.7	14.1	21.9	26.9	28.8	33.4	38.0	40.1	40.9	40.6	49.8	17.0	8.7	19.6
pm3	1.0	0.0	24.0	14.7	13.8	13.0	12.6	13.5	15.2	16.5	16.8	16.3	14.8	15.6	15.1	21.9	25.3	26.4	31.9	38.3	40.9	41.6	41.3	50.1	14.3	7.7	35.3
pm1	2.0	0.0	24.0	15.6	14.8	13.8	13.3	14.2	16.1	17.5	17.9	17.2	15.4	16.0	15.5	22.3	26.8	28.6	32.9	37.1	39.2	40.1	39.9	50.9	14.6	7.2	23.3
pm2	2.0	0.0	24.0	15.3	14.2	12.9	12.5	13.9	16.3	17.7	17.7	17.3	15.7	17.0	16.4	23.6	26.2	26.9	33.6	42.2	45.3	46.0	45.3	51.5	13.9	8.3	43.7
pm2	2.0	0.0	24.0	14.1	13.1	12.3	11.9	12.8	14.5	15.8	16.0	15.5	14.0	14.8	14.4	20.6	24.0	25.3	30.7	36.7	39.3	40.1	39.8	49.0	14.1	7.5	34.8
pm1	1.0	0.0	48.0	16.4	15.4	14.5	14.1	15.0	16.7	17.7	17.8	17.5	16.2	17.1	16.7	22.6	25.1	25.8	31.2	37.5	39.8	40.3	39.7	51.2	11.9	6.4	42.2
pm2	1.0	0.0	48.0	14.6	13.5	12.3	11.8	13.0	15.0	16.3	16.4	16.0	14.5	15.5	14.9	22.0	25.0	25.8	31.6	38.6	41.2	41.8	41.3	49.8	14.4	8.1	37.5
pm3	1.0	0.0	48.0	14.2	13.1	12.4	12.1	13.3	15.1	15.9	15.8	15.6	14.8	16.0	15.6	20.8	22.3	22.6	28.8	37.7	41.0	41.5	40.8	49.3	11.2	7.1	59.6
pm1	2.0	0.0	48.0	14.2	13.1	12.1	11.8	13.0	15.0	16.1	16.1	15.8	14.7	15.8	15.3	21.2	23.6	24.3	30.3	37.7	40.5	41.2	40.8	49.5	12.7	7.7	49.8
pm2	2.0	0.0	48.0	15.3	14.0	13.0	12.7	14.4	16.6	17.5	17.3	17.1	16.3	17.7	17.4	22.9	24.1	24.3	31.2	41.1	44.8	45.3	44.4	51.3	11.2	7.6	66.3
pm3	2.0	0.0	48.0	15.4	14.2	13.2	12.8	14.0	15.8	16.8	16.7	16.4	15.4	16.5	16.0	21.5	23.4	23.7	29.5	37.3	40.3	41.0	40.5	50.1	11.3	6.7	51.2
pm1	1.0	0.0	72.0	16.8	15.7	14.9	14.5	15.6	17.4	18.1	18.1	17.9	17.0	18.0	17.6	22.7	24.1	24.4	30.2	38.0	40.8	41.2	40.5	51.6	9.9	6.0	54.3
pm2	1.0	0.0	72.0	13.9	12.8	11.9	11.5	12.8	14.6	15.5	15.4	15.2	14.2	15.4	14.9	20.6	22.3	22.6	29.1	38.2	41.6	42.1	41.4	48.8	12.1	7.4	54.4
pm3	1.0	0.0	72.0		13.3	12.7	12.4	13.7	15.5	16.0	15.8	15.7	15.2	16.5	16.3	20.6	21.6	21.7	28.1	37.8	41.6	42.2	41.5	49.4	9.9	6.7	69.9
pm1	2.0	0.0	72.0	14.6	13.5	12.5	12.2	13.7	15.7	16.5	16.3	16.1	15.3	16.6	16.2	21.4	22.9	23.2	29.6	38.5	41.8	42.4	41.9	49.9	11.1	7.2	60.5
pm2	2.0	0.0	72.0	15.1	13.9	12.9	12.7	14.7	17.0	17.6	17.2	17.1	16.7	18.4	18.2	22.6	23.3	23.3	30.2	41.4	45.5	46.0	45.0	51.5	9.7	7.4	80.2
pm3	2.0	0.0	72.0	14.2	13.2	12.5	12.2	13.6	15.4	16.0	15.8	15.7	15.2	16.5	16.3	20.5	21.5	21.7	28.0	37.2	40.7	41.3	40.7	49.4	9.8	6.8	70.8
pm1	1.0	0.0	96.0	16.2	15.1	14.3	14.0	15.4	17.2	17.8	17.6	17.5	16.9	18.2	17.8	22.4	23.2	23.3	39.6	38.7	42.1	42.5	41.6	51.4	9.3	6.2	65.4
pm2	1.0	0.0	96.0	14.2	13.0	12.1	11.9	13.3	15.2	15.9	15.7	15.5	14.8	16.1	15.7	20.6	21.7	21.8	28.4	38.0	41.7	42.2	41.3	49.1	10.6	6.9	62.9
pm3	1.0	0.0	96.0	13.7	12.8	12.1	11.9	13.5	15.4	15.8	15.5	15.5	15.2	16.7	16.5	20.2	20.8	20.9	27.5	37.6	41.7	42.4	41.6	49.2	9.1	6.9	78.3
pm1	2.0	0.0	96.0	14.2	13.0	12.0	11.8	13.6	15.7	16.3	16.0	15.9	15.5	16.9	16.6	21.0	21.8	21.9	28.7	38.4	42.1	42.7	41.9	49.8	9.9	7.2	74.0
pm2	2.0	0.0	96.0	15.1	13.7	12.7	12.5	14.7	17.1	17.6	17.1	17.1	16.9	18.7	18.6	22.6	23.1	23.1	30.2	41.3	45.5	46.0	45.0	51.7	9.3	7.7	87.0
pm3	2.0	0.0	96.0	15.5	14.3	13.4	13.2	14.6	16.4	17.0	16.6	16.6	16.1	17.5	17.2	21.2	21.9	21.9	28.0	37.0	40.6	41.3	40.7	50.3	8.8	6.2	70.5
pm1	1.0	1.0	0.0	14.3	13.7	12.6	11.9	12.7	14.4	16.4	17.1	15.9	13.8	14.3	13.9	21.0	28.0	31.8	33.9	35.7	37.3	38.3	38.1	49.8	18.2	8.5	9.9
pm2	1.0	1.0	0.0	16.8	15.9	13.5	12.0	13.8	16.8	19.8	20.6	19.0	15.9	16.6	15.9	24.5	32.0	35.7	37.7	39.4	40.9	41.7	41.5	53.0	18.1	9.0	0.0
pm3	1.0	1.0	0.0	14.2	13.5	12.1	11.3	12.2	14.3	16.6	17.5	16.2	13.6	14.2	13.7	21.8	29.4	33.4	35.8	37.9	39.6	40.7	40.6	50.3	19.7	9.6	1.5
pm4	1.0	1.0	0.0	14.8	14.1	12.3	11.4	12.5	14.9	17.4	18.2	17.0	14.2	14.9	14.3	23.0	30.3	34.1	36.2	38.0	39.5	40.3	40.0	51.1	19.5	9.8	0.0
pm1	2.0	1.0	0.0	15.5	14.7	13.2	12.3	13.3	15.4	17.6	18.5	17.3	14.7	15.3	14.7	24.2	32.5	36.4	38.7	40.6	42.3	43.2	43.1	52.1	20.9	10.3	2.5

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color[+]			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm2	2.0	1.0	0.0	13.4	12.8	11.5	10.8	11.6	13.5	15.7	16.5	15.3	12.9	13.4	12.9	21.1	28.8	32.7	34.9	36.9	38.7	39.8	39.8	49.3	20.4	9.9	1.2
pm3	2.0	1.0	0.0	14.9	14.3	13.1	12.4	13.2	15.1	17.1	18.0	16.9	14.4	15.0	14.4	23.3	31.4	35.2	37.4	39.3	40.9	41.9	41.8	51.5	20.4	9.9	4.9
pm4	2.0	1.0	0.0	14.2	13.6	11.9	11.0	12.1	14.4	16.7	17.6	16.4	13.6	14.3	13.7	23.3	31.4	35.3	37.4	39.2	40.8	41.7	41.5	51.0	21.4	10.8	0.0
pm1	1.0	1.0	24.0	14.7	13.6	12.8	12.5	13.5	15.9	16.6	16.0	15.6	15.4	15.7	16.3	18.4	20.3	21.3	26.8	33.5	36.5	37.6	37.4	48.6	8.3	4.8	64.3
pm2	1.0	1.0	24.0	20.3	18.2	15.8	15.1	17.8	20.9	22.1	21.2	20.8	20.3	21.0	21.4	24.4	26.5	27.3	32.6	38.9	41.4	42.0	41.3	54.8	8.0	5.3	62.6
pm4	1.0	1.0	24.0	16.6	14.9	13.3	13.3	15.7	19.0	19.7	18.7	18.4	18.5	19.1	19.9	22.2	24.2	25.4	31.3	37.7	40.2	40.8	40.0	52.7	8.5	6.0	75.2
pm1	2.0	1.0	24.0	14.2	13.3	12.6	12.5	13.8	16.3	16.7	16.0	15.8	16.1	16.7	17.6	19.1	20.6	21.4	27.7	36.1	39.7	40.9	40.7	49.5	8.0	5.8	83.7
pm2	2.0	1.0	24.0	14.3	13.5	12.5	12.0	13.2	15.2	16.4	16.6	16.2	14.7	15.6	15.1	21.8	24.6	25.4	31.4	38.4	41.1	41.7	41.2	49.9	13.7	7.7	37.9
pm4	2.0	1.0	24.0	15.3	14.4	12.9	12.1	13.6	16.0	17.7	18.1	17.5	15.4	16.3	15.7	24.0	28.0	29.3	34.6	40.2	42.3	42.7	42.1	51.6	15.8	8.8	22.4
pm1	1.0	1.0	48.0	14.6	13.7	13.1	12.9	13.7	15.9	16.5	15.9	15.4	15.4	15.6	16.3	17.9	20.0	21.2	26.5	32.8	35.8	37.0	37.0	48.4	8.0	4.4	65.6
pm2	1.0	1.0	48.0	16.9	15.2	13.6	13.4	15.3	18.6	19.8	18.8	18.3	18.1	18.4	19.2	21.6	24.1	35.4	30.9	37.1	39.8	40.7	40.2	52.2	8.7	5.6	64.4
pm4	1.0	1.0	48.0	16.2	14.6	13.2	13.0	15.0	18.4	19.6	18.6	18.1	17.8	18.2	18.9	21.8	24.5	26.2	31.5	37.0	39.2	39.9	39.3	52.2	9.6	6.0	63.7
pm1	2.0	1.0	48.0	14.2	13.2	12.5	12.3	13.4	16.2	16.9	16.1	15.8	15.9	16.2	17.1	19.0	21.0	22.0	28.2	36.1	39.7	41.0	41.0	49.3	8.7	5.8	73.6
pm2	2.0	1.0	48.0	13.9	12.9	12.0	11.7	13.1	15.1	15.9	15.8	15.5	14.7	15.9	15.5	20.7	22.1	22.3	28.8	37.8	41.2	41.7	41.0	49.2	11.2	7.2	59.8
pm4	2.0	1.0	48.0	15.1	13.9	12.6	12.3	14.5	16.9	17.8	17.6	17.4	16.6	17.9	17.6	22.6	23.7	24.1	30.6	38.6	41.6	42.2	41.6	51.4	10.1	7.3	63.0
pm1	1.0	2.0	0.0	16.4	15.5	13.4	12.3	13.8	16.7	19.7	20.8	19.4	16.0	16.9	16.1	27.0	36.0	40.3	42.9	44.7	46.2	47.0	46.6	54.4	21.7	11.4	0.0
pm2	1.0	2.0	0.0	17.1	16.1	14.2	13.2	14.5	16.9	19.3	20.2	19.0	16.1	16.8	16.1	26.2	34.2	37.9	40.1	41.6	43.1	43.9	43.6	53.8	20.1	10.1	0.3
pm3	1.0	2.0	0.0	16.8	15.9	13.9	12.9	14.3	17.1	19.8	20.8	19.4	16.2	17.0	16.3	26.9	35.4	39.3	42.1	44.1	45.6	46.3	46.0	54.4	21.0	10.6	0.0
pm4	1.0	2.0	0.0	15.6	14.8	13.3	12.5	13.4	15.6	17.8	18.8	17.7	14.9	15.5	14.9	25.0	33.8	37.8	40.2	41.9	43.5	44.3	44.1	52.7	21.7	10.8	0.2
pm1	2.0	2.0	0.0	14.8	14.1	12.9	12.2	12.9	14.9	17.0	17.9	16.7	14.2	14.8	14.3	23.0	30.7	34.5	37.0	38.9	40.5	41.4	41.2	51.2	20.1	9.8	4.9
pm2	2.0	2.0	0.0	14.4	13.7	12.6	12.0	12.6	14.3	16.3	17.0	15.9	13.7	14.2	13.8	20.8	27.8	31.5	33.7	35.5	37.1	38.1	38.1	49.7	18.1	8.4	9.6
pm3	2.0	2.0	0.0	14.0	13.3	12.3	11.7	12.3	14.1	16.3	16.7	15.4	13.5	13.8	13.5	19.1	25.8	29.7	32.3	34.4	36.4	37.8	37.9	48.7	16.7	7.3	11.0
pm4	2.0	2.0	0.0	14.9	14.3	13.0	12.2	13.1	15.0	17.1	17.9	16.7	14.3	14.9	14.4	21.9	29.1	32.8	34.9	36.5	38.0	38.9	38.7	50.7	18.2	8.6	6.1
pm1	1.0	2.0	12.0	16.2	15.4	13.5	12.5	14.1	17.0	19.4	20.3	19.2	16.2	17.2	16.3	27.5	34.1	36.2	41.0	45.4	47.2	47.6	47.1	54.2	19.9	10.7	2.7
pm2	1.0	2.0	12.0	14.5	13.7	12.4	11.7	12.5	14.3	16.0	16.7	15.9	13.7	14.4	13.8	23.4	30.0	32.2	36.5	40.3	41.7	41.9	41.1	50.6	20.4	10.3	11.8
pm3	1.0	2.0	12.0	18.0	16.9	15.0	14.0	15.6	18.4	20.5	21.2	20.2	17.5	18.6	17.8	28.0	33.2	34.6	40.1	46.1	48.1	48.4	47.6	55.0	17.3	9.3	14.2
pm1	2.0	2.0	12.0	15.9	14.9	12.6	11.4	13.4	16.4	18.6	19.3	18.2	15.5	16.4	15.6	25.5	30.5	31.8	36.5	41.5	43.2	43.3	42.4	52.5	17.6	9.5	5.6
pm2	2.0	2.0	12.0	14.1	13.2	12.1	11.6	12.4	14.1	15.7	16.1	15.4	13.6	14.3	13.8	21.4	26.0	27.7	32.5	37.5	39.4	40.0	39.5	49.2	16.7	8.6	23.6
pm3	2.0	2.0	12.0	13.5	12.6	11.7	11.2	12.1	14.0	15.3	15.5	15.0	13.6	14.4	14.0	19.9	23.5	25.0	30.4	36.2	38.7	39.6	39.3	48.3	14.3	7.8	36.3
pm1	1.0	2.0	24.0	16.7	15.7	14.1	13.3	14.8	17.3	19.1	19.6	18.8	16.5	17.5	16.7	26.1	30.5	31.5	37.5	44.2	46.6	46.9	46.1	53.3	16.6	8.9	20.0
pm2	1.0	2.0	24.0	15.1	14.3	13.2	12.6	13.5	15.4	17.0	17.5	16.8	14.8	15.6	15.0	23.9	28.7	30.0	35.6	41.6	43.7	43.9	43.0	51.3	17.5	9.1	20.5
pm3	1.0	2.0	24.0	18.8	17.5	15.8	15.0	16.9	19.5	21.1	21.3	20.7	18.8	20.0	19.2	27.6	30.5	31.0	37.4	45.6	48.4	48.5	47.5	55.2	13.6	7.8	34.5
pm1	2.0	2.0	24.0	14.5	13.4	12.2	11.6	12.8	14.9	16.4	16.7	16.1	14.3	15.2	14.6	22.6	26.2	27.0	32.8	40.0	42.4	42.6	41.6	50.1	15.9	8.6	27.5
pm2	2.0	2.0	24.0	15.4	14.4	13.5	13.0	14.1	16.0	17.3	17.5	17.0	15.5	16.4	15.8	22.6	25.3	25.9	31.6	38.6	41.2	41.8	41.2	50.7	13.1	7.2	35.1
pm3	2.0	2.0	24.0	14.0	12.9	12.2	11.9	13.1	14.8	15.6	15.4	15.2	14.6	15.6	15.3	19.8	21.4	21.9	27.9	36.0	39.2	39.9	39.4	48.6	10.6	6.7	60.6
pm1	1.0	2.0	36.0	15.7	14.5	13.2	12.6	14.0	16.3	17.8	18.1	17.5	15.6	16.7	16.1	24.3	27.6	28.2	34.7	42.9	45.7	45.9	44.8	51.8	15.2	8.6	32.9
pm2	1.0	2.0	36.0	14.4	13.3	12.1	11.5	12.5	14.4	15.8	16.0	15.5	13.8	14.7	14.1	22.2	25.6	26.3	32.4	40.0	42.5	42.7	41.7	49.4	16.2	8.6	28.8
pm3	1.0	2.0	36.0	16.7	15.4	14.0	13.5	15.2	17.5	18.8	18.8	18.4	16.9	18.1	17.5	24.7	27.0	27.4	33.7	42.1	45.0	45.1	44.0	52.7	12.9	7.6	43.6
pm1	2.0	2.0	36.0	13.0	11.9	10.8	10.4	11.7	13.8	14.9	14.9	14.6	13.3	14.5	14.0	20.5	22.4	22.7	29.2	38.4	41.6	41.9	40.8	48.1	13.6	8.3	48.6
pm2	2.0	2.0	36.0	13.9	12.9	11.9	11.5	12.6	14.5	15.5	15.5	15.2	14.0	15.0	14.6	20.5	22.4	22.8	28.9	37.1	39.9	40.3	39.5	48.6	12.5	7.3	48.0

