This is to certify that the

thesis entitled

DEVELOPMENT OF A MATERIAL TESTING PROTOCOL FOR EVALUATION OF RADIO FREQUENCY TRANSPONDER EFFECTS ON BLOOM TIME OF BEEF LOIN MUSCLE

presented by

KEITH L. VORST

has been accepted towards fulfillment
of the requirements for

MASTER degree in PACKAGING

Robb Clarke
Major professor

Date 7/3/02

# DEVELOPMENT OF A MATERIAL TESTING PROTOCOL FOR EVALUATION OF RADIO FREQUENCY TRANSPONDER EFFECTS ON BLOOM TIME OF BEEF LOIN MUSCLE

By

Keith L. Vorst

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Packaging

2002

## ABSTRACT

DEVELOPMENT OF A MATERIAL TESTING PROTOCOL FOR EVALUATION OF RADIO FREQUENCY TRANSPONDER EFFECTS ON BLOOM TIME OF BEEF LOIN MUSCLE

By

Keith L. Vorst

Radio frequency transponders are rapidly becoming a viable technology for tracking of perishable food items through the grocery supply chain. However, the effects of radio frequency transponders on package performance are not well known. This study focused on development of a radio frequency material testing protocol and effect the transponder would have on bloom of beef loin muscle.

A common transponder substrate of polyethylene terephthalate (PET) with an adhered aluminum antenna and integrated circuit was evaluated to better understand material properties. Testing was performed to identify physical and barrier properties of the substrate.

Transponders were received on a stock roll and trimmed to common dimensions found in label applications. Specific testing was performed for substrate identification, surface tension, oxygen and water permeability, and tensile strength.

Beef loin muscles were used to evaluate the effects of transponders (adhered to the primary film) on bloom time of a tray packed steak. Statistical differences of ($P<0.05$) and ($P<0.0001$), differences interpreted as of practical significance, were seen in areas of the beef loin muscle directly beneath the transponder when compared to control areas in the absence of the transponder.

## ACKNOWLEDGEMENTS

I wish to thank my family and friends for their support, encouragement and understanding through my years of study.

I also wish to thank my committee members, Drs. Clarke, Downes, Harte, and Booren for their patience and guidance throughout my research and writing of this thesis. I would like to give a special appreciation to Dr. Booren and Mr. Chuck Allison for their assistance throughout the research.

A very special thanks to my wife Amy for not letting me quit when the end was near. Without her none of this was possible.

## TABLE OF CONTENTS

## LIST OF TABLES

Table Number

## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| CAP | Controlled Atmosphere Packaging |
| CIE | Commission Internationale de l'Eclairage |
| FT-IR | Fourier Transform Infrared |
| GHz | Giga Hertz |
| IC | Integrated Circuit |
| KHz | Kilo Hertz |
| MHz | Mega Hertz |
| MAP | Modified Atmosphere Packaging |
| OTR | Oxygen Transmission Rate |
| PET | Polyethylene Terephthalate |
| PVC | Polyvinyl Chloride |
| RF | Radio Frequency |
| RFID | Radio Frequency Identification |
| TRP | Transponder |
| USDA | United States Department of Agriculture |
| WVTR | Water Vapor Transmission Rate |

## LIST OF APPENDICES

Appendix Number



Images in this thesis are presented in color.

# INTRODUCTION

The use of Radio Frequency (RF) for tracking of animals and products is not a new venture. The first research to explore the possibilities of Radio Frequency Identification (RFID) was introduced in the 1950's where the first applications of reflected-power communications were realized (Landt, 2001). Since the 1950's there has been rapid growth of RFID with new applications being integrated with old methods of tracking animate and inanimate objects. This can be seen with transponders being embedded in cattle to monitor medications, feeding, and any potential diseases. The use of RFID to track animals is now commonplace with embedded transponders. The new challenge for RFID is to track all products through the supply chain.

The ability to carry a living database via RFID through a product life cycle already exists. This study evaluates one application of a radio frequency transponder in a retail meat package. To encourage applications and understanding of RFID potential, the effect of the transponder on bloom time in the retail display case is evaluated. With the understanding of bloom time effects on fresh red meats and a protocol for display and package development, optimal consumer acceptance and RFID performance can be realized.

A basic Radio Frequency Identification (RFID) system is comprised of three main components: a transceiver, antenna or coil, and transponder. A transceiver is used as an energy source for data transmission and reception between transponder and transceiver. The antennae act as a connection between transponder and transceiver. These antennae emit radio signals that can read or write data to the transponder (Clarke, 2001). Transponders are typically referred to as an RF tag that can be electrically encoded with unique data (Landt, 2001). The transfer of data occurs when the antenna emits radio signals, which activate the transponder to read data from the transponder or write data to the transponder.

The success of RFID in the retail food market depends on a successful transfer of data through various mediums, both product and package. With the removal of the line-of-sight needed for traditional bar codes, an RF signal must be able to penetrate the product for successful exchange of data to ensure innermost products of a case or pallet are read. These product mediums may include plant and animal tissue, moisture, and various other particulates. In addition to product mediums, the packaging is another barrier the RF signal must penetrate. Here, such materials as paper, metal, plastic, glass, and composite materials can act on the RF signal. In addition to primary and secondary packaging, a pallet load of product with tertiary packaging and stretch wrap, or a display case of product must also be considered. The realization of RFID for real-time inventory, security, and quality monitoring may only be successful if each of these media allows for the successful transfer of the RF signal. In addition to the successful transfer of the radio signal, properties necessary for quality and safety of the product must not be altered by the application of a radio frequency transponder.

Current RFID technology will allow for a successful transmission through most plant and animal tissue, but at a cost. This cost is not only financial but can be seen in physical size. Current transponders on meat-cased products can occupy as much as 20% of the total film surface area. With Modified Atmosphere Packaging (MAP) or Controlled Atmosphere Packaging (CAP), this transponder size can have an impact on the packaging system. A potential 20% reduction in transfer of gases and water vapor are examples of the impact that can occur as demonstrated by a simple permeability calculation presented in the literature review of this study.

For purposes of this study, transponder functions will be identified as smart packaging, active packaging, and intelligent functions. Smart packaging enables the package to communicate to manufacturer, distributor, retailer, and consumer. This communication may be in the form of tracking, security or even appliance functions such as cooking information. Active packaging can be identified as an interaction between product and environment to increase shelf life of product or ensure safeness (Faber et al., 1995). Examples of this can be seen as time-temperature profiling or tamper evidence via an external reader transmitting data to the product. A new term for transponder and environment interaction can be defined as intelligent functions. Here, transponders monitor conditions between the product, package, and environment. Examples of this emerging technology are radio frequency coupled biosensors for detection of chemical or biological changes in the package environment. A standard classification for the unique capabilities of transponders has yet to be internationally identified.

From a consumer perspective, "smart packaging" may affect heating uniformity in a microwave or dimensional stability of film as a result of attached transponders on convenience foods. These are a few of the noticeable changes in package performance. The more subtle changes may include migration of organic compounds from the film and transponder adhesive into the product headspace and ultimately food. These areas are identified as areas of future research when developing RFID in the food-packaging arena. RFID has opened the possibility for real-time inventory tracking, security, and quality monitoring but has not successfully demonstrated or answered questions on performance in the food market.

A simple model is used to help illustrate the effects of a commonly used RF transponder on a perishable product. Consider a 13.56 MHz transponder with the following attributes: surface area of 36.48 $cm^2$, thickness of 1.6 mil, substrate composition of polyethylene terephathalate (PET), and antenna composition of aluminum. Numerous commercial transponders are available with the same composition, varying only in size and frequency. For this study this was true of the following manufacturers: Texas Instruments, Omron Electronics Incorporated, Phillips Semiconductor, and TAGSYS Incorporated.

The goal for each study was to: 1) develop material testing protocol for evaluation of material properties of a common radio frequency transponder, and 2) utilize testing protocol to gain information on radio frequency transponder properties for evaluation of effects on a perishable meat product. The specific objective of the first study was to determine the barrier and mechanical properties of the transponder substrate. The specific objective for the second study was to evaluate the impact of transponder properties on bloom time of fresh beef loin muscle when attached to the primary film of tray-packed steak.

# LITERATURE REVIEW

## What is RFID

Radio Frequency Identification (RFID), in its simplest form, can be viewed as an electronic label that can be either read-only or read write and is capable of holding upwards of 128Kb of memory. The memory capacity increasing almost monthly. The basic components of an RFID system are a transceiver, antenna or coil, transponder, and computer (Clarke, 2001) . A transceiver interprets electrically encoded data that is both sent and received from the antenna or coil through a radio frequency signal. The transponder acts as a database that when activated by the radio frequency signal from the antenna, will either release or write data. The components of the transponder include an integrated circuit that functions as the electrical carrier of the database and an adhered antenna that enables the reception of the radio frequency signal being generated by the antenna and transceiver (Landt, 2001). Common U.S. operating frequencies for RFID systems are 125 KHz, 13.56 MHz, 915 MHz, and 2.4 GHz (Clarke, 2001). Each of these frequencies displays different properties in terms of reading distance and penetration through mediums. Low frequency (125 KHz) transponders and high frequency (13.56 MHz) have displayed improved performance to that of ultra high frequency (915 MHz) and microwave frequency (2.4 GHz) when considering penetration through moist food products (Brody, 2001).