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm3	2.0	2.0	36.0	13.9	13.0	12.3	12.0	13.4	15.1	15.7	15.5	15.4	14.9	16.1	15.8	19.9	21.0	21.3	27.5	36.4	39.9	40.6	40.0	48.8	9.7	6.6	67.8
pm1	1.0	2.0	48.0	16.2	15.1	13.9	13.3	14.8	17.3	18.7	18.9	18.3	16.6	17.7	17.1	24.7	27.4	27.9	34.3	42.6	45.5	45.8	45.0	52.5	13.6	7.9	37.1
pm2	1.0	2.0	48.0	14.8	13.9	13.0	12.5	13.6	15.5	16.8	17.0	16.5	15.0	15.9	15.3	22.6	25.4	26.0	32.3	40.7	43.6	43.9	42.9	50.4	14.2	7.8	35.3
pm3	1.0	2.0	48.0	18.4	16.9	15.4	14.9	17.1	19.7	20.8	20.6	20.3	19.1	20.6	20.1	26.5	28.1	28.2	35.0	45.1	48.8	49.1	48.0	54.8	11.1	7.2	56.6
pm1	2.0	2.0	48.0	14.7	13.8	13.0	12.6	13.8	15.7	16.6	16.5	16.2	15.3	16.3	15.9	21.5	23.0	23.1	29.5	38.9	42.4	42.7	41.7	49.9	11.3	6.8	52.8
pm2	2.0	2.0	48.0	15.5	14.3	13.0	12.6	14.6	17.0	18.0	17.9	17.6	16.6	17.9	17.4	22.9	24.1	24.2	30.5	39.3	42.4	42.8	41.9	51.5	10.3	7.1	57.1
pm3	2.0	2.0	48.0	13.9	12.9	12.3	12.1	13.6	15.3	15.6	15.3	15.3	15.2	16.6	16.5	19.6	20.2	20.3	26.5	36.3	40.2	40.9	40.2	48.9	8.4	6.5	81.7
pm1	1.0	2.0	60.0	16.3	15.1	13.8	13.3	15.0	17.5	18.8	18.8	18.4	17.0	18.3	17.7	24.8	26.8	27.1	34.0	43.8	47.3	47.5	46.4	52.7	12.7	7.9	48.3
pm2	1.0	2.0	60.0	15.0	14.0	13.0	12.6	13.8	15.7	16.9	17.0	16.6	15.2	16.2	15.6	22.5	24.8	25.2	31.6	40.4	43.4	43.5	42.4	50.4	13.2	7.5	39.9
pm3	1.0	2.0	60.0	17.0	15.6	14.2	13.8	16.1	18.9	19.9	19.7	19.4	18.4	20.0	19.5	25.6	26.7	26.8	33.8	44.2	48.1	48.4	47.3	54.0	10.8	7.6	63.7
pm1	2.0	2.0	60.0	14.6	13.5	12.7	12.4	13.8	15.7	16.4	16.2	16.1	15.4	16.6	16.3	21.2	22.1	22.2	28.7	38.6	42.4	42.6	41.5	49.8	10.3	6.9	63.8
pm2	2.0	2.0	60.0	14.4	13.3	12.4	12.2	13.7	15.6	16.2	16.0	15.9	15.3	16.6	16.4	20.7	21.4	21.5	27.8	37.0	40.5	41.0	40.3	49.5	9.5	6.7	68.9
pm3	2.0	2.0	60.0	14.1	13.0	12.3	12.2	13.9	15.6	15.9	15.6	15.6	15.6	17.0	17.0	19.8	20.3	20.4	26.6	36.1	39.9	40.6	40.0	49.3	7.9	6.5	85.2
pm1	1.0	2.0	72.0	16.3	15.0	13.5	12.9	15.3	18.2	19.6	19.6	19.2	17.8	19.3	18.6	25.9	27.8	28.1	35.2	44.8	48.3	48.6	47.8	53.8	12.6	8.5	52.3
pm2	1.0	2.0	72.0	14.8	13.8	12.8	12.4	13.7	15.7	16.7	16.8	16.5	15.3	16.3	15.8	22.1	23.9	24.2	30.7	39.8	42.9	43.0	41.9	50.2	12.3	7.3	46.3
pm3	1.0	2.0	72.0	16.7	15.1	13.8	13.5	15.8	18.4	19.2	18.8	18.7	18.1	19.8	19.4	24.7	25.6	25.6	32.8	43.9	48.2	48.5	47.3	53.4	10.2	7.7	73.9
pm1	2.0	2.0	72.0	14.7	13.6	12.8	12.5	14.0	15.9	16.6	16.4	16.2	15.6	16.9	16.5	21.1	21.9	21.9	28.3	38.3	42.1	42.4	41.4	49.9	9.7	6.6	66.2
pm2	2.0	2.0	72.0	15.2	14.1	13.0	12.7	14.9	17.3	17.9	17.6	17.5	17.1	18.6	18.3	22.5	23.1	23.2	29.6	39.0	42.7	43.2	42.6	51.6	8.9	7.0	74.4
pm3	2.0	2.0	72.0	13.9	12.9	12.3	12.1	13.8	15.4	15.7	15.3	15.4	15.5	17.1	17.3	19.7	19.9	20.0	26.2	36.1	40.2	40.8	40.2	49.2	7.6	6.7	93.3
pm1	1.0	2.0	84.0	16.9	15.5	14.0	13.5	15.8	18.6	19.7	19.6	19.3	18.1	19.7	19.1	25.8	27.3	27.5	34.7	45.0	48.7	49.0	47.9	53.9	11.7	8.0	58.4
pm2	1.0	2.0	84.0	14.8	13.7	12.7	12.3	13.7	15.8	16.7	16.7	16.4	15.4	16.6	16.1	22.0	23.4	23.6	30.4	40.2	43.8	44.0	42.9	50.2	11.6	7.3	53.1
pm3	1.0	2.0	84.0	17.4	15.9	14.4	14.1	16.8	19.5	20.3	19.9	19.8	19.2	21.0	20.6	25.8	26.5	26.5	33.7	44.5	48.6	48.9	47.7	54.5	9.7	7.6	75.5
pm1	2.0	2.0	84.0	14.9	13.7	12.9	12.6	14.2	16.0	16.6	16.3	16.2	15.8	17.2	17.0	21.1	21.6	21.5	27.9	38.3	42.5	42.8	41.8	50.0	9.0	6.6	75.0
pm2	2.0	2.0	84.0	15.5	14.2	13.1	12.9	15.2	17.6	18.2	17.8	17.7	17.4	19.0	18.8	22.8	23.2	23.3	29.8	39.5	43.1	43.5	42.7	52.0	8.5	7.0	78.6
pm3	2.0	2.0	84.0	14.2	13.2	12.5	12.4	14.2	15.8	16.0	15.6	15.7	15.9	17.5	17.7	19.9	20.1	20.2	26.3	36.1	40.0	40.8	40.2	49.7	7.2	6.6	94.0
pm1	1.0	2.0	96.0	16.2	14.8	13.5	13.1	15.4	18.0	19.0	18.8	18.6	17.6	19.3	18.7	25.0	26.2	26.4	33.5	44.3	48.2	48.3	46.9	53.2	11.4	8.1	64.0
pm2	1.0	2.0	96.0	14.8	13.8	12.8	12.5	14.1	16.2	17.0	16.9	16.7	15.8	17.1	16.6	21.9	23.0	23.1	29.5	39.5	43.2	43.4	42.3	50.4	10.5	7.0	59.0
pm3	1.0	2.0	96.0	17.0	15.5	14.1	13.9	16.5	19.0	19.7	19.3	19.2	18.8	20.7	20.4	25.0	25.6	25.6	32.7	44.0	48.5	48.9	47.8	54.0	9.3	7.5	81.4
pm1	2.0	2.0	96.0	14.3	13.2	12.5	12.3	14.0	15.9	16.4	16.0	16.0	15.8	17.4	17.2	20.8	21.0	21.0	27.4	38.3	42.7	43.1	41.9	49.9	8.5	6.8	82.7
pm2	2.0	2.0	96.0	14.9	13.7	12.8	12.6	14.9	17.1	17.4	17.1	17.1	17.1	18.8	18.7	21.8	22.0	22.0	28.4	38.6	42.6	43.1	42.4	51.3	7.7	7.0	88.5
pm3	2.0	2.0	96.0	13.9	13.0	12.4	12.3	14.0	15.7	15.9	15.4	15.6	15.9	17.5	17.8	19.8	19.9	19.9	26.0	36.1	40.3	41.1	40.5	49.6	7.1	6.8	98.1
pm1	1.0	3.0	0.0	14.8	14.3	13.3	12.7	13.4	14.9	16.5	17.2	16.3	14.3	14.7	14.3	21.5	28.3	31.6	33.6	34.9	36.3	37.0	36.8	50.3	17.7	8.2	12.7
pm2	1.0	3.0	0.0	13.7	13.1	12.2	11.6	12.1	13.4	14.8	15.4	14.6	12.8	13.2	12.8	18.9	25.2	28.4	30.4	31.8	33.3	34.2	34.2	47.8	17.0	7.6	14.0
pm3	1.0	3.0	0.0	17.8	17.0	15.9	15.2	15.5	16.8	18.3	18.9	18.1	16.1	16.6	16.2	23.2	29.9	33.1	35.0	36.4	37.7	38.4	38.0	52.3	16.5	7.2	17.5
pm4	1.0	3.0	0.0	14.6	14.0	12.8	12.1	12.8	14.5	16.5	17.3	16.3	13.9	14.5	13.9	22.4	30.2	34.0	36.0	37.5	38.8	39.5	39.2	50.6	20.1	9.7	5.5
pm1	2.0	3.0	0.0	15.4	14.8	13.7	13.1	13.6	15.1	16.7	17.4	16.5	14.5	14.9	14.5	22.1	29.3	32.7	34.7	36.0	37.4	38.2	38.0	50.7	18.4	8.5	12.4
pm2	2.0	3.0	0.0	14.8	14.1	12.8	12.0	12.8	14.7	16.7	17.5	16.4	14.0	14.6	14.0	22.4	30.0	33.7	35.8	37.2	38.6	39.3	39.1	50.7	19.6	9.5	5.1
pm3	2.0	3.0	0.0	16.0	15.3	13.9	13.0	13.9	15.9	18.0	18.9	17.8	15.1	15.7	15.2	24.5	32.4	35.9	37.8	39.0	40.3	40.8	40.3	52.4	19.9	9.7	3.4
pm4	2.0	3.0	0.0	14.0	13.4	12.4	11.8	12.3	13.8	15.4	16.1	15.2	13.2	13.6	13.2	20.1	26.7	30.1	32.1	33.4	34.8	35.5	35.3	48.8	17.9	8.2	10.3
pm1	1.0	3.0	12.0	15.8	14.9	13.8	13.1	13.9	15.5	16.8	17.3	16.6	14.8	15.3	14.8	22.5	27.5	29.0	33.3	37.5	39.0	39.2	38.5	50.5	16.3	7.7	18.8

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																			Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm2	1.0	3.0	12.0	13.9	13.2	12.3	11.8	12.4	13.9	15.2	15.6	15.0	13.3	13.8	13.3	20.4	25.2	26.9	30.9	34.8	36.4	36.9	36.4	48.5	16.3	7.8	19.5
pm3	1.0	3.0	12.0	17.1	16.3	15.4	14.8	15.3	16.5	17.7	18.2	17.6	16.0	16.4	16.0	23.2	28.3	30.0	34.0	37.8	39.4	39.8	39.3	51.7	15.4	7.1	24.7
pm1	2.0	3.0	12.0	17.1	16.2	15.0	14.3	15.1	16.7	18.0	18.5	17.9	16.0	16.6	16.0	24.2	29.3	30.8	35.2	39.5	41.0	41.2	40.4	52.2	16.3	7.7	20.4
pm2	2.0	3.0	12.0	14.5	13.8	12.7	12.1	12.9	14.6	16.2	16.8	16.0	14.0	14.7	14.2	22.3	27.7	29.6	34.1	38.3	40.1	40.5	39.8	50.1	17.7	8.9	17.7
pm3	2.0	3.0	12.0	16.0	15.1	13.8	13.0	13.9	15.9	17.7	18.3	17.5	15.1	15.8	15.2	24.8	31.1	33.2	37.2	40.7	42.0	42.1	41.2	52.1	19.0	9.4	11.6
pm1	1.0	3.0	24.0	15.3	14.4	13.3	12.7	13.6	15.1	16.3	16.7	16.1	14.5	15.2	14.7	21.8	25.5	26.2	31.4	37.6	39.6	39.8	39.0	49.8	14.7	7.3	26.7
pm2	1.0	3.0	24.0	14.2	13.4	12.4	11.8	12.6	14.4	15.7	16.1	15.5	13.8	14.4	13.9	21.4	25.5	26.5	31.5	37.0	39.0	39.3	38.7	49.1	15.8	8.0	22.1
pm3	1.0	3.0	24.0	16.1	15.3	14.3	13.7	14.3	15.7	16.9	17.2	16.7	15.2	15.8	15.3	22.3	26.4	27.4	32.4	38.0	40.1	40.4	39.7	50.6	14.8	7.1	28.1
pm1	2.0	3.0	24.0	15.5	14.7	13.8	13.2	14.1	15.8	17.1	17.5	16.9	15.2	15.9	15.3	22.7	26.7	27.6	32.8	38.7	40.7	40.9	40.2	50.8	14.9	7.5	25.1
pm2	2.0	3.0	24.0	14.4	13.6	12.6	12.0	13.0	0.0	16.2	16.6	16.0	14.2	15.0	14.5	22.0	25.8	26.8	32.2	38.4	40.6	41.0	40.2	49.7	15.5	8.1	26.6
pm3	2.0	3.0	24.0	15.7	14.6	13.3	12.6	13.6	15.6	17.2	17.7	17.0	14.9	15.7	15.1	23.8	28.4	29.7	34.8	40.0	41.7	41.8	41.0	51.2	16.9	8.8	20.1
pm1	1.0	3.0	36.0	15.8	14.9	14.0	13.4	14.4	16.1	17.1	17.2	16.8	15.4	16.2	15.7	21.6	23.9	24.3	29.5	36.6	39.2	39.4	38.6	50.1	11.7	6.0	35.0
pm2	1.0	3.0	36.0	14.5	13.6	12.4	11.8	12.9	14.9	16.2	16.4	15.9	14.2	15.0	14.4	21.1	23.9	24.4	29.5	36.1	38.5	38.9	38.2	49.1	13.3	7.1	28.0
pm3	1.0	3.0	36.0	16.1	15.1	14.2	13.6	14.3	15.7	16.7	16.9	16.5	15.1	15.8	15.3	21.8	24.8	25.4	30.8	37.7	40.2	40.4	39.5	50.1	13.3	6.5	33.2
pm1	2.0	3.0	36.0	15.2	14.3	13.3	12.8	13.8	15.6	16.8	17.1	16.6	15.1	15.9	15.4	22.1	24.8	25.3	30.7	37.9	40.5	40.8	40.1	50.2	13.1	7.1	32.7
pm2	2.0	3.0	36.0	14.8	13.8	12.7	12.2	13.3	15.2	16.4	16.6	16.1	14.7	15.5	15.0	21.7	24.4	25.0	30.8	38.1	40.7	41.1	40.2	49.7	13.5	7.4	35.9
pm3	2.0	3.0	36.0	14.0	13.2	12.1	11.6	12.4	14.2	15.4	15.7	15.1	13.5	14.1	13.7	19.9	22.9	23.7	28.4	33.6	35.5	35.9	35.3	48.0	13.4	6.7	25.3
pm1	1.0	3.0	48.0	14.4	13.7	13.0	12.7	13.6	15.0	15.7	15.8	15.5	14.6	15.3	14.9	19.7	21.1	21.3	26.7	34.7	37.6	38.0	37.2	48.4	10.1	5.5	46.0
pm2	1.0	3.0	48.0	14.0	13.1	12.2	11.7	12.9	14.7	15.8	15.9	15.5	14.2	15.1	14.5	20.5	22.5	22.7	28.1	35.8	38.5	38.8	38.1	48.6	12.0	6.7	38.4
pm3	1.0	3.0	48.0	16.4	15.5	14.7	14.2	14.8	16.2	17.1	17.2	16.9	15.7	16.4	16.0	21.9	24.1	24.5	30.1	37.9	40.6	40.8	39.8	50.4	11.8	6.0	40.3
pm1	2.0	3.0	48.0	14.9	14.1	13.2	12.7	13.8	15.5	16.5	16.5	16.2	15.1	15.9	15.4	21.1	22.9	23.1	28.7	36.8	39.7	40.0	39.3	49.5	11.2	6.3	43.2
pm2	2.0	3.0	48.0	14.7	13.7	12.7	12.3	13.5	15.5	16.5	16.6	16.2	15.0	16.0	15.5	21.6	23.5	23.9	30.0	38.2	41.1	41.4	40.4	49.8	12.2	7.1	45.2
pm3	2.0	3.0	48.0	13.9	13.1	12.1	11.6	12.6	14.3	15.5	15.6	15.1	13.7	14.4	14.0	19.8	22.0	22.4	27.4	33.5	35.7	36.1	35.4	47.9	12.1	6.3	32.7
pm1	1.0	3.0	60.0	15.3	14.3	13.4	13.0	14.2	15.8	16.5	16.5	16.2	15.3	16.2	15.8	20.5	21.7	21.7	27.2	35.5	38.7	39.0	38.2	49.3	9.5	5.5	50.3
pm2	1.0	3.0	60.0	14.8	13.7	12.5	11.9	13.5	15.7	16.8	16.9	16.5	15.1	16.2	15.6	21.7	23.6	23.9	29.4	37.3	40.1	40.5	39.9	50.0	11.7	7.0	42.1
pm3	1.0	3.0	60.0	15.5	14.5	13.6	13.1	14.0	15.5	16.3	16.3	16.0	15.0	15.8	15.4	21.0	22.8	23.0	28.9	37.6	40.6	40.8	39.8	49.4	11.5	6.2	45.9
pm1	2.0	3.0	60.0	16.3	15.3	14.3	13.8	15.0	16.6	17.4	17.4	17.1	16.2	17.2	16.7	21.9	23.2	23.3	29.1	37.8	41.0	41.3	40.5	50.7	10.1	5.9	51.2
pm2	2.0	3.0	60.0	14.2	13.1	12.2	11.8	13.2	15.2	16.1	16.1	15.8	14.8	15.9	15.5	21.1	22.5	22.7	29.0	37.7	40.8	41.1	40.1	49.4	11.4	7.1	53.0
pm3	2.0	3.0	60.0	13.4	12.5	11.6	11.2	12.3	14.2	15.2	15.2	14.8	13.6	14.5	14.0	19.4	21.0	21.4	26.6	33.3	35.8	36.1	35.5	47.6	11.2	6.3	41.5
pm1	1.0	3.0	72.0	14.6	13.7	13.1	12.8	13.8	15.3	15.9	15.8	15.6	15.0	15.9	15.6	19.7	20.6	20.6	26.2	35.3	38.9	39.3	38.6	48.7	9.0	5.5	58,1
pm2	1.0	3.0	72.0	14.3	13.2	12.2	11.8	13.3	15.3	16.2	16.1	15.8	14.9	16.0	15.5	20.7	21.9	22.0	27.7	36.3	39.5	39.9	39.1	49.2	10.5	6.6	53.5
pm3	1.0	3.0	72.0	16.2	15.1	14.3	13.8	14.7	16.1	16.9	16.8	16.6	15.7	16.6	16.2	21.4	23.0	23.1	29.1	38.0	41.1	41.3	40.3	50.1	10.7	5.8	49.6
pm1	2.0	3.0	72.0	15.4	14.5	13.7	13.4	14.5	16.0	16.6	16.4	16.3	15.6	16.6	16.2	20.5	21.3	21.3	26.8	35.5	38.9	39.3	38.4	49.5	8.8	5.3	56.7
pm2	2.0	3.0	72.0	14.3	13.2	12.3	11.9	13.4	15.4	16.2	16.1	15.9	15.0	16.2	15.8	21.0	22.1	22.3	28.7	37.8	41.2	41.5	40.5	49.5	10.7	7.0	59.4
pm3	2.0	3.0	72.0	13.6	12.8	12.0	11.6	12.6	14.4	15.3	15.4	15.0	13.9	14.7	14.2	19.5	21.0	21.3	26.6	33.5	36.0	36.4	35.7	47.8	10.9	6.1	42.7
pm1	1.0	3.0	84.0	14.3	13.4	12.7	12.4	13.6	15.1	15.6	15.5	15.3	14.8	15.9	15.6	19.4	20.0	20.0	25.6	34.6	38.2	38.6	37.9	48.4	8.5	5.5	63.0
pm2	1.0	3.0	84.0	14.6	13.5	12.4	12.0	13.7	15.9	16.7	16.6	16.3	15.4	16.6	16.1	21.3	22.4	22.5	28.4	37.1	40.4	40.8	40.0	49.8	10.2	6.7	55.8
pm3	1.0	3.0	84.0	16.1	15.1	14.3	13.9	14.7	16.1	16.8	16.7	16.5	15.7	16.6	16.3	21.1	22.3	22.3	28.1	37.2	40.6	40.7	39.6	49.9	9.9	5.6	53.2
pm1	2.0	3.0	84.0	15.5	14.5	13.6	13.3	14.4	16.0	16.5	16.4	16.2	15.6	16.7	16.3	20.6	21.4	21.3	27.1	36.2	39.7	40.1	39.3	49.6	8.9	5.6	60.5
pm2	2.0	3.0	84.0	13.8	12.8	11.9	11.6	13.2	15.2	15.9	15.7	15.6	15.0	16.3	16.0	20.6	21.4	21.5	27.8	37.1	40.5	40.8	39.8	49.2	9.9	7.1	68.3