In addition to frequency differences, transponders can be classified as active or passive. Active transponders will carry an internal power source such as a battery while passive transponders utilize power generated by the energy field generated from the reader and/or antenna (Hickman, 1997).

## Current Applications of RFID

RFID has become a viable technology for some packaging applications. Starting at the point of manufacture and ending at the consumer, there has been a requirement for increased product knowledge and identity. RFID can take previous methods of product information and tracking to a new level. Promising applications of this technology include increased data storage capability, real-time tracking/inventory, time/temperature profiling and, in some cases, the elimination of the requirement for line-of-sight data interchange.

The use of RFID in manufacturing is now commonplace (Krizner, 2000). Tracking of large-scale operations through the manufacturing cycle is now being done by almost every large automotive manufacturer. Rewritable transponders are now used in identifying assembly staging of engine blocks and even individual piece parts (Krizner, 2000). Here, the tags are written with such information as model, style, options, date, and assembly code. Recent additions to this technology are the use of RFID to locate vehicles, lock or unlock doors, start, stop, or even summon emergency personnel (Mykytiuk, 2002).

In recent years, food packaging has seen an increase in the use of RF technology to help monitor various attributes during the distribution of food products. Currently, Associated Grocers of Maine is using handheld radio frequency scanners for all receiving and put away as well as selection for meat (Uniteq, 2001). A sales potential as high as $12 billion is predicted by the end of the year 2005 (Venture Development Corporation, 2002). The price per unit will be economically feasible for use in the food industry when the volume is realized. Wal-Mart is currently testing RFID technology to automate distribution center operations (Burnell, 2000). The development of "active packaging", in which the packaging material interacts with the product to extend shelf life and monitor other quality attributes, has been established in the food industry (Brody, 2001). These attributes become increasingly important with oxygen, water, and temperature sensitive products. Recent developments in active packaging have included oxygen and water scavenging films as well as antioxidant and antibacterial agents incorporated in the food package (Anon, 2002). Active packaging using transponders is the next logical step for monitoring quality attributes as seen with the advent of intelligent functions in transponders. With current RF technologies being utilized in the grocery industry, the added feature of quality monitoring can be an addition to the current system, and not an entirely new enterprise.

Active packaging, smart packaging, and intelligent functions can now be coupled together using the same transponder. An attached or embedded transponder that monitors quality attributes from an active packaging prospective can now be utilized for automatic cooking of microwave meals. This automated cooking function defines the smart packaging role of the transponder. Companies have already demonstrated the RF transponder's ability to measure temperature successfully with the distribution of fruits and vegetables Freshloc™ (Freshloc Technologies, Dallas, TX). This application defines the active packaging and intelligent functions of a transponder through increased shelf life, insuring safeness, and monitoring conditions between the product, package, and environment.

## Application of RFID to perishable food products

Growth in the case-ready products in the US market is predicted to be over 21% annually between the years 2000-2002 and case-ready meats are leading the growth market of flexible films (Demetrakakes, 2002). Consumer acceptance, historically, has been identified as a primary stumbling block in the evolution of case-ready meat. Unlike poultry and pork, a problem with consumer acceptance of case-ready red meat is the purplish meat color resulting from lack of oxygen (Galosich, 1999). Time is critical in development of muscle color or "bloom" of meat. Within 30-40 min after muscle is exposed to oxygen, the reduced myoglobin (Mb), associated with a purple color, will be oxygenated to oxymyoglobin ($MbO_2$) associated with a red color. Continued exposure to air takes the oxymoglobin to an oxidized form or metmyoglobin (MMb), metmyoglobin is a gray to brown color often associated with loss of quality (Insausti et al., 1999). Studies performed found that a relationship between instrumental color measurements and visual color measurements was needed to evaluate fresh pork colors (Brewer et al., 2001). While research has been done on red meats products in regards to color, this research has primarily focused on properties of meat such as muscle type, age, and pH affecting meat color and bloom time. Very little research has been done on properties such as display case lighting, temperature, or film variations affecting meat color. Past studies have suggested certain lighting sources will affect color scores of beef muscles (Kropf et al., 1984). These studies found incandescent lighting to be optimal for improving carcass maturity scores and final grade quality. While lean color score was significantly improved by light source, lighting intensity was found to have no effect on grade quality of beef. Research has measured the muscle color of beef carcasses using the L * a *b * color space from a Minolta colorimeter (Wulf et al., 1999). This research primarily focused on evaluating factors that affected colorimeter readings in the carcass. It was found that days of postmortem did not affect color readings and a* was the best predictor of redness associated with bloom time for meat. Similar research was performed on pork samples using a HunterLab Spectrocolorimeter (Brewer et al., 2001). The L* values associated with luminosity or lightness-darkness were found to have little affect on bloom time. The a* values, representing the redness of the muscle, was used in combination with L* values for a predictor of bloom time. The b* value for yellowness is not commonly used when predicting the red bloom of fresh meat.

**Impact of RFID on the Packaging System:**

A simple model can be used to demonstrate the effects of a transponder substrate on the permeability of case-ready meat. A typical tray-packed rib eye steak was selected for this model. This tray-packed steak will consist of a polystyrene tray and a low oxygen barrier overwrap film to allow for bloom of meat. A common film used for fresh meat packaging is plasticized polyvinyl chloride (PVC). This model utilizes PVC as the primary permeable film to allow a proper bloom and simulate a retail display case. An exposed surface area of 284 $cm^2$ and 1 mil (0.0254 mm) thick representing a common tray was selected for this estimation. For this model 0.21 atmospheres of oxygen and 25°

C will be used for ambient conditions. A common permeability expression, $P=q*l/A*t*\Delta p$ (Hernandez. 2001), can be used to estimate gain of oxygen where:

q = total quantity of the permeant throughout the exposed area during time t, expressed in cubic centimeters,

l = thickness of film, expressed in mils,

A = area of package, expressed in 100 $in^2$,

t = time in days,

$\Delta p$ = change in pressure expressed in atmospheres.

Once the variables have been identified and added to the previous equation, the quantity of oxygen gained through the package per day can then be calculated.

To account for reduction in oxygen transmission rates with an attached transponder, a common substrate of polyethylene terephthalate (PET) with a permeability coefficient of 9.7 $cc*mil/100in^2*day*atm$ will be used (Hernandez, 2001). The permeable layer of plasticized PVC has a permeability coefficient of 838.7 cc*mil/100 $in^2$ * day* atm. (Hernandez, 2001). A common RF/smart label surface area can range from 19-40 $cm^2$ (this will depend largely on the application). This accounts for 7-14% of total package surface area. Using these conditions, an estimation in the gain of oxygen from a package with no transponder can be calculated at 369 cc per day. With an attached transponder, the value drops to a range of 319-343 cc of oxygen per day. This represents a decrease of 26-50 cc of oxygen, or a 7-14% decrease in diffusion. This model will vary with storage conditions since pressure and relative humidity can increase or decrease permeability coefficients. This decrease in oxygen permeation can adversely affect the bloom time of fresh red meats. This is especially important when considering transponders that can occupy as much as 16% of the total surface area of the package. Depending on application, these large transponders may be necessary for proper communication between the RF components. With information on transponder effects on bloom time, a better selection of transponder and packaging materials can be made to avoid any rejection by consumers.

**Future Applications of RFID:**

Recent developments have enabled transponders to be laminated between layers of plastic, film, and paper. (Brody, 2001). After laminating transponders between layers, transponder substrates can be utilized for primary packaging applications such as food and pharmaceutical products.

Specifications have been developed for most commercially available transponders. These specifications are designed to communicate operating frequency, read ranges, memory capacity, and allowable temperature operating ranges. There is very little mention of material composition and no mention of barrier properties in these specifications.

Research is currently being done to identify intelligent functions in packaging by manufacturers such as Aromascan and 3M (Brody, 2001). Intelligent functions enable transponders to sense gases, liquids, temperature, and pressure in addition to the traditional inventory control and tracking. With the onset of intelligent functions, transponders are monitoring not only dynamic movement but internal conditions of the package as well. Transponder applications utilizing intelligent functions are impacted by material composition, barrier properties, and location within a case or pallet. Intelligent functions combine both smart and active packaging concepts.

Future applications of transponders in packaging will allow for profiling quality attributes of foods. Several companies are developing transponders that allow for time, temperature, and gas mixture profiling in pharmaceutical and food products (Brody, 2001). Embedded transponders in the primary package film can also increase security and tamper evidence by transmitting an alarm signal once a connection is broken within the seal of the package preventing consumer use. They can also be utilized in Hazard Analysis Critical Control Point (HACCP) decisions when food safety is considered. These intelligent function transponders will combine all the abilities of security, quality, and tracking.