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm3	2.0	3.0	84.0	13.1	12.3	11.5	11.2	12.5	14.3	15.1	15.0	14.7	13.8	14.8	14.4	18.9	19.9	20.1	25.5	32.7	35.4	35.9	35.2	47.4	9.7	6.0	52.7
pm1	1.0	3.0	96.0	14.9	13.9	13.1	12.9	14.5	16.1	16.5	16.2	16.2	15.9	17.2	16.9	20.2	20.5	20.4	25.9	35.2	39.0	39.5	38.7	49.6	7.4	5.6	73.7
pm2	1.0	3.0	96.0	14.3	13.1	12.2	11.9	13.5	15.5	16.2	15.9	15.8	15.1	16.4	16.0	20.4	21.2	21.2	26.9	35.8	39.2	39.5	38.7	49.2	9.3	6.4	63.7
pm3	1.0	3.0	96.0	16.4	15.5	14.8	14.4	15.3	16.7	17.3	17.2	17.0	16.3	17.3	16.9	21.6	22.7	22.8	28.7	38.0	41.5	41.7	40.5	50.6	9.5	5.4	55.3
pm1	2.0	3.0	96.0	15.9	14.7	13.8	13.6	15.3	16.9	17.4	17.1	17.1	16.7	17.9	17.6	21.3	21.7	21.6	27.3	36.6	40.4	40.9	40.2	50.7	7.7	5.6	69.1
pm2	2.0	3.0	96.0	13.6	12.6	11.8	11.6	13.4	15.4	16.1	15.8	15.7	15.2	16.6	16.2	20.6	21.2	21.3	27.5	37.1	40.7	41.2	40.4	49.3	9.5	7.0	70.5
pm3	2.0	3.0	96.0	13.7	12.7	11.9	11.7	13.0	14.7	15.4	15.2	15.0	14.3	15.4	15.0	19.0	19.7	19.7	25.1	32.8	35.7	36.1	35.4	47.8	8.7	5.7	60.2
pm1	1.0	4.0	0.0	14.9	14.2	12.8	12.0	12.9	15.0	17.3	18.3	17.0	14.2	14.9	14.3	24.0	32.2	35.9	38.2	39.7	41.0	41.6	41.2	51.7	21.2	10.4	0.0
pm2	1.0	4.0	0.0	15.7	14.9	13.3	12.4	13.4	15.8	18.1	19.1	17.9	14.9	15.7	15.0	25.5	34.0	37.6	39.7	41.0	42.2	42.7	42.2	52.9	21.5	10.8	0.0
pm3	1.0	4.0	0.0	17.8	17.0	15.4	14.5	15.2	17.3	19.5	20.4	19.2	16.4	17.1	16.5	27.1	35.6	39.1	41.3	42.9	44.1	44.6	44.1	54.4	21.0	10.0	2.7
pm4	1.0	4.0	0.0	15.1	14.3	12.8	12.0	12.8	15.0	17.1	17.8	16.6	14.1	14.6	14.1	22.1	29.2	32.7	35.0	36.6	38.1	38.9	38.5	50.6	18.6	8.7	2.4
pm1	2.0	4.0	0.0	16.8	16.1	14.4	13.4	14.5	16.8	19.1	20.1	19.0	16.1	16.9	16.2	26.3	34.5	38.1	40.2	41.7	43.0	43.5	43.1	53.9	20.3	10.3	2.6
pm2	2.0	4.0	0.0	14.5	13.8	12.6	11.9	12.6	14.4	16.4	17.0	16.0	13.8	14.3	13.9	20.8	27.5	31.0	33.5	35.6	37.3	38.4	38.2	49.7	17.6	8.3	10.5
pm3	2.0	4.0	0.0	16.3	15.6	13.7	12.6	13.9	16.5	18.9	19.9	18.6	15.6	16.4	15.7	25.4	33.2	36.7	38.8	40.2	41.5	42.2	41.7	53.2	19.7	10.0	0.0
pm4	2.0	4.0	0.0	15.0	14.3	13.1	12.4	13.1	14.8	16.6	17.3	16.3	14.1	14.6	14.2	22.0	29.0	32.3	34.2	35.6	37.0	37.8	37.5	50.4	18.5	8.7	9.1
pm1	1.0	4.0	12.0	15.8	14.8	13.3	12.5	13.6	15.7	17.7	18.4	17.4	14.9	15.6	14.9	25.7	32.8	34.8	39.7	44.1	45.5	45.3	44.2	52.5	21.0	10.5	5.3
pm2	1.0	4.0	12.0	15.6	14.7	13.1	12.2	13.4	15.5	17.5	18.3	17.3	14.8	15.5	14.9	25.4	32.2	34.3	38.7	42.4	43.7	43.6	42.6	52.3	20.5	10.5	6.2
pm3	1.0	4.0	12.0	16.3	15.3	13.7	12.9	13.9	16.1	18.2	18.9	17.9	15.3	16.0	15.4	26.5	33.5	35.3	40.2	44.7	46.1	45.9	44.7	53.1	20.9	10.6	6.8
pm1	2.0	4.0	12.0	16.5	15.4	14.3	13.7	14.8	16.9	18.4	18.7	18.2	16.4	17.3	16.7	24.1	27.7	28.7	34.0	39.8	41.9	42.3	41.6	52.2	14.1	7.7	29.9
pm2	2.0	4.0	12.0	14.0	13.1	12.2	11.8	12.7	14.4	15.6	15.7	15.3	14.0	14.7	14.3	20.2	23.2	24.3	29.6	35.7	38.2	39.0	38.5	48.6	13.4	7.2	36.7
pm3	2.0	4.0	12.0	16.4	15.5	13.9	13.0	14.4	17.0	19.0	19.6	18.7	16.3	17.2	16.4	25.7	30.7	32.2	37.2	42.1	43.9	44.2	43.6	53.1	16.8	9.1	14.2
pm1	1.0	4.0	24.0	15.7	14.8	13.5	12.8	13.8	15.9	17.6	18.2	17.3	15.1	15.9	15.3	24.9	30.3	31.5	37.2	43.5	45.4	45.3	44.1	52.0	18.5	9.4	15.2
pm2	1.0	4.0	24.0	16.2	15.2	13.6	12.8	14.2	16.7	18.7	19.3	18.4	15.8	16.7	16.0	26.5	32.0	33.2	38.8	44.9	46.7	46.5	45.3	53.2	18.7	9.9	12.0
pm3	1.0	4.0	24.0	17.5	16.5	15.1	14.4	15.5	17.6	19.4	20.0	19.1	16.8	17.6	17.0	26.9	32.1	33.3	38.8	44.9	46.8	46.6	45.3	53.9	17.6	8.9	16.5
pm1	2.0	4.0	24.0	17.3	16.2	15.0	14.5	16.0	18.3	19.4	19.5	19.1	17.8	19.0	18.4	25.0	27.0	27.3	33.4	41.3	44.1	44.5	43.5	53.3	11.7	7.1	46.6
pm2	2.0	4.0	24.0	13.7	12.8	12.1	11.8	12.7	14.4	15.3	15.3	15.0	14.0	14.9	14.5	19.8	21.8	22.4	28.3	36.0	39.1	39.7	39.0	48.2	11.9	6.8	47.7
pm3	2.0	4.0	24.0	16.4	15.4	13.9	13.1	14.8	17.5	19.3	19.7	19.0	16.8	17.9	17.1	25.8	29.4	30.2	36.1	42.9	45.2	45.6	44.9	53.3	15.0	8.6	25.3
pm1	1.0	4.0	36.0	16.0	15.0	13.7	13.0	14.2	16.4	18.1	18.5	17.8	15.7	16.5	15.9	24.7	28.7	29.3	35.3	42.9	45.4	45.3	44.1	52.0	16.1	8.4	20.6
pm2	1.0	4.0	36.0	13.1	12.1	10.6	10.0	11.7	14.3	16.2	16.7	15.9	13.6	14.5	13.8	23.6	27.8	28.4	34.6	42.1	44.6	44.5	43.5	50.1	18.3	10.3	16.1
pm3	1.0	4.0	36.0	15.5	14.4	13.1	12.5	13.7	15.9	17.6	17.9	17.2	15.2	16.1	15.5	24.4	27.9	28.4	34.6	42.6	45.4	45.4	44.3	51.5	16.1	8.7	24.6
pm1	2.0	4.0	36.0	17.1	15.8	14.6	14.2	15.9	17.9	18.8	18.6	18.4	17.5	18.8	18.4	23.6	24.7	24.8	30.9	39.5	42.6	42.9	41.9	52.4	9.8	6.4	58.7
pm2	2.0	4.0	36.0	13.7	12.8	12.1	11.9	13.0	14.7	15.4	15.3	15.1	14.4	15.4	15.1	19.7	21.0	21.3	27.5	36.1	39.5	40.0	39.1	48.4	10.5	6.5	57.9
pm3	2.0	4.0	36.0	16.5	15.2	13.6	12.9	15.1	17.8	19.2	19.2	18.8	17.2	18.5	17.8	24.8	26.9	27.1	33.3	41.4	44.2	44.4	43.6	52.9	12.1	7.7	42.4
pm1	1.0	4.0	48.0	16.2	15.1	13.9	13.3	14.6	16.9	18.4	18.7	18.0	16.2	17.2	16.5	24.6	27.4	27.8	34.0	42.5	45.4	45.4	44.3	52.2	14.2	7.8	30.0
pm2	1.0	4.0	48.0	15.3	14.3	12.9	12.3	14.1	16.8	18.4	18.8	18.1	16.1	17.2	16.5	25.3	28.5	29.0	35.5	43.9	46.8	46.8	45.6	52.5	15.3	8.9	28.8
pm3	1.0	4.0	48.0	16.2	15.0	13.7	13.2	14.5	16.7	18.2	18.3	17.8	16.1	17.1	16.5	24.2	26.7	27.0	33.3	42.2	45.5	45.7	44.6	51.9	13.7	7.8	35.2
pm1	2.0	4.0	48.0	16.5	15.4	14.4	14.1	15.6	17.5	18.1	17.9	17.8	17.2	18.5	18.2	22.6	23.5	23.5	29.9	39.4	43.1	43.5	42.6	51.7	9.1	6.2	66.4
pm2	2.0	4.0	48.0	12.9	12.0	11.4	11.2	12.5	14.2	14.8	14.7	14.5	14.0	15.1	14.8	18.9	19.9	20.1	26.1	35.2	38.7	39.2	38.4	47.6	9.7	6.5	65.1
pm3	2.0	4.0	48.0	16.1	14.8	13.3	12.8	15.0	17.8	19.1	19.0	18.7	17.3	18.7	18.1	24.8	26.5	26.7	33.2	42.1	45.2	45.5	44.7	52.9	11.7	7.9	50.9
pm1	1.0	4.0	60.0	16.4	15.2	14.0	13.5	14.9	17.2	18.5	18.6	18.1	16.5	17.6	17.0	24.2	26.3	26.5	32.8	42.0	45.3	45.4	44.2	52.1	12.7	7.3	39.6

Meat-type & repli-cate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																			Color*			% of metmyoglo-bin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm2	1.0	4.0	60.0	15.8	14.6	13.3	12.8	14.4	16.8	18.2	18.4	17.9	16.2	17.2	16.6	24.3	26.8	27.1	33.3	41.9	44.8	44.9	43.7	52.0	13.6	7.9	36.0
pm3	1.0	4.0	60.0	16.7	15.5	14.3	13.8	15.1	17.1	18.3	18.2	17.9	16.6	17.8	17.2	23.8	25.4	25.5	32.0	41.6	45.2	45.5	44.5	51.9	11.8	7.0	48.2
pm1	1.0	4.0	60.0	17.3	15.9	14.6	14.3	16.6	18.9	19.6	19.3	19.2	18.8	20.5	20.1	24.7	25.4	25.4	32.1	42.1	45.8	46.3	45.4	53.8	9.0	7.1	75.6
pm2	1.0	4.0	60.0	13.8	12.9	12.2	12.0	13.4	15.1	15.7	15.4	15.3	14.9	16.1	15.9	19.7	20.5	20.6	26.8	36.2	39.9	40.4	39.5	48.7	9.1	6.3	69.8
pm3	1.0	4.0	60.0	16.0	14.8	13.4	12.9	15.2	18.0	19.1	19.0	18.7	17.5	19.0	18.4	24.6	26.1	26.3	32.9	42.2	45.6	45.9	45.1	53.0	11.1	7.7	55.8
pm1	1.0	4.0	72.0	16.4	15.2	14.1	13.6	15.2	17.4	18.4	18.4	18.0	16.8	18.0	17.4	23.7	25.0	25.1	31.4	40.9	44.5	44.7	43.6	52.0	11.1	6.8	49.5
pm2	1.0	4.0	72.0	16.2	14.8	13.5	13.0	14.7	17.1	18.3	18.3	17.9	16.4	17.6	17.0	23.8	25.6	25.8	32.1	41.1	44.3	44.4	43.3	51.8	12.1	7.3	44.1
pm3	1.0	4.0	72.0	16.6	15.4	14.3	13.8	15.3	17.3	18.3	18.1	17.9	16.9	18.1	17.7	23.5	24.6	24.7	31.1	40.7	44.4	44.7	43.7	51.9	10.7	6.7	55.9
pm1	2.0	4.0	72.0	16.7	15.5	14.6	14.3	16.1	18.1	18.5	18.1	18.1	17.9	19.4	19.2	23.0	23.4	23.5	29.9	39.8	43.5	43.9	42.9	52.4	8.2	6.3	77.4
pm2	2.0	4.0	72.0	13.7	12.7	12.1	11.9	13.4	15.1	15.5	15.2	15.2	15.0	16.3	16.2	19.4	19.9	20.0	26.1	35.7	39.5	40.0	39.2	48.6	8.2	6.3	78.0
pm3	2.0	4.0	72.0	15.3	14.0	12.8	12.4	14.5	16.8	17.7	17.5	17.3	16.5	17.9	17.4	22.6	23.6	23.7	30.1	39.4	42.7	43.1	42.2	51.3	10.1	7.1	62.2
pm1	1.0	4.0	84.0	15.5	14.3	13.2	12.9	14.8	17.1	17.9	17.7	17.5	16.6	18.0	17.5	22.8	23.7	23.7	30.1	39.9	43.6	44.0	43.0	51.4	10.0	6.9	61.4
pm2	1.0	4.0	84.0	15.0	14.0	13.0	12.6	14.1	16.1	17.1	17.1	16.7	15.6	16.7	16.2	22.2	23.6	23.7	30.0	39.1	42.5	42.7	41.7	50.4	11.4	6.8	49.2
pm3	1.0	4.0	84.0	15.3	14.3	13.3	13.0	14.5	16.5	17.3	17.1	16.9	16.1	17.5	17.1	22.2	23.1	23.1	29.6	39.3	43.0	43.3	42.3	50.8	10.1	6.8	64.1
pm1	2.0	4.0	84.0	17.3	15.7	14.2	14.2	17.7	20.3	20.7	20.1	20.2	20.4	22.5	22.5	26.0	26.1	26.0	32.7	42.7	46.3	46.6	45.6	55.3	7.7	7.7	95.4
pm2	2.0	4.0	84.0	13.7	12.8	12.3	12.1	13.7	15.4	15.6	15.3	15.3	15.5	16.8	16.9	19.2	19.5	19.6	25.7	35.4	39.4	40.0	39.3	48.9	7.2	6.2	87.3
pm3	2.0	4.0	84.0	15.4	14.1	12.9	12.5	14.7	17.1	17.9	17.6	17.5	16.8	18.3	17.8	22.8	23.7	23.7	30.3	39.8	43.2	43.6	42.6	51.6	9.8	7.2	66.9
pm1	1.0	4.0	96.0	15.5	14.3	13.3	13.0	15.0	17.2	18.0	17.7	17.5	16.9	18.4	18.1	22.8	23.4	23.4	29.8	39.6	43.6	44.0	43.0	51.6	9.3	6.9	70.0
pm2	1.0	4.0	96.0	16.1	14.9	13.9	13.6	15.5	17.7	18.5	18.4	18.1	17.3	18.6	18.1	23.4	24.3	24.4	30.5	39.7	43.2	43.5	42.5	52.1	9.7	6.5	60.0
pm3	1.0	4.0	96.0	15.8	14.6	13.6	13.4	115.3	17.3	17.9	17.6	17.5	17.1	18.6	18.3	22.6	23.0	22.9	29.3	39.4	43.6	44.0	43.0	51.6	8.7	6.7	74.9
pm1	2.0	4.0	96.0	16.9	15.6	14.6	14.5	16.9	18.9	19.2	18.7	18.8	19.1	20.8	20.9	23.5	23.6	23.5	29.7	39.6	43.6	44.0	43.1	53.4	6.8	6.6	92.6
pm2	2.0	4.0	96.0	13.6	12.7	12.1	11.9	13.5	15.2	15.5	15.2	15.2	15.4	16.7	16.9	19.1	19.5	19.7	25.8	35.4	39.4	40.2	39.6	48.8	7.4	6.5	88.2
pm3	2.0	4.0	96.0	15.8	14.4	13.0	12.7	15.5	18.1	18.9	18.5	18.5	17.9	19.7	19.3	24.1	24.6	24.6	31.3	41.3	45.0	45.3	44.3	52.9	9.3	7.6	76.4
pm1	1.0	5.0	0.0	16.2	15.3	13.2	12.1	13.7	16.8	19.8	21.1	19.5	15.9	16.9	16.1	28.1	37.0	40.9	42.9	44.7	46.1	46.8	46.2	54.8	22.3	11.9	0.0
pm2	1.0	5.0	0.0	16.2	15.4	13.2	12.1	13.7	16.9	19.8	21.0	19.4	15.8	16.8	16.0	27.8	36.5	40.4	42.4	44.1	45.5	46.1	45.6	54.6	22.0	11.5	0.0
pm3	1.0	5.0	0.0	17.2	16.3	14.0	12.9	14.5	17.2	19.9	20.8	19.6	16.4	17.3	16.5	27.3	35.2	38.4	40.1	41.5	42.4	42.6	41.7	54.5	20.1	10.5	0.0
pm4	1.0	5.0	0.0	16.2	15.4	14.0	13.2	14.0	16.0	18.2	19.1	18.0	15.3	16.0	15.4	25.7	34.4	38.3	40.5	42.3	43.7	44.4	44.1	53.2	21.6	10.7	4.3
pm1	2.0	5.0	0.0	14.3	13.6	12.4	11.8	12.5	14.2	16.0	16.7	15.6	13.4	13.9	13.4	20.8	27.5	30.9	32.6	34.2	35.4	36.0	35.5	49.3	18.2	8.3	7.4
pm2	2.0	5.0	0.0	14.8	14.0	12.6	11.8	12.7	14.6	16.7	17.5	16.2	13.8	14.3	13.8	22.0	29.2	32.7	34.6	36.2	37.6	38.3	37.9	50.3	19.1	9.0	3.7
pm3	2.0	5.0	0.0	17.1	16.2	14.2	13.2	14.5	17.0	19.5	20.4	19.1	15.9	16.7	16.1	26.8	34.8	38.1	39.7	41.1	41.9	42.0	41.0	54.0	20.5	10.1	0.0
pm4	2.0	5.0	0.0	14.6	13.8	12.4	11.6	12.5	14.4	16.5	17.3	16.2	13.7	14.2	13.8	22.2	29.4	32.8	34.5	36.0	37.1	37.6	37.1	50.2	19.4	9.3	3.7
pm1	1.0	5.0	12.0	16.0	15.0	13.1	12.3	13.9	16.9	19.3	20.1	19.0	16.0	17.1	16.4	27.6	33.4	35.2	40.5	45.3	47.2	47.5	46.7	54.0	19.5	10.8	8.3
pm2	1.0	5.0	12.0	16.4	15.4	13.3	12.3	14.1	17.2	19.8	20.8	19.5	16.3	17.4	16.6	28.7	35.2	37.3	42.1	46.4	47.9	48.1	47.2	54.7	20.6	11.2	2.7
pm3	1.0	5.0	12.0	17.4	16.1	13.9	12.9	14.8	17.5	19.7	20.1	19.3	16.7	17.8	17.0	26.4	30.4	31.3	36.2	41.2	42.8	42.7	41.5	53.5	15.6	8.8	17.3
pm1	2.0	5.0	12.0	15.1	14.1	12.6	11.9	13.1	15.5	17.5	18.0	17.1	14.7	15.6	15.0	24.1	28.5	29.7	35.1	40.5	42.4	42.6	41.9	51.2	17.1	9.0	15.3
pm2	2.0	5.0	12.0	14.5	13.7	12.5	11.9	12.7	14.6	16.2	16.8	15.9	13.8	14.5	13.9	21.9	26.5	28.1	32.5	36.8	38.4	38.8	38.1	49.6	16.7	8.2	14.6
pm3	2.0	5.0	12.0	16.8	15.6	13.5	12.6	14.2	16.9	19.4	20.1	19.0	15.9	16.9	16.1	28.2	34.7	36.5	41.5	46.0	47.2	46.9	45.4	54.2	20.8	10.9	3.6
pm1	1.0	5.0	24.0	15.7	14.7	12.9	12.2	14.0	17.0	19.2	19.8	18.9	16.2	17.4	16.7	27.3	31.8	33.0	39.2	45.7	47.8	48.1	47.2	53.7	18.0	10.3	18.5
pm2	1.0	5.0	24.0	16.0	15.0	13.2	12.4	14.2	17.3	19.6	20.3	19.3	16.3	17.5	16.7	27.8	33.0	34.4	40.1	45.9	47.8	47.9	47.0	54.1	18.7	10.4	11.2
pm3	1.0	5.0	24.0	16.5	15.2	13.5	12.9	14.6	17.0	18.6	18.7	18.2	16.4	17.6	17.0	24.3	26.5	26.8	32.3	39.3	41.5	41.5	40.5	52.1	12.7	7.6	37.1