Current research of transponder applications has focused on transponder performance in terms of read range, accuracy, and data retention. The pharmaceutical industry has acknowledged the need for research on transponder and product interactions because of stringent governmental regulations on packaging of products such as interferon bags. With pharmaceutical applications, current knowledge of transponder performance is not the only determining factor for successful application. The successful integration of RFID in the primary packaging of pharmaceutical products requires knowledge of the interactions between the transponder and the product/packaging system.

From a consumer perspective, "smart packaging" may be impacted by heating uniformity in a microwave or dimensional stability of film as a result of attached transponders on convenience foods. Active packaging enables the quantification of gases through all packaging substrates including the transponder in addition to product tracking. This can be done using sensors such as Fresh Tag™ for detection of organic compounds (Cox Technologies Inc., Belmont, NC). RFID has opened the possibility for real-time inventory tracking, security, and quality monitoring through intelligent functions, but has not successfully demonstrated or answered questions on performance and interactions in foods. It is the goal of this research to provide data on transponder substrate material properties and the effects of transponders on a particular application such as bloom time in red meat. This research has identified a commercially available and commonly used substrate for transponders. Different substrate and transponder configurations are commercially available with new designs being made available nearly every month. While the data presented in this research cannot be directly applied to different compositions and configurations, experimental design and justification following this protocol can aid in the advancement of new packaging technologies. Future research is suggested for design and implementation of transponders in primary packaging of gas and water vapor sensitive products.

# CHAPTER 1

# DEVELOPMENT OF A MATERIAL TESTING PROTOCOL FOR RADIO FREQUENCY TRANSPONDERS

## ABSTRACT

A material testing protocol was developed to evaluate a common radio frequency transponder substrate. Stock rolls of 13.56 MHz transponders were provided by Texas Instruments (Plano, Texas). Transponders provided were passive with an adhered transponder and integrated circuit (IC). Development of this protocol included substrate identification, oxygen and water vapor permeability, surface tension, and tensile strength. This protocol identified a polyethylene terephthalate (PET) substrate with low oxygen and water vapor permeabilities. Tensile strength was identified at 16,400 psi, and a surface tension of 46 dynes/cm. These properties follow closely to published data for PET film. Knowledge of these properties was used to evaluate the impact of a transponder on a perishable food product for study 2.

# INTRODUCTION

Radio Frequency Identification (RFID) has enabled complete product tracking from procurement to finished goods. This product tracking has enabled retailers to track products through the supply chain without additional labor traditionally seen with the scanning of bar codes. RFID is being utilized in for manufacturing, livestock tracking, and various warehouse applications. A significant move for RFID is integration into pharmaceutical and perishable grocery products (Barry, 2001). With the integration of RFID into perishable packaging come many design considerations. The RFID transponders are no longer an addition to the package, but an integral part of it.

The majority of research currently being done for RFID applications is performed by transponder manufacturers. The focus of their research is transponder performance from a readability and read range prospective. Manufacturers have not yet addressed the product and package interaction with the transponder.

Embedding of transponders between layers of packaging requires knowledge of transponder properties. Very little information on transponder material properties is available from suppliers. The objective of this study was to design a material testing protocol to enable packaging and industry professionals to design and implement RFID into pharmaceutical and food packaging. This goal was achieved by establishing key test methods for identifying material properties to ensure successful integration of an RFID transponder in primary package design.

# MATERIALS AND METHODS

## Study 1

Material properties of a common 13.56 MHz transponder were evaluated for substrate identification, oxygen and water vapor permeability, surface tension, and tensile strength. All tested transponder samples were held at 23° C and 48% relative humidity and handled with forceps and lint free towels to reduce human contact contamination.

### Identification and preparation of transponder samples

Two separate rolls of 500 count 13.56 MHz passive transponders were received from Texas Instruments (Plano, TX). Transponders utilized for this research were cut to a uniform length and width of 7.6 and 4.8 cm "respectively" as given by common Tag-it™ applications for Texas Instruments.

### Minimum and maximum thickness of transponder samples

Thickness of the transponder was found using a Mitutoyo Vernier caliper model CD-6" CS (Mitutoyo Co., Aurora, IL). Thickness seen in the transponder is not uniform due to the presence of an IC (integrated circuit) chip and subsequent antenna material. Measurements of thickness were taken at the minimum (substrate only) and maximum (substrate film with IC chip) points. The minimum and maximum points were taken for each material test performed in this study.