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm1	2.0	5.0	24.0	14.8	13.8	12.5	12.0	13.6	16.1	17.6	17.8	17.2	15.4	16.5	15.9	23.4	25.8	26.3	32.6	40.0	42.5	42.8	42.1	51.1	13.7	8.0	36.2
pm2	2.0	5.0	24.0	15.9	14.9	13.5	12.7	13.7	15.7	17.5	18.1	17.2	14.8	15.5	14.9	23.9	28.7	29.8	34.2	38.5	39.9	39.7	38.7	51.2	17.0	8.3	11.0
pm3	2.0	5.0	24.0	16.2	15.2	13.4	12.6	14.2	16.7	18.8	19.2	18.3	15.8	16.8	16.1	26.0	30.2	31.1	36.6	42.4	44.2	44.0	42.6	52.7	17.1	9.0	14.9
pm1	1.0	5.0	36.0	15.7	14.5	12.9	12.2	14.2	17.2	19.2	19.5	18.8	16.5	17.9	17.2	26.6	29.7	30.5	37.1	44.8	47.4	47.7	46.8	53.4	15.8	9.6	30.8
pm2	1.0	5.0	36.0	16.0	14.9	13.1	12.4	14.3	17.4	19.5	20.1	19.2	16.6	17.8	17.1	27.4	31.3	32.2	38.6	45.7	47.9	48.0	47.0	53.9	17.0	9.9	22.2
pm3	1.0	5.0	36.0	16.7	15.2	13.4	12.8	15.1	17.7	19.0	18.8	18.6	17.2	18.7	18.2	24.6	25.8	25.7	31.7	40.0	42.7	42.7	41.4	52.7	11.0	7.6	54.9
pm1	2.0	5.0	36.0	14.2	13.1	12.3	11.9	12.9	14.6	15.5	15.4	15.0	14.0	14.9	14.5	19.3	20.6	20.9	26.3	33.2	35.7	36.1	35.4	47.8	10.2	5.7	47.7
pm2	2.0	5.0	36.0	16.0	15.0	13.6	13.0	14.0	16.0	17.6	18.0	17.2	15.1	15.9	15.3	23.4	26.8	27.4	32.3	38.1	40.0	39.9	38.9	50.9	14.8	7.4	19.2
pm3	2.0	5.0	36.0	16.7	15.3	13.5	12.9	15.0	17.9	19.5	19.6	19.0	17.0	18.5	17.8	26.4	28.7	29.1	35.8	44.1	46.6	46.5	45.0	53.5	14.2	8.5	38.7
pm1	1.0	5.0	48.0	15.5	14.3	12.7	12.2	14.5	17.5	19.2	19.3	18.8	17.0	18.5	17.9	26.2	28.3	28.8	36.0	44.6	47.6	47.9	47.0	53.4	14.1	9.2	45.2
pm2	1.0	5.0	48.0	15.8	14.7	13.1	12.5	14.4	17.3	19.2	19.6	18.8	16.5	17.8	17.1	26.7	30.0	30.7	37.5	45.1	47.7	47.8	46.7	53.5	16.1	9.4	28.2
pm3	1.0	5.0	48.0	15.9	14.4	13.0	12.7	14.9	17.2	18.2	17.9	17.8	17.0	18.6	18.2	23.4	24.0	23.8	29.8	38.6	41.7	41.8	40.7	51.9	9.6	7.4	69.2
pm1	2.0	5.0	48.0	14.6	13.4	12.3	12.0	13.9	16.2	17.1	16.9	16.7	15.8	17.3	17.0	22.2	23.0	23.1	29.7	38.7	42.0	42.4	41.5	50.6	10.4	7.4	66.9
pm2	2.0	5.0	48.0	14.2	13.2	12.3	11.9	13.3	15.3	16.2	16.1	15.8	14.9	16.0	15.6	20.7	21.8	22.0	28.1	36.2	39.2	39.6	38.9	49.2	10.4	6.6	55.2
pm3	2.0	5.0	48.0	16.4	14.9	13.3	12.9	15.3	18.0	19.3	19.2	18.8	17.4	19.0	18.4	25.6	27.0	27.2	34.2	43.1	46.0	45.9	44.4	53.3	12.2	8.1	55.0
pm1	1.0	5.0	60.0	16.4	15.1	13.6	13.2	15.5	18.4	19.7	19.7	19.3	17.8	19.3	18.8	26.1	27.7	28.1	35.3	44.1	47.3	47.7	46.8	53.9	12.5	8.3	53.1
pm2	1.0	5.0	60.0	15.7	14.5	13.0	12.5	14.6	17.6	19.3	19.6	18.9	16.9	18.2	17.6	26.4	29.0	29.6	36.6	45.1	47.9	48.2	47.2	53.5	14.8	9.1	37.2
pm3	1.0	5.0	60.0	17.0	15.1	13.4	13.2	15.9	18.4	19.4	18.9	18.9	18.2	20.1	19.7	24.6	24.9	24.6	30.5	39.4	42.5	42.5	41.3	53.3	8.8	7.4	76.1
pm1	2.0	5.0	60.0	14.7	13.4	12.3	12.1	14.6	16.9	17.4	17.0	16.9	16.7	18.3	18.2	22.2	22.5	22.5	29.3	38.7	42.3	42.8	42.0	51.2	8.9	7.3	83.1
pm2	2.0	5.0	60.0	14.4	13.3	12.3	12.0	13.6	15.6	16.4	16.2	15.9	15.2	16.4	16.1	20.6	21.4	21.5	27.5	35.9	39.0	39.4	38.6	49.4	9.5	6.4	63.4
pm3	2.0	5.0	60.0	16.3	14.7	13.2	12.9	15.4	18.1	19.1	18.8	18.6	17.6	19.3	18.8	25.0	25.8	25.9	33.0	42.3	45.5	45.5	43.9	53.1	11.0	7.9	66.2
pm1	1.0	5.0	72.0	15.6	14.1	12.7	12.4	14.8	17.5	18.6	18.5	18.2	17.1	18.7	18.3	24.6	25.7	26.0	33.1	42.2	45.5	45.9	45.1	52.7	11.5	8.3	62.8
pm2	1.0	5.0	72.0	15.7	14.5	12.9	12.4	14.7	17.6	19.1	19.2	18.7	16.9	18.4	17.8	25.9	28.0	28.5	35.6	44.5	47.5	47.8	46.7	53.3	13.9	8.8	44.6
pm3	1.0	5.0	72.0	16.1	14.5	12.9	12.8	15.4	17.8	18.5	18.0	18.1	17.7	19.7	19.6	23.5	23.6	23.2	29.3	38.5	41.9	42.0	40.9	52.5	8.1	7.5	86.3
pm1	2.0	5.0	72.0	14.8	13.4	12.4	12.3	15.1	17.2	17.5	16.9	17.0	17.3	19.2	19.5	21.9	21.8	21.8	28.6	38.3	42.1	42.7	42.0	51.6	7.3	7.3	100.0
pm2	2.0	5.0	72.0	15.7	14.5	13.4	12.9	14.2	16.2	17.3	17.3	16.8	15.6	16.6	16.1	21.9	23.2	23.2	28.8	36.3	38.9	39.0	38.1	50.2	10.6	6.2	45.6
pm3	2.0	5.0	72.0	15.6	14.3	13.1	12.8	14.9	17.2	18.0	17.6	17.5	16.7	18.3	17.9	22.9	23.5	23.5	29.9	38.6	41.7	41.9	40.7	51.5	9.6	6.9	68.5
pm1	1.0	5.0	84.0	16.5	15.1	13.6	13.4	16.1	18.9	19.8	19.5	19.4	18.6	20.4	20.1	25.9	26.6	26.8	34.3	43.9	47.4	47.8	46.9	54.2	10.6	8.2	73.3
pm2	1.0	5.0	84.0	15.8	14.5	13.0	12.6	14.7	17.5	18.9	18.9	18.5	16.9	18.3	17.7	25.4	27.3	27.6	34.6	43.5	46.6	46.8	45.7	52.9	13.2	8.5	47.8
pm3	1.0	5.0	84.0	16.1	14.4	12.9	12.8	15.7	17.9	18.5	17.9	18.1	17.9	19.9	19.9	23.4	23.3	23.0	29.0	38.3	41.7	41.9	40.8	52.6	7.6	7.4	91.9
pm1	2.0	5.0	84.0	14.4	13.3	12.3	12.3	15.1	17.2	17.3	16.7	16.9	17.6	19.4	20.0	21.4	21.2	21.3	27.9	37.5	41.3	42.0	41.4	51.6	6.3	7.4	100.0
pm2	2.0	5.0	84.0	16.7	15.0	13.3	13.1	15.8	18.1	18.8	18.3	18.2	17.7	19.3	19.1	22.8	23.0	22.8	28.4	36.2	39.1	39.3	38.3	52.1	7.5	6.1	74.9
pm3	2.0	5.0	84.0	15.7	14.3	12.9	12.7	15.0	17.4	18.2	17.8	17.7	17.1	18.8	18.5	23.5	24.0	24.0	30.8	39.9	43.0	43.1	41.6	52.1	9.7	7.5	75.8
pm1	1.0	5.0	96.0	15.5	14.1	12.7	12.6	15.6	18.3	19.0	18.7	18.6	18.3	20.2	20.1	25.0	25.4	25.5	33.1	43.1	46.9	47.4	46.6	53.6	9.8	8.5	86.2
pm2	1.0	5.0	96.0	15.8	14.3	12.9	12.5	15.1	18.1	19.3	19.1	18.8	17.6	19.3	18.9	25.7	26.9	27.1	34.5	44.1	47.6	47.9	46.8	53.5	12.0	8.6	62.5
pm3	1.0	5.0	96.0	15.7	14.1	12.7	12.7	15.5	17.6	18.0	17.4	17.7	17.8	19.9	20.2	21.1	21.0	21.3	27.6	36.8	40.7	41.6	41.3	52.3	7.2	7.5	100.0
pm1	2.0	5.0	96.0	14.4	13.4	12.4	12.4	15.0	17.0	17.3	16.8	17.0	17.8	19.5	20.2	21.1	21.0	21.3	27.6	36.8	40.7	41.6	41.3	51.6	5.9	7.6	100.0
pm2	2.0	5.0	96.0	15.8	14.2	12.8	12.8	15.5	17.5	17.8	17.2	17.3	17.3	19.0	19.1	21.5	21.4	21.3	26.8	34.9	37.8	38.1	37.2	51.3	6.4	6.1	89.3
pm3	2.0	5.0	96.0	15.9	14.4	13.0	12.9	15.8	18.3	18.9	18.3	18.4	18.2	20.2	20.2	24.3	24.4	24.4	31.5	41.4	45.0	45.3	43.9	53.3	8.8	7.9	90.0
pm1	1.0	6.0	0.0	16.1	15.2	13.1	12.1	13.5	16.4	19.3	20.5	18.9	15.4	16.3	15.5	26.7	35.2	39.0	40.8	42.3	43.5	44.0	43.4	53.8	21.5	11.0	0.0

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm2	1.0	6.0	0.0	15.3	14.5	12.8	12.0	13.1	15.4	17.8	18.7	17.4	14.6	15.2	14.7	23.9	31.4	34.9	36.7	38.4	39.9	40.8	40.5	51.8	19.7	9.7	0.0
pm3	1.0	6.0	0.0	17.9	16.9	14.8	13.7	15.0	17.7	20.4	21.5	20.1	16.6	17.5	16.7	28.1	36.6	40.2	42.0	43.5	44.8	45.2	44.7	55.1	21.0	10.5	0.0
pm4	1.0	6.0	0.0	14.8	14.1	12.7	12.0	13.0	15.3	17.7	18.8	17.5	14.6	15.3	14.7	24.7	33.0	36.9	38.9	40.7	42.3	43.2	42.9	52.3	21.3	10.8	0.0
pm1	2.0	6.0	0.0	15.8	15.2	14.1	13.4	14.2	16.1	18.0	18.9	17.8	15.5	16.0	15.5	23.9	31.4	34.8	36.5	38.0	39.2	39.8	39.6	52.3	18.6	9.0	7.9
pm2	2.0	6.0	0.0	15.7	14.9	13.1	12.2	13.4	16.0	18.7	19.8	18.3	15.1	15.8	15.2	25.7	34.1	37.9	39.9	41.6	43.1	43.7	43.2	53.1	21.3	10.7	0.0
pm3	2.0	6.0	0.0	16.7	15.9	14.3	13.4	14.3	16.4	18.6	19.6	18.5	15.6	16.3	15.6	25.7	34.1	37.8	39.6	41.1	42.4	42.9	42.5	53.4	20.7	10.1	0.0
pm4	2.0	6.0	0.0	16.3	15.4	13.5	12.6	13.8	16.4	19.0	20.0	18.6	15.4	16.2	15.5	26.5	35.0	38.6	40.3	41.8	43.0	43.6	43.0	53.6	21.5	10.8	0.0
pm1	1.0	6.0	12.0	16.0	15.0	13.3	12.4	13.6	16.1	18.4	19.2	18.1	15.2	16.1	15.4	26.3	32.8	34.7	38.9	42.6	43.9	44.0	43.1	52.9	20.1	10.4	4.3
pm2	1.0	6.0	12.0	17.4	16.4	14.5	13.6	15.0	17.6	20.0	20.8	19.8	16.8	17.7	17.0	28.4	34.9	37.0	41.5	45.7	47.1	47.2	46.2	54.9	19.8	10.4	6.3
pm3	1.0	6.0	12.0	15.7	14.8	13.3	12.6	13.7	16.0	18.0	18.9	17.8	15.1	15.8	15.1	25.8	32.8	35.0	38.8	42.1	43.3	43.3	42.3	52.7	20.5	10.2	3.3
pm1	2.0	6.0	12.0	15.2	14.4	13.0	12.3	13.3	15.4	17.3	18.1	17.2	14.6	15.4	14.8	24.8	31.5	33.6	37.6	41.2	42.5	42.6	41.7	51.9	20.0	10.2	8.0
pm2	2.0	6.0	12.0	16.2	15.1	13.4	12.6	13.9	16.5	18.8	19.6	18.5	15.6	16.5	15.8	26.7	32.9	34.8	39.3	43.5	45.1	45.3	44.4	53.3	19.7	10.3	4.6
pm3	2.0	6.0	12.0	17.8	16.8	15.4	14.5	15.4	17.4	19.2	19.9	19.0	16.6	17.3	16.7	26.2	32.2	34.1	38.3	42.4	43.9	44.2	43.5	53.7	17.8	8.8	12.4
pm1	1.0	6.0	24.0	15.5	14.5	12.9	12.2	13.7	16.5	18.5	19.1	18.2	15.7	16.7	16.0	26.0	30.3	31.2	37.0	43.1	45.1	45.2	44.3	52.7	17.3	9.6	16.0
pm2	1.0	6.0	24.0	17.9	16.7	14.8	13.9	15.5	18.3	20.4	21.0	20.1	17.5	18.6	17.9	28.1	32.5	33.5	39.3	45.4	47.4	47.4	46.3	54.8	16.8	9.3	19.4
pm3	1.0	6.0	24.0	16.1	15.2	13.8	13.1	14.2	16.4	18.4	19.0	18.0	15.5	16.3	15.7	25.6	30.9	32.1	37.2	42.5	44.1	43.9	42.8	52.6	18.2	9.1	11.4
pm1	2.0	6.0	24.0	15.2	14.3	13.1	12.5	13.4	15.3	17.0	17.4	16.7	14.7	15.4	14.8	23.5	28.1	29.2	34.4	40.1	42.0	42.1	41.2	50.9	17.0	8.7	19.5
pm2	2.0	6.0	24.0	15.5	14.5	13.0	12.4	13.8	16.6	18.6	19.1	18.2	15.8	16.9	16.2	25.6	29.4	30.3	36.2	42.8	45.1	45.3	44.4	52.6	16.4	9.2	19.9
pm3	2.0	6.0	24.0	17.3	16.2	14.8	14.1	15.1	17.1	18.8	19.2	18.5	16.4	17.3	16.7	25.1	29.2	30.2	35.8	42.1	44.3	44.5	43.6	52.8	15.5	8.0	23.2
pm1	1.0	6.0	36.0	15.5	14.3	12.7	12.2	14.1	16.9	18.5	18.6	18.1	16.3	17.7	17.1	24.9	27.0	27.4	34.0	42.3	45.2	45.5	44.6	52.4	13.6	8.6	42.9
pm2	1.0	6.0	36.0	16.8	15.7	14.2	13.5	15.0	17.3	19.0	19.3	18.6	16.6	17.7	17.1	25.8	28.8	29.4	35.8	43.2	45.6	45.7	44.6	53.0	14.9	8.3	31.3
pm3	1.0	6.0	36.0	15.9	14.7	13.1	12.5	14.1	16.7	18.5	18.9	18.2	15.9	17.0	16.3	25.6	29.1	29.8	36.2	43.7	46.1	46.0	44.7	52.6	16.1	9.0	24.9
pm1	2.0	6.0	36.0	14.6	13.7	12.6	12.1	13.2	15.1	16.5	16.8	16.2	14.6	15.5	14.9	22.0	24.8	25.4	31.1	38.2	40.7	40.9	40.0	49.8	13.9	7.6	31.8
pm2	2.0	6.0	36.0	15.6	14.5	13.3	12.7	14.1	16.5	18.1	18.4	17.8	15.9	17.1	16.5	24.5	27.1	27.6	34.0	41.8	44.4	44.6	43.7	52.0	14.3	8.3	35.8
pm3	2.0	6.0	36.0	16.4	15.3	14.0	13.4	14.5	16.6	18.0	18.2	17.7	15.9	16.9	16.2	24.1	27.3	27.9	34.3	42.0	44.5	44.6	43.6	51.8	14.6	7.8	31.0
pm1	1.0	6.0	48.0	15.4	14.1	12.7	12.3	14.7	17.6	18.6	18.5	18.2	17.1	18.8	18.3	24.5	25.6	25.7	32.7	42.1	45.5	45.9	45.0	52.6	11.3	8.2	64.5
pm2	1.0	6.0	48.0	17.2	15.9	14.4	13.8	15.7	18.2	19.6	19.8	19.3	17.6	18.9	18.3	26.3	28.6	29.1	35.8	44.2	46.9	47.0	45.8	53.8	13.6	8.2	42.5
pm3	1.0	6.0	48.0	14.6	13.4	12.0	11.5	13.4	16.0	17.6	17.8	17.2	15.3	16.5	15.8	24.3	27.0	27.5	34.1	42.3	45.0	45.0	43.8	51.5	15.1	8.9	34.1
pm1	2.0	6.0	48.0	14.8	13.8	12.9	12.4	13.7	15.6	16.7	16.8	16.4	15.1	16.2	15.7	21.7	23.6	23.9	29.9	37.8	40.6	40.8	39.9	50.0	11.9	7.0	45.4
pm2	2.0	6.0	48.0	15.1	14.0	12.9	12.5	14.1	16.5	17.8	17.8	17.4	16.0	17.3	16.8	23.5	25.2	25.5	32.0	40.5	43.5	43.9	43.0	51.4	12.4	7.8	49.1
pm3	2.0	6.0	48.0	15.7	14.5	13.3	12.7	14.1	16.3	17.6	17.8	17.3	15.7	16.7	16.0	23.4	26.1	26.6	33.0	41.3	44.1	44.2	43.2	51.3	13.8	7.7	35.5
pm1	1.0	6.0	60.0	15.8	14.3	12.9	12.7	15.6	18.5	19.4	19.0	18.9	18.3	20.2	20.0	25.2	25.7	25.7	33.0	42.8	46.5	46.9	46.1	53.7	9.9	8.3	79.5
pm2	1.0	6.0	60.0	16.9	15.7	14.3	13.9	15.6	17.8	19.0	19.0	18.7	17.3	18.7	18.1	25.2	26.9	27.1	34.0	42.9	45.9	46.1	44.9	53.1	12.4	7.7	50.9
pm3	1.0	6.0	60.0	15.1	13.7	12.3	11.9	14.0	16.7	18.1	18.1	17.6	16.1	17.5	16.9	24.4	26.3	26.6	33.3	42.0	44.9	44.9	43.6	52.0	13.3	8.5	47.8
pm1	2.0	6.0	60.0	15.1	14.0	13.0	12.7	14.0	16.0	16.9	16.9	16.6	15.6	16.8	16.3	21.6	23.0	23.2	29.2	37.5	40.4	40.8	39.9	50.2	10.6	6.7	54.2
pm2	2.0	6.0	60.0	15.1	14.0	13.0	12.7	14.3	16.6	17.6	17.4	17.2	16.3	17.7	17.3	23.0	24.0	24.2	30.9	40.0	43.4	43.9	43.2	51.3	10.9	7.5	63.0
pm3	2.0	6.0	60.0	15.5	14.4	13.2	12.7	14.1	16.1	17.3	17.4	17.0	15.6	16.7	16.1	22.9	25.1	25.5	32.1	41.1	44.1	44.2	42.9	50.9	13.0	7.5	42.3
pm1	1.0	6.0	72.0	15.6	14.1	12.8	12.8	15.7	18.2	18.6	18.1	18.2	18.2	20.2	20.3	23.9	24.0	23.9	31.1	41.2	45.1	45.6	44.8	53.1	8.5	7.9	94.9
pm2	1.0	6.0	72.0	17.9	16.6	15.2	14.7	16.6	18.8	19.9	19.8	19.5	18.4	19.8	19.3	25.7	26.9	27.1	33.9	43.0	46.1	46.3	45.1	53.9	11.0	7.2	57.2
pm3	1.0	6.0	72.0	15.5	14.0	12.7	12.4	14.5	17.1	18.2	18.1	17.7	16.6	18.1	17.6	24.2	25.6	25.7	32.6	41.9	45.1	45.1	43.8	52.1	12.0	8.1	59.0

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																			Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm1	2.0	6.0	72.0	15.3	14.1	13.2	12.8	14.3	16.3	17.0	16.8	16.7	15.9	17.2	16.8	21.6	22.5	22.6	28.7	37.4	40.6	40.9	40.0	50.4	9.7	6.5	62.7
pm2	2.0	6.0	72.0	15.4	14.1	13.1	13.0	15.3	17.6	18.2	17.9	17.9	17.5	19.1	19.0	23.2	23.7	23.7	30.4	39.8	43.5	44.1	43.4	52.2	9.0	7.3	80.1
pm3	2.0	6.0	72.0	15.3	14.2	13.1	12.7	14.1	16.2	17.2	17.2	16.9	15.7	16.8	16.3	22.5	24.3	24.5	31.2	40.5	43.8	43.9	42.6	50.7	12.0	7.2	48.5
pm1	1.0	6.0	84.0	16.0	14.3	12.8	13.0	16.7	19.3	19.5	18.8	19.0	19.6	22.0	22.4	24.8	24.5	24.5	32.0	42.8	47.0	47.6	46.8	54.5	7.4	8.4	100.0
pm2	1.0	6.0	84.0	17.4	15.9	14.6	14.2	16.1	18.2	19.1	18.9	18.7	17.9	19.4	19.0	24.6	25.4	25.6	32.4	41.9	45.3	45.5	44.4	53.1	10.3	7.1	65.6
pm3	1.0	6.0	84.0	15.1	13.7	12.5	12.2	14.2	16.7	17.7	17.5	17.3	16.3	17.8	17.4	23.3	24.5	24.5	31.4	41.0	44.4	44.6	43.4	51.5	11.4	7.8	62.7
pm1	2.0	6.0	84.0	15.4	14.2	13.2	13.0	14.5	16.5	17.2	16.9	16.8	16.2	17.6	17.2	21.6	22.4	22.5	28.6	37.3	40.6	40.9	40.0	50.6	9.2	6.5	67.4
pm2	2.0	6.0	84.0	15.3	14.1	13.2	13.1	15.5	17.7	18.1	17.7	17.7	17.7	19.4	19.5	22.8	22.9	23.0	29.6	39.1	42.8	43.5	42.9	52.2	7.9	7.1	90.2
pm3	2.0	6.0	84.0	15.3	14.1	13.1	12.8	14.3	16.2	17.0	16.9	16.6	15.8	17.1	16.6	22.0	23.2	23.4	30.1	40.1	43.7	43.9	42.7	50.5	10.9	6.9	59.4
pm1	1.0	6.0	96.0	15.8	14.3	12.9	13.1	16.9	19.5	19.6	18.9	19.2	20.1	22.4	23.1	24.7	24.4	24.5	31.8	42.5	46.8	47.4	46.7	54.8	6.8	8.5	100.0
pm2	1.0	6.0	96.0	16.2	14.9	13.7	13.5	15.7	17.8	18.6	18.2	18.2	17.6	19.2	19.0	24.0	24.6	24.7	31.7	41.6	45.2	45.4	44.2	52.7	9.9	7.4	74.4
pm3	1.0	6.0	96.0	15.1	13.7	12.5	12.4	14.7	17.1	17.9	17.5	17.4	17.0	18.6	18.5	23.1	23.8	23.9	30.9	40.7	44.4	44.6	43.5	51.9	9.8	7.8	78.6
pm1	2.0	6.0	96.0	15.2	14.1	13.2	13.0	14.6	16.5	17.1	16.8	16.7	16.3	17.6	17.3	21.5	22.1	22.1	28.2	37.1	40.5	40.9	39.9	50.5	8.8	6.4	70.6
pm2	2.0	6.0	96.0	15.3	14.1	13.1	13.1	15.6	17.7	18.0	17.5	17.6	17.9	19.8	20.1	22.5	22.5	22.5	29.0	38.6	42.5	43.2	42.6	52.3	7.2	7.3	99.4
pm3	2.0	6.0	96.0	15.1	14.0	13.0	12.8	14.6	16.5	17.1	16.8	16.7	16.3	17.6	17.4	21.7	22.5	22.6	29.3	39.7	43.5	43.7	42.4	50.7	9.5	6.8	72.4
pm1	1.0	7.0	0.0	18.7	17.8	16.3	15.4	16.1	17.7	19.6	20.4	19.4	17.0	17.6	17.1	25.9	33.7	37.2	39.2	40.6	41.8	42.4	42.0	54.2	18.6	8.7	11.2
pm2	1.0	7.0	0.0	14.7	14.0	13.0	12.3	13.0	14.5	16.2	16.9	16.0	13.9	14.4	14.0	21.9	29.3	32.8	35.4	37.6	39.3	40.3	40.1	50.3	19.4	9.2	13.0
pm3	1.0	7.0	0.0	15.9	15.2	13.6	12.6	13.8	16.1	18.4	19.3	18.2	15.3	16.1	15.4	25.5	33.9	37.5	39.6	41.2	42.5	43.3	43.2	53.1	20.9	10.6	0.5
pm4	1.0	7.0	0.0	14.2	13.5	12.4	11.8	12.5	14.0	15.8	16.5	15.6	13.5	14.0	13.6	21.2	28.2	31.7	34.2	36.2	37.8	38.6	38.4	49.6	19.0	9.1	11.4
pm1	2.0	7.0	0.0	16.7	15.7	13.9	12.9	13.9	16.3	18.7	19.7	18.4	15.4	16.1	15.4	25.5	33.7	37.1	39.0	40.3	41.4	41.8	41.2	53.1	20.4	10.0	0.0
pm2	2.0	7.0	0.0	15.9	15.1	13.6	12.8	13.7	15.7	17.8	18.7	17.6	14.9	15.6	15.0	24.4	32.0	35.3	37.0	38.2	39.3	39.6	39.1	52.2	19.8	9.7	3.3
pm3	2.0	7.0	0.0	16.8	15.9	14.3	13.4	14.4	16.6	18.8	19.7	18.6	15.8	16.5	15.8	26.2	34.6	37.9	39.7	40.9	41.8	42.1	41.4	53.6	20.8	10.2	1.9
pm4	2.0	7.0	0.0	15.7	15.0	13.4	12.6	13.6	15.8	18.0	19.0	17.8	15.0	15.7	15.0	24.9	33.1	36.4	38.3	39.6	40.7	41.2	40.7	52.6	20.6	10.2	0.5
pm1	1.0	7.0	12.0	17.3	16.3	15.0	14.2	15.0	16.7	18.3	18.8	18.1	16.1	16.8	16.2	24.6	29.6	31.1	35.7	40.6	42.5	42.9	42.2	52.5	16.4	8.0	20.6
pm2	1.0	7.0	12.0	14.7	13.9	12.9	12.3	13.0	14.6	15.9	16.3	15.7	14.0	14.6	14.2	21.7	26.0	27.3	32.5	38.1	40.3	40.7	40.1	49.5	16.2	8.1	25.7
pm3	1.0	7.0	12.0	15.5	14.6	13.3	12.6	13.7	15.8	17.6	18.2	17.4	15.1	15.9	15.2	24.7	30.5	32.3	36.9	41.7	43.5	43.9	43.3	52.0	18.6	9.6	14.5
pm1	2.0	7.0	12.0	16.0	15.1	13.6	12.8	14.0	16.3	18.3	19.0	18.1	15.5	16.3	15.7	25.6	31.7	33.4	37.9	42.3	43.8	44.0	43.1	52.7	18.8	9.7	10.4
pm2	2.0	7.0	12.0	15.2	14.4	13.1	12.4	13.3	15.2	17.0	17.7	16.8	14.5	15.2	14.7	24.0	30.0	31.9	35.7	39.2	40.4	40.5	39.7	51.3	18.8	9.6	12.8
pm3	2.0	7.0	12.0	16.9	15.9	14.2	13.3	14.4	16.6	18.7	19.5	18.5	15.8	16.6	15.9	26.9	34.2	36.3	40.0	43.1	44.0	43.9	42.9	53.7	20.5	10.4	7.2
pm1	1.0	7.0	24.0	15.8	14.9	13.8	13.2	14.1	15.8	17.1	17.4	16.9	15.2	16.1	15.5	22.8	26.2	27.0	32.8	40.1	42.7	43.1	42.4	50.8	14.5	7.5	30.8
pm2	1.0	7.0	24.0	14.8	14.0	13.3	12.8	13.5	15.0	16.0	16.2	15.8	14.5	15.2	14.8	21.1	23.8	24.4	30.0	37.3	39.9	40.3	39.5	49.3	13.3	6.8	36.5
pm3	1.0	7.0	24.0	15.4	14.6	13.3	12.6	14.0	16.3	17.9	18.3	17.7	15.6	16.6	15.9	24.4	28.2	29.0	34.7	41.7	44.2	44.6	44.0	51.9	15.6	8.6	25.2
pm1	2.0	7.0	24.0	15.7	14.7	13.3	12.6	13.9	16.2	18.1	18.5	17.8	15.5	16.5	15.8	25.0	29.3	30.2	35.7	42.0	44.1	44.1	43.2	52.1	16.8	9.0	19.3
pm2	2.0	7.0	24.0	14.9	14.1	12.9	12.3	13.2	15.1	16.8	17.3	16.6	14.5	15.3	14.7	23.3	27.7	28.8	33.5	38.7	40.4	40.4	39.5	50.7	16.7	8.7	19.7
pm3	2.0	7.0	24.0	16.3	15.4	13.9	13.0	14.2	16.4	18.3	18.9	18.0	15.6	16.5	15.8	25.8	31.4	32.6	37.6	42.8	44.5	44.6	43.7	52.8	18.5	9.5	14.3
pm1	1.0	7.0	36.0	17.2	16.1	15.0	14.5	15.4	17.1	18.2	18.3	18.0	16.6	17.6	17.1	23.3	25.5	25.9	31.8	40.1	43.1	43.5	42.7	51.8	11.8	6.4	41.8
pm2	1.0	7.0	36.0	16.6	15.3	13.8	13.1	14.5	16.4	17.7	17.8	17.4	15.7	16.7	16.2	23.5	26.1	26.5	31.9	39.1	41.4	41.3	40.0	51.3	13.5	7.4	35.5
pm3	1.0	7.0	36.0	15.5	14.6	13.3	12.7	14.1	16.3	17.7	18.0	17.5	15.8	16.9	16.2	23.8	26.6	27.1	33.3	41.6	44.5	44.9	44.2	51.6	14.0	8.1	36.1
pm1	2.0	7.0	36.0	15.6	14.5	13.3	12.7	14.0	16.3	17.9	18.2	17.6	15.6	16.6	16.0	24.1	27.3	27.9	33.9	41.5	44.0	44.1	43.1	51.6	14.8	8.2	28.4
pm2	2.0	7.0	36.0	15.1	14.2	13.0	12.4	13.4	15.3	16.8	17.2	16.6	14.7	15.5	14.9	22.9	26.5	27.2	32.3	38.3	40.2	40.1	39.1	50.4	15.3	8.1	23.8