**Transponder substrate and film identification**

Transponder substrate identification, and overwrap and pouch identification for study 2, was performed with the Perkin Elmer Model 1000 Fourier Transform-Infrared Spectrometer FT-IR (Perkin Elmer Corporation, Norwalk, CT). An IR spectrum was obtained by irradiating the transponder sample with an IR source of light. This light passes through the sample and is then detected by an IR detector. Thus, the molecule can be determined by the different frequencies absorbed. Each bond will absorb IR radiation at different frequencies. Peaks are analyzed to determine the frequency at which they occur to develop a frequency spectrum. Each peak intensity is denoted by a percent transmittance (%T). Frequencies are listed in wave numbers as the reciprocal of centimeters ($cm^{-1}$).

**Transponder water vapor transmission rate and permeability coefficient**

The Permatran W3/31 (Modern Controls Inc., Minneapolis, MN) was used to evaluate water vapor transmission rates of the transponder substrate. The Permatran W3/31 allows for two simultaneous measurements of water vapor transmission. Samples were conditioned for 3 hours. After conditioning each sample is subject to a continuous flow using dry nitrogen gas and a humid nitrogen gas. Test conditions for the five samples used were 23.8° C with an exposed area of 5 $cm^2$. Relative humidity varied for each sample from a low of 42% to a high of 51%. Water vapor transmission rate is the average of 10 values during steady state. Once steady state has been reached in each chamber of the Permatran W3/31, a printout is taken and an average water vapor transmission rate is given (Appendix 3). A conversion from water vapor transmission rate to permeability coefficient is found using the following equation (Hernandez et al., 2000).

$P = (WVTR * L) / \Delta p$, where:

$P$ = permeability coefficient, expressed in grams*mil/$m^2$*day*mmHg,

$WVTR$ = water vapor transmission rate, expressed in grams/$m^2$*day,

$L$ = thickness, expressed in mils,

$\Delta p$ = partial pressure, expressed in mmHg.

**Transponder oxygen transmission rate and permeability coefficient**

To determine the rate of oxygen transmission through the radio frequency transponder, the Oxtran 2/60 (Modorn Controls Inc., Minneapolis, MN) was utilized. Five samples were installed in each of the chambers of the Oxtran 2/60. These samples were measured across the substrate material only and did not include any adhered antenna material. Test conditions for these five samples were 23°C and 50% relative humidity. Pressure difference in each chamber was held at one atmosphere using nitrogen as the carrier gas on one side and oxygen gas on the other side of each test sample. Each sample was conditioned for two hours prior to testing. The area of the exposed sample was 5 $cm^2$.

Values given by the Oxtran are reported in cc*mil/$m^2$ *day. These permeance values are then converted to a permeability coefficient given in cc*mil/100$in^2$ *day*atm using the permeability equation as follows (Hernandez et al., 2000).

$P = p * l$, where:

P = permeability coefficient, expressed in cc*mil/100$in^2$*day*atm,

p = permeance, expressed in cc/100$in^2$*day*atm,

l = thickness, expressed in mils.

## Transponder tensile strength

Tensile strength is used to determine the maximum tensile stress a polymer can sustain and is commonly expressed in $lb/in^2$. Mechanical behavior of a polymer is often evaluated with tensile strength. Tensile strength is also important in determining visco-elastic properties of a polymer.

Properties associated with tensile strength are very important when designing a film or substrate for packaging applications. A successful product must be able to withstand the physical abuse seen in the distribution cycle. Tensile testing enables a product developer to model strength of various materials to appropriately design a package and/or product to meet the demands of the distribution cycle.

Tensile strength of the transponder was determined according to ASTM D 882-97 using the Instron 4201 (Instron Corp.,Canton, MA) in the machine direction for unsealed plastic samples. Following this procedure, test specimens were conditioned at 22°C and 46% relative humidity for 48 hours. Tests were performed utilizing substrate with adhered antenna. Five test specimens were used for these tests and corresponding tensile strengths were found using the following equation for unsealed plastic samples where tensile strength = load at peak / cross sectional area. The load at peak is expressed in pounds and the cross sectional area in $mm^2$. Grip separation and crosshead speed for the Instron were 2 inches and 20 in/min respectively. The adhered antenna material for each transponder sample had a cross sectional area of 6 $mm^2$.

**Surface Tension**

Surface tension is a function of cohesive forces between liquid molecules (Rodriguez, 1996). These surface molecules will cohere more strongly to similar molecules, thus yielding a surface tension. Surface tension is measured in dynes/cm. Surface tension is an important factor when considering application of adhesives. It is necessary to have an adhesive at least 10 dyne/cm smaller than the critical surface tension of the substrate (Hernandez, et al., 2000). Most commercially used transponders are treated with adhesives or coatings to allow for attachment to products, and/or printable surfaces for visual communication, as seen with smart labels.