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm3	2.0	7.0	36.0	16.8	15.7	14.1	13.3	14.6	16.7	18.5	18.9	18.2	16.0	16.9	16.2	25.5	29.8	30.6	36.1	42.5	44.5	44.5	43.5	52.6	16.6	8.7	19.9
pm1	1.0	7.0	48.0	17.0	15.9	14.8	14.4	15.4	17.1	18.0	17.9	17.7	16.7	17.7	17.2	22.7	24.3	24.4	30.5	39.7	43.1	43.5	42.6	51.4	10.6	6.1	50.3
pm2	1.0	7.0	48.0	16.3	15.1	13.7	13.1	14.6	16.4	17.6	17.6	17.3	15.9	16.9	16.4	22.9	24.9	25.0	30.5	38.3	41.0	41.0	39.7	51.0	12.0	6.9	42.6
pm3	1.0	7.0	48.0	15.1	14.1	12.9	12.4	13.9	16.0	17.3	17.4	17.0	15.5	16.6	16.0	23.0	25.4	25.9	32.2	41.0	44.3	44.7	44.0	51.0	13.3	7.8	41.1
pm1	2.0	7.0	48.0	15.6	14.5	13.2	12.8	14.4	16.7	18.0	18.1	17.6	16.1	17.2	16.6	23.8	26.0	26.2	32.5	41.1	44.0	44.1	43.0	51.7	13.0	7.7	40.6
pm2	2.0	7.0	48.0	14.5	13.6	12.5	12.1	13.1	15.1	16.5	16.7	16.2	14.7	15.6	15.0	22.1	24.6	25.0	30.6	37.9	40.4	40.5	39.5	49.9	13.5	7.7	34.4
pm3	2.0	7.0	48.0	16.9	15.6	14.1	13.4	14.8	17.2	18.8	19.1	18.5	16.5	17.5	16.8	25.4	28.7	29.2	35.1	42.5	44.8	44.7	43.5	52.8	14.9	8.2	27.8
pm1	1.0	7.0	60.0	16.0	14.8	13.8	13.4	14.6	16.4	17.2	17.0	16.8	16.0	17.1	16.7	21.9	23.1	23.1	29.4	39.3	43.0	43.4	42.4	50.5	10.3	6.3	56.8
pm2	1.0	7.0	60.0	15.0	14.0	13.3	13.0	13.9	15.4	16.0	15.9	15.7	15.0	15.9	15.6	20.1	21.1	21.3	27.2	36.4	40.0	40.5	39.6	48.9	9.7	5.7	56.6
pm3	1.0	7.0	60.0	15.6	14.5	13.3	12.9	14.6	16.8	17.8	17.7	17.5	16.4	17.7	17.2	23.0	24.4	24.6	31.0	40.6	44.4	44.8	44.0	51.4	11.0	7.2	55.2
pm1	2.0	7.0	60.0	15.2	14.0	12.9	12.5	14.0	16.2	17.4	17.4	17.0	15.6	16.8	16.2	23.0	24.8	24.9	31.4	40.5	43.7	43.8	42.8	50.9	12.5	7.5	45.4
pm2	2.0	7.0	60.0	14.7	13.7	12.7	12.2	13.3	15.3	16.6	16.7	16.3	14.9	15.9	15.4	21.8	23.7	23.9	29.5	37.0	39.6	39.7	38.7	49.8	12.2	7.2	41.6
pm3	2.0	7.0	60.0	13.0	11.8	10.4	9.9	11.4	13.8	15.3	15.6	15.0	13.2	14.3	13.6	21.7	24.3	24.7	31.0	39.1	41.9	42.1	41.0	48.6	15.6	9.2	31.3
pm1	1.0	7.0	72.0	16.3	15.2	14.3	13.8	15.0	16.6	17.3	17.1	17.0	16.2	17.4	17.0	21.7	22.8	22.7	29.0	39.3	43.2	43.6	42.6	50.6	9.7	6.0	59.3
pm2	1.0	7.0	72.0	14.9	13.9	13.2	12.9	14.0	15.5	16.0	15.8	15.7	15.2	16.3	16.0	20.1	20.8	20.8	26.9	36.7	40.6	41.1	40.2	49.0	9.1	5.8	64.4
pm3	1.0	7.0	72.0	15.7	14.6	13.4	13.1	14.9	17.0	17.9	17.7	17.5	16.7	18.1	17.7	22.9	23.9	24.0	30.5	40.6	44.6	45.0	44.2	51.6	10.2	7.1	63.5
pm1	2.0	7.0	72.0	15.5	14.4	13.3	12.9	14.6	16.8	17.8	17.7	17.4	16.3	17.6	17.1	23.1	24.5	24.6	31.1	40.7	44.2	44.4	43.3	51.4	11.3	7.2	54.1
pm2	2.0	7.0	72.0	14.5	13.5	12.5	12.1	13.5	15.5	16.5	16.5	16.2	15.2	16.4	15.9	21.5	22.7	22.8	28.8	37.2	40.2	40.5	39.5	49.8	10.9	7.1	54.9
pm3	2.0	7.0	72.0	16.6	15.3	13.9	13.4	15.0	17.3	18.6	18.6	18.3	16.8	18.0	17.4	24.5	26.5	26.5	32.8	41.8	45.0	45.2	44.2	52.4	12.4	7.6	44.5
pm1	1.0	7.0	84.0	15.1	14.0	13.2	12.9	14.0	15.6	16.3	16.1	16.0	15.3	16.5	16.1	20.7	21.7	21.7	28.1	38.8	43.0	43.3	42.2	49.5	9.9	6.3	62.1
pm2	1.0	7.0	84.0	15.7	14.6	13.5	13.2	14.8	16.6	17.4	17.2	17.1	16.3	17.6	17.2	22.4	23.3	23.3	29.6	39.0	42.4	42.4	41.2	51.0	10.2	6.7	63.2
pm3	1.0	7.0	84.0	16.2	15.0	13.9	13.5	15.5	17.7	18.4	18.2	18.1	17.4	18.9	18.5	23.3	24.1	24.1	30.6	40.7	44.7	45.2	44.3	52.2	9.4	6.9	68.3
pm1	2.0	7.0	84.0	15.5	14.3	13.2	12.9	14.6	16.8	17.7	17.5	17.3	16.3	17.7	17.2	22.8	23.9	24.0	30.5	40.2	43.6	43.8	42.5	51.2	10.7	7.0	59.2
pm2	2.0	7.0	84.0	14.6	13.6	12.7	12.4	13.9	15.9	16.7	16.6	16.4	15.6	16.9	16.5	21.5	22.4	22.5	28.5	37.0	40.1	40.5	39.6	50.1	10.0	6.9	61.4
pm3	2.0	7.0	84.0	15.5	14.4	13.3	12.8	14.4	16.6	17.7	17.7	17.3	16.1	17.3	16.7	23.2	24.9	25.1	31.6	40.8	44.2	44.4	43.4	51.3	12.1	7.4	48.1
pm1	1.0	7.0	96.0	16.6	15.4	14.5	14.2	15.4	17.0	17.6	17.3	17.2	16.7	17.9	17.6	21.8	22.5	22.4	28.4	38.8	42.9	43.3	42.3	50.9	8.7	5.7	65.5
pm2	1.0	7.0	96.0	14.9	13.9	13.2	12.9	14.1	15.5	15.9	15.7	15.6	15.3	16.4	16.3	19.7	20.2	20.2	26.2	36.2	40.3	40.7	39.6	48.9	8.2	5.5	70.7
pm3	1.0	7.0	96.0	16.6	15.4	14.3	14.0	16.0	18.2	18.8	18.6	18.5	18.0	19.5	19.2	23.6	24.2	24.3	30.6	40.9	45.0	45.4	44.3	52.8	8.8	6.7	72.6
pm1	2.0	7.0	96.0	15.2	14.1	13.1	12.9	14.5	16.6	17.4	17.2	17.1	16.3	17.7	17.2	22.4	23.3	23.3	29.9	40.0	43.9	44.2	43.2	51.0	10.2	6.9	63.8
pm2	2.0	7.0	96.0	14.6	13.5	12.7	12.4	14.1	16.0	16.7	16.4	16.3	15.9	17.3	17.0	21.2	21.8	21.8	27.7	36.4	39.6	39.9	39.0	50.1	9.0	6.8	72.1
pm3	2.0	7.0	96.0	16.1	14.9	13.7	13.4	15.1	17.3	18.4	18.2	18.0	16.9	18.3	17.8	23.8	25.0	25.0	31.5	41.1	44.6	44.9	43.9	52.1	10.9	7.2	57.6
pm1	1.0	8.0	0.0	14.8	14.0	12.6	11.9	12.9	15.2	17.6	18.5	17.1	14.3	15.0	14.5	23.4	31.1	34.9	37.4	39.2	40.7	41.5	41.1	51.5	20.0	9.8	0.4
pm2	1.0	8.0	0.0	14.9	14.2	12.8	12.1	12.9	14.9	17.1	18.0	16.8	14.3	14.9	14.4	22.4	30.1	34.0	36.2	37.8	39.2	40.0	39.8	51.0	19.2	9.4	4.4
pm3	1.0	8.0	0.0	17.1	16.3	14.0	12.7	14.6	17.7	20.5	21.6	20.1	16.8	17.7	16.9	26.9	34.4	38.0	39.9	41.3	42.5	43.1	42.7	54.6	18.8	9.9	0.0
pm4	1.0	8.0	0.0	15.3	14.5	13.0	12.2	13.1	15.5	18.0	19.0	17.6	14.7	15.4	14.8	24.5	32.8	36.7	38.9	40.6	42.0	42.8	42.5	52.3	20.9	10.4	0.0
pm1	2.0	8.0	0.0	17.2	16.2	14.5	13.6	14.6	17.0	19.4	20.4	19.1	16.1	16.9	16.3	26.9	35.3	39.0	41.4	43.2	44.6	45.3	44.8	54.2	21.0	10.4	1.5
pm2	2.0	8.0	0.0	16.8	16.0	14.5	13.7	14.5	16.6	18.8	19.8	18.5	15.8	16.4	15.9	26.0	34.4	38.2	40.2	41.7	43.1	43.8	43.3	53.6	20.9	10.1	4.1
pm3	2.0	8.0	0.0	18.4	17.5	16.3	15.5	16.1	17.7	19.4	20.1	19.2	17.0	17.5	17.0	25.2	32.4	35.7	37.5	38.9	40.2	40.9	40.8	53.8	17.5	8.0	14.6
pm4	2.0	8.0	0.0	15.4	14.8	13.6	12.9	13.7	15.5	17.4	18.3	17.2	14.8	15.4	14.9	23.6	31.3	34.8	36.7	38.1	39.4	40.1	39.8	51.8	19.6	9.4	7.5
pm1	1.0	8.0	12.0	15.4	14.4	13.3	12.7	13.6	15.4	16.9	17.2	16.5	14.7	15.5	15.0	21.9	25.3	26.3	31.4	36.7	38.7	39.2	38.5	50.0	14.0	7.2	26.2

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																					Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B		
pm2	1.0	8.0	12.0	15.2	14.4	13.3	12.7	13.5	15.3	16.9	17.5	16.7	14.6	15.3	14.8	23.0	28.3	30.1	34.4	38.9	40.6	41.0	40.4	50.8	17.2	8.5		16.6
pm3	1.0	8.0	12.0	17.9	16.8	14.4	13.2	15.3	18.4	20.9	21.8	20.7	17.5	18.6	17.8	28.5	34.1	35.8	39.5	43.0	44.3	44.5	43.8	55.2	17.5	9.8		5.1
pm1	2.0	8.0	12.0	16.1	14.9	13.5	12.9	14.3	16.6	18.3	18.5	17.9	16.0	17.1	16.5	24.8	27.8	28.5	35.1	42.8	45.4	45.7	44.8	52.2	14.9	8.4		33.0
pm2	2.0	8.0	12.0	16.7	15.8	14.5	13.8	14.7	16.7	18.4	19.0	18.2	15.9	16.7	16.2	25.2	29.8	31.1	36.5	42.1	44.0	44.3	43.4	52.6	16.8	8.4		19.1
pm3	2.0	8.0	12.0	14.9	14.1	12.9	12.3	13.1	14.8	16.3	16.8	16.1	14.1	14.8	14.3	22.6	27.4	28.9	34.1	39.7	41.8	42.3	41.6	50.2	17.4	8.6		20.1
pm1	1.0	8.0	24.0	14.1	13.1	12.3	11.9	13.0	14.9	15.8	15.7	15.5	14.5	15.5	15.2	20.2	21.6	22.0	27.9	35.4	38.2	38.7	38.0	48.7	10.8	6.6		34.0
pm2	1.0	8.0	24.0	15.9	15.1	14.2	13.6	14.4	16.1	17.4	17.8	17.2	15.5	16.2	15.7	22.9	26.5	27.5	32.7	38.9	41.1	41.5	40.8	51.0	14.3	7.2		27.5
pm3	1.0	8.0	24.0	17.3	16.1	13.9	12.9	15.1	18.2	20.5	21.0	20.2	17.5	18.7	17.8	27.7	31.8	32.8	37.8	43.2	45.0	45.1	44.2	54.6	15.9	9.4		17.3
pm1	2.0	8.0	24.0	16.2	14.9	13.7	13.2	14.9	17.3	18.5	18.4	18.1	16.8	18.3	17.8	24.4	25.9	26.1	33.1	42.7	46.1	46.5	45.4	52.4	12.0	7.8		34.0
pm2	2.0	8.0	24.0	17.3	16.2	15.0	14.4	15.4	17.5	18.9	19.1	18.6	16.8	17.8	17.2	25.0	27.9	28.5	34.8	42.5	45.2	45.5	44.6	52.8	13.9	7.5		34.1
pm3	2.0	8.0	24.0	14.5	13.6	12.6	12.1	13.0	14.7	16.0	16.3	15.7	14.2	14.9	14.4	21.9	25.3	26.1	32.1	39.6	42.2	42.6	41.8	49.6	15.4	8.0		30.5
pm1	1.0	8.0	36.0	13.7	12.8	12.1	11.9	13.2	15.1	15.7	15.4	15.3	14.8	16.1	15.9	19.9	20.6	20.8	26.9	35.0	38.1	38.7	38.1	48.8	9.2	6.6		
pm2	1.0	8.0	36.0	15.3	14.5	13.7	13.2	14.1	15.7	16.9	17.1	16.6	15.3	16.1	15.6	22.0	24.7	25.2	30.9	38.4	41.0	41.3	40.6	50.3	12.9	6.9		36.6
pm3	1.0	8.0	36.0	16.5	15.4	13.7	13.0	15.0	17.8	19.7	20.1	19.5	17.3	18.5	17.8	26.7	29.9	30.5	36.2	42.8	44.9	44.9	43.8	53.9	14.7	9.0		29.7
pm1	2.0	8.0	36.0	15.7	14.4	13.3	13.0	14.9	17.3	18.1	17.8	17.7	17.0	18.7	18.4	23.6	24.3	24.4	31.5	42.1	46.0	46.4	45.3	52.2	10.3	7.7		
pm2	2.0	8.0	36.0	16.4	15.4	14.4	13.9	15.0	17.0	18.3	18.3	17.9	16.5	17.6	17.1	24.1	26.0	26.4	32.9	41.6	44.7	44.9	43.9	52.0	12.7	7.2		44.1
pm3	2.0	8.0	36.0	13.9	13.0	12.1	11.7	12.8	14.5	15.6	15.7	15.3	14.0	14.9	14.4	21.0	23.3	23.8	30.2	38.8	42.0	42.3	41.4	48.8	13.6	7.5		40.1
pm1	1.0	8.0	48.0	13.7	12.7	12.1	11.9	13.4	15.2	15.6	15.2	15.2	15.1	16.6	16.6	19.6	19.9	20.0	26.0	34.6	38.0	38.6	38.0	48.8	8.1	6.6		
pm2	1.0	8.0	48.0	15.0	14.1	13.2	12.8	13.8	15.6	16.7	16.8	16.4	15.2	16.1	15.6	21.7	23.9	24.3	30.0	38.1	40.9	41.3	40.5	50.0	12.2	6.9		42.5
pm3	1.0	8.0	48.0	15.8	14.6	13.3	12.8	14.6	17.0	18.6	18.7	18.3	16.6	17.8	17.3	24.8	27.1	27.5	33.4	41.0	43.5	43.6	42.5	52.5	13.2	8.3		41.3
pm1	2.0	8.0	48.0	16.2	14.7	13.6	13.4	15.5	17.7	18.3	17.9	17.9	17.6	19.3	19.2	23.6	24.0	24.0	31.1	41.9	46.1	46.5	45.4	52.5	9.3	7.4		
pm2	2.0	8.0	48.0	16.4	15.1	14.1	13.7	15.0	17.0	18.1	18.0	17.7	16.5	17.8	17.3	23.6	25.1	25.3	31.9	41.3	44.6	44.9	43.8	51.8	11.7	7.1		52.6
pm3	2.0	8.0	48.0	15.1	14.2	13.3	12.9	13.7	15.3	16.2	16.3	15.9	14.8	15.7	15.3	21.3	23.2	23.6	29.8	38.7	41.9	42.3	41.2	49.5	12.3	6.7		44.8
pm1	1.0	8.0	60.0	13.8	12.7	12.1	11.9	13.6	15.3	15.6	15.2	15.3	15.5	17.0	17.2	19.5	19.6	19.7	25.7	34.5	38.0	38.6	38.0	49.1	7.2	6.7		
pm2	1.0	8.0	60.0	15.8	14.8	13.9	13.5	14.5	16.1	17.0	17.0	16.8	15.7	16.7	16.2	21.7	23.3	23.6	29.3	37.8	40.9	41.3	40.5	50.3	10.9	6.3		48.9
pm3	1.0	8.0	60.0	16.4	15.2	13.7	13.3	15.5	18.2	19.5	19.6	19.2	17.8	19.1	18.5	25.1	27.0	27.4	33.4	41.4	44.2	44.5	43.6	53.4	11.5	7.8		48.5
pm1	2.0	8.0	60.0	15.8	14.4	13.3	13.1	15.3	17.5	18.0	17.6	17.7	17.5	19.4	19.4	23.2	23.4	23.4	30.5	41.7	46.1	46.6	45.4	52.3	8.8	7.7		
pm2	2.0	8.0	60.0	16.8	15.7	14.7	14.3	15.6	17.5	18.4	18.2	18.0	17.1	18.4	18.0	23.5	24.6	24.7	31.2	40.8	44.4	44.7	43.6	52.1	10.4	6.6		60.0
pm3	2.0	8.0	60.0	13.2	12.3	11.5	11.2	12.2	13.9	14.7	14.7	14.5	13.6	14.6	14.2	19.7	21.2	21.6	28.0	37.6	41.3	41.7	40.6	47.7	12.2	7.3		52.8
pm1	1.0	8.0	72.0	13.6	12.6	12.0	12.0	13.9	15.5	15.6	15.1	15.3	15.8	17.4	17.9	19.3	19.2	19.2	25.2	34.2	37.9	38.6	38.0	49.2	6.4	6.8		
pm2	1.0	8.0	72.0	15.2	14.3	13.4	13.1	14.3	16.0	16.9	16.8	16.6	15.7	16.8	16.4	21.3	22.6	22.8	28.5	37.3	40.5	40.9	40.0	50.1	10.1	6.3		55.7
pm3	1.0	8.0	72.0	15.6	14.5	13.2	12.8	15.0	17.6	18.8	18.7	18.5	17.3	18.8	18.3	24.5	25.9	26.1	32.2	40.6	43.6	43.7	42.7	52.8	11.1	8.0		58.6
pm1	2.0	8.0	72.0	15.5	14.2	13.3	13.1	15.3	17.4	17.8	17.3	17.4	17.5	19.4	19.5	22.8	22.8	22.7	29.7	40.8	45.3	45.8	44.7	52.1	8.2	7.6		
pm2	2.0	8.0	72.0	16.6	15.5	14.5	14.2	15.6	17.4	18.1	17.9	17.8	17.1	18.4	18.1	23.0	23.7	23.7	30.2	40.0	43.7	44.0	42.9	51.8	9.5	6.4		65.6
pm3	2.0	8.0	72.0	14.0	13.1	12.3	12.0	13.1	14.7	15.4	15.3	15.1	14.4	15.5	15.2	20.0	20.9	21.1	27.5	37.5	41.5	41.8	40.7	48.5	10.5	6.5		59.9
pm1	1.0	8.0	84.0	13.8	12.7	12.1	12.0	13.9	15.6	15.6	15.2	15.4	16.0	17.7	18.4	19.2	19.1	19.2	25.1	34.0	37.7	38.5	38.0	49.4	5.9	7.0		
pm2	1.0	8.0	84.0	15.2	14.2	13.3	13.0	14.2	15.9	16.7	16.6	16.4	15.6	16.8	16.4	21.1	22.2	22.3	28.1	37.1	40.5	40.9	40.1	49.9	9.7	6.3		59.7
pm3	1.0	8.0	84.0	16.4	15.0	13.4	13.2	16.3	19.1	20.1	19.9	19.8	19.1	20.8	20.5	25.5	26.3	26.6	32.9	41.6	44.8	45.2	44.3	54.4	9.3	8.0		73.1
pm1	2.0	8.0	84.0	15.7	14.4	13.4	13.3	15.5	17.5	17.9	17.4	17.5	17.7	19.7	20.0	22.8	22.7	22.6	29.6	40.8	45.4	46.0	44.9	52.3	7.8	7.6		
pm2	2.0	8.0	84.0	17.4	16.1	15.1	14.8	16.3	18.1	18.7	18.4	18.3	17.8	19.2	19.0	23.2	23.7	23.7	30.1	39.9	43.7	44.1	43.1	52.4	8.5	6.0		71.6