An ACCU DYNE TEST™ (Diversified Enterprises) was used to determine surface tension of the transponders used in this study. This test was performed according to ASTM D2578-99. Following this procedure, transponders were conditioned for 48 hours at 22°C and 46% relative humidity. Testing was performed using the same conditions on five different transponders at three points across each sample 6.5 mm apart. This test has a precision of ± 2.0 dyne/cm.

# RESULTS AND DISCUSSION

## Minimum and maximum thickness of transponder samples

Thickness of the transponder was found to be a minimum of 1.6 mil and maximum of 13 mil using a micrometer. Thickness in the transponder is not uniform due to the presence of an IC chip and subsequent antenna material. The significance of a minimum and maximum thickness applies to manufacturing where this transponder might be used in primary film applications. Should the application require a transponder to be attached to a film during manufacturing, necessary steps would need to be taken to insure an evenly distributed film roll diameter. In addition to manufacturing concerns, performance has also been shown to be adversely affected by antenna and IC chip placement (Hohberger, 2001). Transponder performance can be adversely affected if manufacturing guidelines are not met.

Transponders used for this research were found to have various pinholes throughout the roll. These pinholes were found when transponders were examined under a microscope. Pinholes found in the sample could be attributed to puncturing from IC chips.

## Substrate Film Identification

Data provided by Texas Instruments indicate a polyethylene terephthalate substrate. Verification of the substrate material was done to allow confident predictions of barrier properties using current knowledge of PET transmission rates. Analyses of infrared peak frequencies were compared to a database of common polymer frequencies (Appendix 2). Corresponding data provided by the FT-IR allowed for a 75% confidence interval for a substrate of PET. PET barrier properties have been well established. Knowledge of these barrier properties provides insight for the next succession of tests completed on the transponder substrate.

A thin layer of adhesive is used on the transponder substrate to adhere the components of the antenna and IC chip. This would explain the slight variation in IR frequencies on the substrate when compared to common PET (Appendix 2, Figure 1). Similar tests were performed on both the primary overwrap and nylon pouch for the bloom time model. These tests show film identifications of plasticized PVC for the primary film (Appendix 2, Figure 2) and nylon for the pouch (Appendix 2, Figure 3). Initial results for PVC were not clear due to the amount of plasticizer added to the PVC resin. A comparison of IR spectras was made for pure unplasticized PVC and plasticized PVC. From these comparisons, peaks could be identified as PVC in the plasticzed film with the primary plasticizer being adipate.

**Water Vapor Permeability Coefficient**

The water vapor permeability coefficient was found to be 0.576 $\pm$ 0.02 g*mil/m$^2$ *d*mmHg using the Permatran W3/31. Data provided by the Permatran yields a water vapor transmission rate. Water vapor transmission rate values were converted to permeability coefficients using the formula on page 26. Permeability coefficients provide a better understanding of barrier properties in terms of thickness and pressure when designing packaging for a water sensitive product. These transponders provided a relatively good barrier for water vapor and would be well suited for most food applications. Refer to Appendix 3 for an example chart of water vapor transmission rates of a transponder sample.

**Oxygen Permeability Coefficient**

The oxygen permeability coefficient was found to be 4.23 $\pm$ 0.3 cc*mil/100in$^2$*d *atm using the Oxtran 2/60. This coefficient was calculated using transmission rate values given by the Oxtran 2/60. The PET substrate used for this determination omitted any adhered antenna material. The coefficient found follows closely to published values for uncoated PET film (Hernandez, et al., 2000). The substrate coefficient represents a good barrier for oxygen and would be well suited for most oxygen sensitive products, including food.

**Surface Tension**

Using the ACCU DYNE TEST™, the surface tension was found to be 46 ± 2.0 dyne/cm. These results follow closely to published data giving a value of 43 dyne/cm (Hernandez et al., 2000). Surface tension values are significant when designing methods of application of transponders to products. For selection of adhesive for the transponder, the surface tension of the adhesive should be less than that of the transponder substrate to allow for complete wetting. A recommended surface tension of at least 10 dyne/cm smaller is necessary for proper adherence (Hernandez et. al., 2000).

**Tensile Strength**

Very little variation was seen within samples of antenna and substrate film. A graphical representation of Instron data for this test is seen in Appendix 4. From the graph in Appendix 4, the maximum tensile stress can be seen as the peak force prior to break or the second peak on the graph. This is the ultimate stress the transponder can hold prior to breakage.