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm3	2.0	8.0	84.0	14.1	13.1	12.5	12.2	13.3	14.9	15.5	15.3	15.2	14.7	15.8	15.5	19.8	20.6	20.6	27.0	37.3	41.4	41.7	40.6	48.5	9.7	6.3	64.6
pm1	1.0	8.0	96.0	13.7	12.8	12.1	12.1	14.0	15.5	15.7	15.3	15.5	16.2	17.9	18.5	19.2	19.1	19.3	25.0	33.7	37.3	38.1	37.8	49.5	5.6	7.1	
pm2	1.0	8.0	96.0	15.4	14.4	13.6	13.3	14.5	16.2	16.8	16.6	16.5	15.9	17.2	16.9	21.1	21.9	21.9	27.6	36.8	40.3	40.8	39.9	50.1	9.0	6.1	66.1
pm3	1.0	8.0	96.0	16.3	14.9	13.3	13.2	16.5	19.3	20.1	19.7	19.8	19.5	21.4	21.3	25.3	25.9	26.0	32.4	41.4	44.7	45.1	44.3	54.6	8.4	8.1	85.0
pm1	2.0	8.0	96.0	15.6	14.3	13.4	13.3	15.5	17.5	17.9	17.3	17.5	17.8	19.8	20.1	22.7	22.6	22.5	29.5	40.8	45.6	46.1	45.0	52.3	7.7	7.6	
pm2	2.0	8.0	96.0	17.1	16.0	15.1	14.8	16.4	18.2	18.8	18.4	18.4	18.1	19.6	19.5	23.4	23.7	23.7	30.0	40.1	44.1	44.6	43.5	52.7	8.2	6.3	77.5
pm3	2.0	8.0	96.0	13.9	13.0	12.3	12.0	13.2	14.8	15.3	15.1	15.0	14.6	15.8	15.5	19.5	20.1	20.2	26.5	36.9	41.0	41.4	40.2	48.3	9.3	6.3	69.1
pm1	1.0	9.0	0.0	15.1	14.5	13.4	12.7	13.6	15.6	17.5	18.5	17.4	15.0	15.6	15.1	23.6	31.1	34.6	36.6	38.1	39.4	40.0	39.6	51.9	19.1	9.5	9.5
pm2	1.0	9.0	0.0	14.8	14.1	12.6	11.9	12.8	15.0	17.4	18.3	17.0	14.2	14.8	14.3	23.6	31.6	35.4	37.5	39.2	40.7	41.6	41.3	51.5	20.7	10.1	0.0
pm3	1.0	9.0	0.0	15.8	15.0	13.2	12.2	13.4	16.0	18.6	19.6	18.2	15.2	15.9	15.3	25.0	33.1	37.0	39.5	41.2	42.8	43.5	43.1	52.8	20.4	10.3	0.0
pm4	1.0	9.0	0.0	15.7	14.8	13.0	12.2	13.3	15.8	18.3	19.4	18.0	14.8	15.6	15.0	26.3	35.2	39.0	41.1	42.6	43.8	44.3	43.6	53.2	22.7	11.4	0.0
pm1	2.0	9.0	0.0	15.5	14.6	12.8	12.0	13.1	15.6	18.2	19.3	17.9	14.7	15.5	14.9	25.3	33.7	37.5	39.5	41.0	42.4	43.1	42.6	52.7	21.5	10.8	0.0
pm2	2.0	9.0	0.0	14.4	13.8	12.5	11.8	12.6	14.5	16.5	17.3	16.1	13.7	14.2	13.7	21.6	28.7	32.2	34.1	35.7	37.1	37.9	37.5	50.0	18.8	8.8	3.9
pm3	2.0	9.0	0.0	15.9	15.0	13.2	12.3	13.5	16.2	18.8	19.9	18.5	15.2	16.1	15.4	27.0	36.3	40.2	42.4	44.0	45.3	45.9	45.3	53.9	23.0	11.7	0.0
pm4	2.0	9.0	0.0	15.1	14.3	12.7	12.0	12.9	15.2	17.6	18.5	17.2	14.3	15.0	14.4	24.5	32.9	36.6	38.6	40.2	41.7	42.4	42.1	52.0	21.5	10.6	0.0
pm1	1.0	9.0	12.0	14.7	14.0	12.8	12.1	13.0	14.9	16.6	17.4	16.5	14.3	15.0	14.4	23.2	29.1	31.1	34.9	38.4	39.8	40.1	39.3	50.8	18.4	9.4	13.5
pm2	1.0	9.0	12.0	15.0	14.2	12.7	12.0	13.1	15.4	17.5	18.3	17.3	14.5	15.4	14.7	25.3	31.9	34.1	38.1	41.8	43.2	43.4	42.6	52.1	20.5	10.5	5.4
pm3	1.0	9.0	12.0	14.9	13.8	12.5	11.9	13.0	15.3	17.2	17.6	16.9	14.8	15.8	15.2	23.6	27.8	29.2	34.8	40.8	43.2	43.8	43.2	51.1	16.5	9.2	25.0
pm1	2.0	9.0	12.0	14.9	14.0	12.6	11.8	12.9	15.0	16.9	17.7	16.7	14.2	14.9	14.3	24.2	30.5	32.7	36.7	40.3	41.8	42.2	41.5	51.3	19.9	10.1	7.3
pm2	2.0	9.0	12.0	14.6	13.7	12.5	11.8	12.7	14.6	16.3	17.0	16.1	13.9	14.6	14.0	22.7	28.1	29.9	34.0	37.7	39.2	39.5	38.8	50.2	18.0	9.1	12.7
pm3	2.0	9.0	12.0	15.9	15.0	13.2	12.4	13.8	16.4	18.7	19.5	18.5	15.5	16.5	15.8	27.4	33.7	35.4	40.6	45.7	47.5	47.7	46.8	53.6	20.6	11.0	5.8
pm1	1.0	9.0	24.0	15.0	14.3	13.1	12.4	13.6	15.7	17.3	18.0	17.2	15.1	15.9	15.3	23.7	27.9	29.1	33.9	39.3	41.2	41.4	40.7	51.2	16.1	8.6	19.5
pm2	1.0	9.0	24.0	15.5	14.5	13.1	12.4	13.5	15.8	17.7	18.3	17.4	15.0	15.9	15.2	25.0	29.9	31.1	36.4	42.0	43.8	43.9	43.0	51.9	18.1	9.4	14.7
pm3	1.0	9.0	24.0	14.4	13.4	12.3	11.9	13.4	15.7	17.0	17.0	16.7	15.3	16.7	16.2	22.7	24.7	25.2	31.9	40.4	43.6	44.1	43.4	50.7	12.9	8.3	51.7
pm1	2.0	9.0	24.0	14.8	13.8	12.5	11.9	13.1	15.3	17.2	17.7	16.9	14.6	15.5	14.9	24.2	28.6	29.7	35.2	41.2	43.2	43.4	42.5	51.2	17.5	9.4	17.4
pm2	2.0	9.0	24.0	14.2	13.4	12.3	11.8	12.7	14.6	16.1	16.5	15.8	14.0	14.7	14.2	21.9	25.5	26.4	31.7	37.6	39.7	39.9	39.0	49.5	15.5	8.1	23.3
pm3	2.0	9.0	24.0	15.5	14.4	12.9	12.3	13.8	16.4	18.4	18.9	18.1	15.6	16.7	16.0	26.4	30.8	31.7	38.2	45.6	48.1	48.3	47.3	52.9	18.1	10.1	19.6
pm1	1.0	9.0	36.0	14.7	13.8	12.7	12.1	13.3	15.3	16.7	17.2	16.6	14.8	15.6	15.1	22.7	26.1	26.9	32.3	38.8	41.0	41.3	40.6	50.4	14.9	8.2	27.4
pm2	1.0	9.0	36.0	15.6	14.5	13.3	12.7	13.9	16.1	17.9	18.3	17.6	15.4	16.4	15.8	24.7	28.2	28.9	34.9	42.1	44.5	44.8	43.9	51.8	15.9	8.7	25.1
pm3	1.0	9.0	36.0	14.7	13.5	12.4	12.0	13.8	16.2	17.3	17.1	16.9	15.9	17.5	17.1	22.8	24.1	24.3	31.2	40.5	43.9	44.3	43.5	51.1	11.4	8.1	64.8
pm1	2.0	9.0	36.0	15.7	14.6	12.9	12.2	13.8	16.4	18.2	18.7	17.9	15.6	16.6	15.9	25.2	28.9	29.7	35.7	42.7	44.9	44.9	43.8	52.2	16.3	9.1	22.2
pm2	2.0	9.0	36.0	14.2	13.3	12.3	11.8	12.9	14.8	16.2	16.5	15.9	14.2	15.1	14.5	21.8	24.5	25.1	30.9	37.9	40.2	40.4	39.4	49.4	14.2	7.7	30.3
pm3	2.0	9.0	36.0	15.7	14.5	13.1	12.5	14.1	16.6	18.3	18.6	18.0	15.9	17.1	16.4	25.6	28.8	29.3	36.2	44.7	47.5	47.7	46.5	52.5	16.0	9.2	30.5
pm1	1.0	9.0	48.0	14.1	13.3	12.4	12.0	13.0	14.8	16.0	16.3	15.8	14.4	15.2	14.7	21.4	23.9	24.5	30.0	37.2	39.7	40.0	39.1	49.3	13.4	7.5	35.0
pm2	1.0	9.0	48.0	15.3	14.1	12.9	12.3	13.7	15.9	17.4	17.7	17.1	15.2	16.3	15.7	23.6	26.2	26.7	32.9	40.6	43.3	43.6	42.7	51.0	14.4	8.1	32.6
pm3	1.0	9.0	48.0	14.1	12.9	12.1	11.8	13.6	15.8	16.6	16.3	16.3	15.9	17.6	17.5	21.8	22.5	22.7	29.5	39.6	43.4	44.1	43.5	50.6	10.0	8.2	83.1
pm1	2.0	9.0	48.0	15.4	14.2	12.7	12.1	13.8	16.3	18.1	18.4	17.7	15.7	16.8	16.2	24.8	27.8	28.3	34.6	42.2	44.7	44.7	43.5	52.0	15.2	8.8	30.2
pm2	2.0	9.0	48.0	14.1	13.1	12.2	11.8	12.9	14.8	16.0	16.1	15.7	14.3	15.2	14.8	21.2	23.1	23.5	29.4	37.1	39.8	40.0	39.0	49.1	12.7	7.2	40.1
pm3	2.0	9.0	48.0	15.7	14.5	13.1	12.7	14.5	17.1	18.6	18.8	18.3	16.5	17.9	17.3	25.6	28.1	28.5	35.7	45.1	48.4	48.6	47.4	52.9	14.6	9.0	42.5
pm1	1.0	9.0	60.0	14.6	13.9	13.0	12.6	13.9	15.9	17.0	17.3	16.8	15.5	16.4	15.9	22.4	24.5	25.0	30.7	38.2	40.9	41.3	40.7	50.5	12.4	7.3	40.0

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm2	1.0	9.0	60.0	15.2	14.0	12.9	12.4	13.7	15.9	17.3	17.5	16.9	15.3	16.4	15.9	23.2	25.3	25.7	32.0	40.0	42.8	43.0	42.1	50.9	13.4	7.8	39.9
pm3	1.0	9.0	60.0	14.8	13.5	12.4	12.2	14.4	16.6	17.3	17.0	17.0	16.7	18.5	18.5	22.5	22.9	23.0	29.7	39.7	43.5	44.0	43.2	51.5	9.2	8.0	86.3
pm1	2.0	9.0	60.0	16.1	14.7	13.1	12.5	14.4	17.1	18.8	19.0	18.4	16.5	17.7	17.0	25.1	27.6	28.0	34.2	41.9	44.5	44.5	43.4	52.6	13.8	8.4	35.4
pm2	2.0	9.0	60.0	14.0	13.0	12.1	11.8	13.1	15.0	16.0	15.9	15.6	14.6	15.7	15.3	20.7	22.0	22.2	28.3	36.7	39.7	40.0	39.1	49.0	11.1	6.9	52.0
pm3	2.0	9.0	60.0	15.6	14.3	13.0	12.6	14.4	16.8	18.2	18.2	17.8	16.3	17.7	17.1	24.8	26.7	27.0	34.2	43.9	47.3	47.5	46.3	52.3	13.6	8.5	48.3
pm1	1.0	9.0	72.0	14.3	13.4	12.5	12.1	13.4	15.4	16.4	16.6	16.2	15.0	16.0	15.6	21.4	23.2	23.5	29.3	37.2	40.1	40.5	39.8	49.7	11.6	7.1	45.8
pm2	1.0	9.0	72.0	15.2	14.1	13.0	12.6	14.3	16.6	17.6	17.6	17.2	16.1	17.4	17.0	23.1	24.4	24.6	31.1	39.9	43.2	43.6	42.8	51.3	11.4	7.5	56.4
pm3	1.0	9.0	72.0	14.5	13.2	12.3	12.1	14.3	16.5	17.0	16.6	16.7	16.7	18.6	18.8	22.0	22.3	22.3	29.0	39.1	43.0	43.7	43.0	51.3	8.5	8.1	95.4
pm1	2.0	9.0	72.0	15.6	14.3	12.9	12.4	14.3	17.0	18.4	18.5	18.0	16.3	17.6	17.0	24.6	26.6	26.9	33.2	41.4	44.2	44.3	43.2	52.2	13.1	8.2	42.5
pm2	2.0	9.0	72.0	14.0	13.0	12.1	11.8	13.1	15.0	16.0	15.9	15.6	14.6	15.7	15.3	20.8	21.9	22.1	28.3	36.9	40.0	40.2	39.2	49.0	11.0	6.8	52.8
pm3	2.0	9.0	72.0	15.1	13.9	12.7	12.5	14.5	16.9	18.1	18.0	17.7	16.6	18.1	17.7	24.4	25.9	26.1	33.5	43.6	47.3	47.5	46.3	52.3	12.5	8.5	59.9
pm1	1.0	10.0	0.0	15.3	14.6	13.3	12.6	13.6	15.7	17.8	18.8	17.6	15.0	15.7	15.1	24.3	32.4	36.1	38.2	39.7	41.0	41.7	41.3	52.4	20.1	10.0	5.1
pm2	1.0	10.0	0.0	14.5	13.8	12.8	12.3	12.8	14.5	16.3	17.1	16.1	13.9	14.5	14.0	22.3	30.1	33.8	36.2	38.2	39.9	40.8	40.6	50.6	20.1	9.7	10.6
pm3	1.0	10.0	0.0	14.4	13.7	12.6	12.0	12.7	14.5	16.6	17.4	16.3	13.9	14.5	14.0	22.3	30.0	33.7	35.8	37.5	39.0	39.9	39.7	50.6	19.8	9.6	6.5
pm4	1.0	10.0	0.0	14.2	13.5	12.4	11.8	12.4	14.3	16.5	17.3	16.1	13.7	14.3	13.8	22.1	29.8	33.7	36.3	38.4	40.1	41.2	41.0	50.4	20.1	9.8	6.0
pm1	2.0	10.0	0.0	16.2	15.4	13.7	12.9	13.9	16.2	18.5	19.4	18.2	15.3	16.1	15.4	25.6	33.9	37.3	39.2	40.3	41.3	41.7	41.0	53.1	20.8	10.3	0.6
pm2	2.0	10.0	0.0	16.6	15.7	14.0	13.1	14.1	16.2	18.4	19.4	18.2	15.4	16.1	15.4	25.7	34.2	37.8	39.7	41.0	42.3	42.8	42.2	53.2	21.2	10.4	1.1
pm3	2.0	10.0	0.0	16.7	15.8	13.9	12.9	14.2	16.6	19.0	20.0	18.8	15.7	16.4	15.7	26.7	35.5	39.2	41.2	42.7	44.0	44.6	44.1	53.9	21.7	10.8	0.0
pm4	2.0	10.0	0.0	14.6	13.9	12.5	11.8	12.6	14.5	16.6	17.4	16.2	13.7	14.3	13.8	22.6	30.3	33.9	36.2	37.9	39.3	40.0	39.6	50.6	20.4	9.8	3.1
pm1	1.0	10.0	12.0	15.4	14.6	13.3	12.6	13.5	15.4	17.2	17.8	17.0	14.8	15.5	14.9	23.8	29.4	31.3	35.6	39.8	41.3	41.6	40.9	51.4	18.0	9.1	14.7
pm2	1.0	10.0	12.0	14.3	13.5	12.6	12.1	12.9	14.6	16.0	16.4	15.8	14.1	14.8	14.3	21.7	25.7	27.0	32.5	38.5	40.8	41.5	41.0	49.6	15.8	8.2	26.4
pm3	1.0	10.0	12.0	14.3	13.5	12.5	11.9	12.7	14.4	16.0	16.5	15.8	13.8	14.5	14.0	22.2	27.4	29.2	33.8	38.5	40.4	40.8	40.3	49.9	17.8	9.0	17.8
pm1	2.0	10.0	12.0	15.1	14.2	12.8	12.1	13.1	15.2	17.2	17.8	17.0	14.5	15.4	14.7	24.3	29.8	31.4	35.7	39.8	41.4	41.6	40.8	51.4	18.5	9.6	12.0
pm2	2.0	10.0	12.0	16.4	15.4	13.8	13.0	14.0	15.9	17.8	18.5	17.6	15.1	15.8	15.2	25.5	32.2	34.2	38.1	41.6	42.9	42.9	41.9	52.5	19.9	9.9	9.2
pm3	2.0	10.0	12.0	16.5	15.5	13.8	12.8	14.1	16.4	18.6	19.4	18.4	15.6	16.4	15.7	26.8	33.7	35.7	39.8	43.5	44.9	45.0	44.1	53.4	20.4	10.5	5.1
pm1	1.0	10.0	24.0	15.1	14.3	13.1	12.5	13.5	15.4	16.9	17.4	16.7	14.9	15.7	15.1	23.0	27.0	28.0	33.5	39.9	42.1	42.4	41.5	50.7	15.7	8.3	25.2
pm2	1.0	10.0	24.0	13.9	13.2	12.4	12.1	12.9	14.6	15.6	15.8	15.4	14.2	15.1	14.7	20.7	23.0	23.6	29.8	38.1	41.2	41.8	41.2	48.9	13.0	7.3	43.1
pm3	1.0	10.0	24.0	13.9	13.1	12.3	11.8	12.7	14.5	15.9	16.3	15.7	14.1	14.9	14.4	21.7	25.0	25.9	31.4	38.1	40.5	40.9	40.1	49.4	15.0	8.1	29.4
pm1	2.0	10.0	24.0	14.6	13.7	12.5	11.9	13.1	15.2	16.9	17.3	16.6	14.6	15.5	14.9	23.4	27.0	27.8	33.3	39.7	41.8	41.9	40.9	50.7	16.0	8.7	24.2
pm2	2.0	10.0	24.0	16.3	15.3	13.8	13.1	14.2	16.3	18.0	18.6	17.8	15.5	16.3	15.7	25.1	30.0	31.0	36.1	41.5	43.2	43.3	42.3	52.2	17.4	8.9	16.8
pm3	2.0	10.0	24.0	15.2	14.3	12.9	12.2	13.4	15.7	17.7	18.3	17.4	15.0	15.9	15.2	25.1	29.8	30.8	36.4	42.6	44.7	44.9	43.9	51.9	18.0	9.6	14.5
pm1	1.0	10.0	36.0	15.8	14.9	13.8	13.2	14.2	15.9	17.3	17.5	17.1	15.4	16.4	15.8	23.0	26.0	26.6	32.4	39.6	42.0	42.3	41.4	51.0	13.9	7.6	34.1
pm2	1.0	10.0	36.0	14.4	13.5	12.7	12.4	13.5	15.2	16.0	16.0	15.8	14.8	15.9	15.5	20.9	22.4	22.7	29.2	38.4	42.0	42.6	42.0	49.3	11.4	6.9	54.1
pm3	1.0	10.0	36.0	12.5	11.6	10.6	10.2	11.3	13.2	14.5	14.7	14.2	12.7	13.6	13.1	20.1	22.7	23.3	29.2	36.8	39.5	39.8	39.0	47.5	14.7	8.5	35.1
pm1	2.0	10.0	36.0	11.2	10.3	9.0	8.6	10.1	12.5	14.1	14.4	13.8	12.0	13.0	12.4	20.4	23.1	23.5	29.4	36.7	39.1	39.4	38.6	47.1	16.1	9.8	29.0
pm2	2.0	10.0	36.0	14.8	13.8	12.6	12.0	13.2	15.4	17.0	17.5	16.8	14.7	15.6	15.0	23.9	27.7	28.4	34.2	40.9	43.1	43.3	42.5	50.9	16.6	8.9	22.1
pm3	2.0	10.0	36.0	15.3	14.2	12.8	12.2	13.6	16.0	17.8	18.2	17.5	15.3	16.3	15.7	24.6	28.0	28.6	34.7	42.1	44.6	44.8	43.7	51.7	15.9	8.9	24.0
pm1	1.0	10.0	48.0	15.5	14.5	13.5	13.0	14.1	15.9	17.1	17.2	16.8	15.4	16.5	15.9	22.5	24.8	25.2	31.2	39.1	41.8	42.1	41.1	50.6	12.8	7.3	41.6
pm2	1.0	10.0	48.0	14.4	13.5	12.8	12.5	13.9	15.6	16.2	16.1	16.0	15.4	16.6	16.3	20.7	21.7	21.8	28.4	38.2	42.1	42.8	42.2	49.6	9.9	6.6	65.1
pm3	1.0	10.0	48.0	13.9	13.0	12.1	11.8	12.9	14.7	15.8	15.9	15.5	14.3	15.3	14.9	21.0	22.9	23.3	29.5	37.9	41.0	41.4	40.6	49.0	12.6	7.4	45.2

Meat-type & replicate #	Bag #	Week	Hour	Reflectance values at wavelengths (nm) of																				Color*			% of metmyoglobin
				360.0	380.0	400.0	420.0	440.0	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0	700.0	720.0	740.0	L	A	B	
pm1	2.0	10.0	48.0	14.8	13.6	12.4	12.0	13.4	15.5	16.8	16.9	16.5	15.1	16.2	15.7	22.6	24.4	24.6	30.7	38.9	41.7	41.9	40.9	50.3	12.8	7.8	43.8
pm2	2.0	10.0	48.0	15.7	14.7	13.5	12.9	14.2	16.2	17.7	17.9	17.4	15.6	16.6	16.0	23.9	26.7	27.1	33.1	40.6	43.0	43.1	42.0	51.4	14.3	7.9	31.1
pm3	2.0	10.0	48.0	14.8	13.8	12.6	12.1	13.5	15.9	17.4	17.7	17.1	15.3	16.4	15.7	23.8	26.4	26.9	33.5	41.9	44.8	45.0	43.8	51.2	14.6	8.5	33.5
pm1	1.0	10.0	60.0	16.6	15.6	14.5	14.0	15.2	17.0	18.0	18.1	17.8	16.6	17.6	17.1	23.3	25.1	25.4	31.3	39.6	42.4	42.6	41.6	51.7	11.5	6.7	47.0
pm2	1.0	10.0	60.0	14.3	13.3	12.6	12.4	13.8	15.4	15.9	15.6	15.6	15.3	16.6	16.5	20.1	20.6	20.7	27.1	37.3	41.4	42.2	41.5	49.2	8.8	6.5	75.7
pm3	1.0	10.0	60.0	13.8	12.8	11.9	11.6	12.8	14.7	15.7	15.7	15.4	14.4	15.4	15.0	20.9	22.5	22.7	29.0	38.1	41.4	41.7	40.8	48.9	12.1	7.5	51.1
pm1	2.0	10.0	60.0	14.5	13.4	12.4	12.0	13.6	15.7	16.7	16.6	16.4	15.3	16.6	16.1	21.9	23.2	23.3	29.5	38.4	41.6	41.9	41.0	50.1	11.3	7.3	54.9
pm2	2.0	10.0	60.0	15.8	14.7	13.6	13.1	14.4	16.5	17.8	17.9	17.5	16.0	17.0	16.4	23.7	26.0	26.3	32.5	40.8	43.7	43.9	42.9	51.5	13.2	7.6	39.2
pm3	2.0	10.0	60.0	14.7	13.7	12.5	12.1	13.7	16.1	17.5	17.6	17.1	15.6	16.8	16.2	23.6	25.6	25.9	32.7	41.6	44.7	44.9	43.8	51.2	13.4	8.2	42.4
pm1	1.0	10.0	72.0	15.5	14.5	13.5	13.1	14.4	16.2	17.1	17.0	16.8	15.9	17.0	16.6	22.1	23.5	23.8	29.9	38.7	41.8	42.1	41.3	50.6	11.0	6.8	54.4
pm2	1.0	10.0	72.0	14.3	13.3	12.6	12.5	14.0	15.6	16.0	15.7	15.7	15.7	17.1	17.1	20.1	20.3	20.4	26.8	37.2	41.6	42.4	41.8	49.5	8.0	6.5	84.4
pm3	1.0	10.0	72.0	13.3	12.3	11.5	11.3	12.5	14.4	15.3	15.3	15.0	14.1	15.2	14.8	20.2	21.6	21.8	28.0	37.3	40.9	41.3	40.4	48.4	11.5	7.3	55.2
pm1	2.0	10.0	72.0	14.6	13.5	12.5	12.2	13.9	16.0	16.8	16.6	16.5	15.7	17.0	16.7	21.7	22.6	22.6	28.9	37.9	41.3	41.6	40.7	50.2	10.1	7.1	64.3
pm2	2.0	10.0	72.0	15.5	14.4	13.3	12.9	14.2	16.2	17.3	17.3	17.0	15.7	16.8	16.3	22.7	24.4	24.5	30.8	39.6	42.9	43.2	42.3	50.8	12.0	7.2	46.7
pm3	2.0	10.0	72.0	14.9	13.6	12.5	12.1	14.0	16.4	17.5	17.4	17.2	16.0	17.4	16.9	23.2	24.5	24.6	31.4	40.5	43.8	44.0	42.9	51.3	11.7	7.9	56.6
pm1	1.0	10.0	84.0	15.7	14.7	13.8	13.5	14.9	16.7	17.4	17.4	17.2	16.4	17.6	17.2	22.2	23.3	23.6	29.7	38.8	42.1	42.5	41.7	51.0	10.0	6.5	58.6
pm2	1.0	10.0	84.0	10.1	9.2	8.5	8.5	10.5	12.2	12.5	12.1	12.2	12.4	14.1	14.2	16.8	16.9	16.9	23.5	34.1	38.5	39.3	38.7	45.3	8.8	8.5	100.0
pm3	1.0	10.0	84.0	8.9	8.1	7.3	7.3	9.0	11.0	11.9	11.9	11.7	10.8	12.0	11.7	17.0	18.1	18.3	24.8	34.3	37.9	38.4	37.6	44.0	12.9	9.2	62.5
pm1	2.0	10.0	84.0	13.2	12.2	11.2	11.0	13.0	15.1	15.8	15.5	15.4	14.9	16.4	16.1	20.5	21.1	21.0	27.2	36.3	39.8	40.3	39.7	49.1	9.6	7.4	73.2
pm2	2.0	10.0	84.0	15.9	14.8	13.7	13.3	14.7	16.7	17.7	17.7	17.4	16.3	17.5	17.0	22.8	24.1	24.2	30.2	38.9	42.0	42.3	41.3	51.2	10.8	6.8	52.3
pm3	2.0	10.0	84.0	14.7	13.4	12.3	12.1	14.1	16.5	17.4	17.2	17.1	16.2	17.7	17.3	23.0	23.9	24.0	30.8	40.4	43.8	44.1	43.0	51.3	10.9	7.9	66.0
pm1	1.0	10.0	96.0	16.2	15.1	14.2	13.9	15.3	17.0	17.7	17.5	17.4	16.7	18.0	17.6	22.3	23.2	23.3	29.2	38.3	41.7	42.0	41.1	51.2	9.3	6.2	63.4
pm2	1.0	10.0	96.0	14.2	13.3	12.6	12.6	14.5	16.1	16.2	15.8	15.9	16.3	17.9	18.2	20.1	20.0	20.0	26.2	36.7	41.2	42.0	41.4	49.9	6.7	6.6	98.2
pm3	1.0	10.0	96.0	13.9	12.9	12.1	11.8	13.2	14.9	15.7	15.5	15.4	14.7	15.9	15.6	20.3	21.2	21.3	27.7	37.5	41.4	41.8	40.9	48.9	10.3	6.9	64.3
pm1	2.0	10.0	96.0	14.9	13.7	12.8	12.6	14.4	16.3	16.8	16.4	16.4	16.2	17.7	17.6	21.1	21.3	21.3	27.4	36.9	40.7	41.2	40.4	50.3	8.1	6.6	80.9
pm2	2.0	10.0	96.0	15.8	14.7	13.7	13.4	15.0	17.0	17.8	17.7	17.5	16.7	17.9	17.5	22.6	23.5	23.5	29.5	38.4	41.7	42.1	41.2	51.3	9.6	6.5	60.4
pm3	2.0	10.0	96.0	15.0	13.6	12.4	12.2	14.5	16.8	17.4	17.1	17.1	16.7	18.4	18.2	22.6	23.1	23.2	30.0	39.9	43.5	43.8	42.7	51.4	9.5	7.8	81.1

* Hunterlab scale.

APPENDIX I

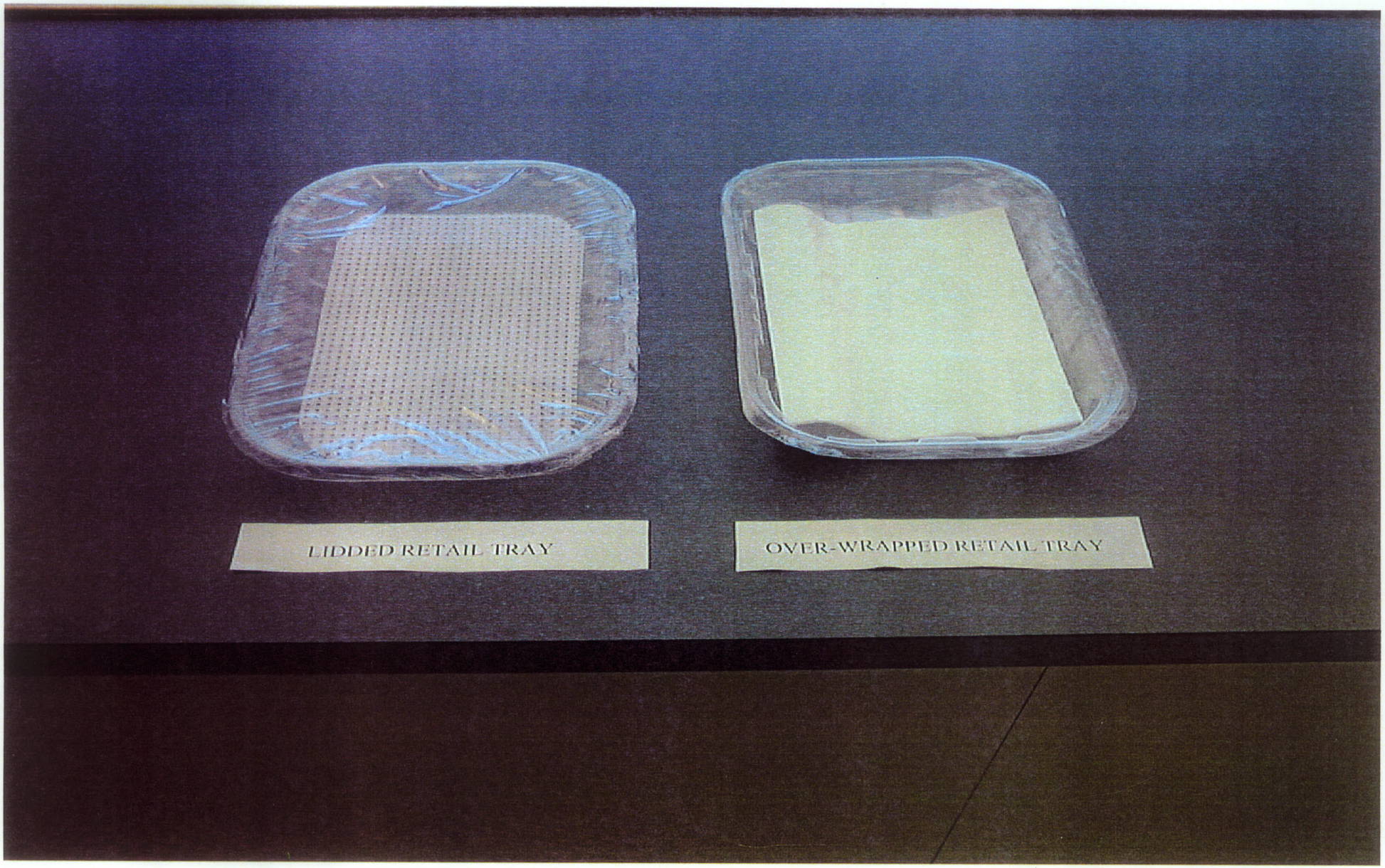

Fig. I1 Lidded and over-wrapped trays used in the retail packaging system design study.
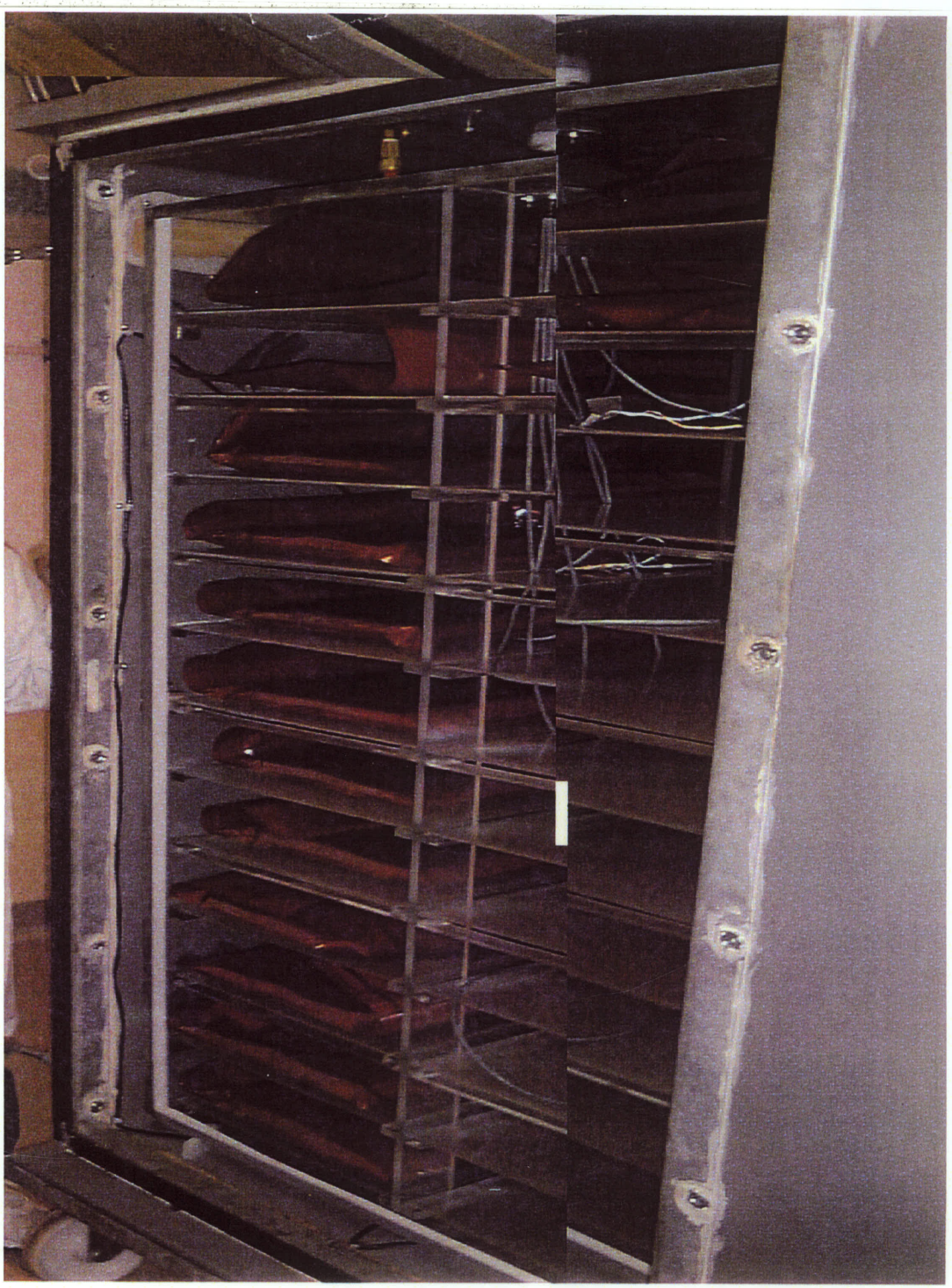
Fig. I2 Master-packaged steaks under 100% N_2 atmosphere stored at -1.5°C in liquid-N_2 refrigerated container.