The antenna/film configuration yielded an average tensile strength of 16,400 psi. The cross sectional area of aluminum antenna was 6 $mm^2$ when compared to the film at 50 $mm^2$. Tensile strength was taken at ultimate stress or break point of the transponder. The elastic limit occurred at a much lower stress. The elastic limit can be defined as the stress at which permanent deformation occurs (Rodriguez, 1996). This is significant when design considerations are being made for a product.

The material testing protocol utilized a sample configuration of antenna and substrate film to provide a basis for tensile strength testing of RFID transponders. When designing a package it is important to know the impact adhered materials will have on substrate performance. A large variation in antenna placement can be seen between manufacturers. Tensile testing of transponders will need to be performed when using different antenna configurations. Each of these configurations is proprietary to the manufacturer. Evaluation of antenna material affects on substrate film performance can be performed using methods discussed in this research. Further research needs to be done to determine and understand these differences in tensile strength with adhered antenna material when considering different antenna applications and placement of transponders.

Some products may require a stress value taken at the proportional limit for consumer acceptability or distribution requirements. This research utilizes a meat package model where ultimate stress is of importance and permanent deformation will not be a significant factor in product performance.

## Summary

The identification and quantification of necessary physical and barrier properties of the transponder was found using a testing protocol and design knowledge given by the manufacturer. Texas Instruments provided more information than most manufacturers of radio frequency transponders. Utilizing the knowledge from Texas Instruments a well-defined protocol for identifying transponder properties could be developed. From the research performed in this study, it became clear that manufacturing of these transponders is not controlled well enough for the substrate to be used in primary packaging applications of perishable products. In every lot used for testing, pinholes and abrasions were found on a number of transponders. These pinholes resulted in increased in erratic test results and increased scrutiny of transponder samples to insure proper reporting of barrier properties.

For future application of transponders in primary packaging of a perishable food or pharmaceutical products, packaging professionals will need to utilize similar testing methods to ensure performance and cost effectiveness of the package.

Transponder manufacturers are beginning to understand the impact the manufacturing process can have on transponder performance with respect to read range and data retention (Hohberger, 2001). The next area of transponder performance must include the manufacturing impact on physical and barrier properties as addressed in this study. Future growth of RFID will demand economical modifications such as adding antennas and IC chips directly to primary packaging substrates. Current transponder manufacturing results in substrate pinholing rendering the substrate less effective as a gas and moisture barrier. Successful integration of this technology into pharmaceutical and perishable food packaging will demand this knowledge of transponder properties to maintain quality and shelf stability.

# CHAPTER 2

# EVALUATION OF RADIO FREQUENCY TRANSPONDER EFFECTS ON BLOOM TIME OF BEEF MUSCLE

## ABSTRACT

This study was designed to observe the effects of transponder treatments on bloom time of tray-packed beef muscle when applied to the primary overwrap film. A 13.56 MHz RFID passive transponder with a polyethylene terephthalate (PET) substrate was applied to primary tray-packed overwrap film of deoxygenated beef round steak (171B, NAMP 1997) and beef strip loin (180, 1997). Once samples were allowed to bloom at 0.21 atmospheres of oxygen, color measurements were taken directly below transponder and control areas for color development of muscle using the CIE L*, a*, and b*colorspace. It was determined that transponder treatments did not affect bloom time after 40 min of exposure to air at 0.21 atm of oxygen. A statistical difference between treatments was realized for all L*, a*, and b* values ($P<0.05$). The greatest difference was seen in a* and b* values after initial removal of primary overwrap with adhered transponders ($P<0.0001$). It was concluded that a visible difference between treatment areas and control areas, purple deoxygenated muscle, was greatest at time zero and may be of consumer concern. After achieving full bloom at 40 min the values were less significant ($P<0.05$) and no longer visible.

# INTRODUCTION

Consumer purchasing of fresh red meat products is largely influenced by bloom or red cherry like appearance of the meat. This red beef color is traditionally associated with freshness. The bloom of meat or conversion of myoglobin (Mb) to the red oxymyoglobin ($MbO_2$), or to the gray or brown oxidized metmyoglobin (MMb) is well documented (Aberle et al., 2001). Various studies have identified packaging factors influencing this bloom or development of color. These studies have included the effects of vacuum packaging, modified atmosphere packaging (Lynch et al., 1986) and lighting type and intensity on beef carcass grade factors (Kropf et al., 1984). Deoxygenated beef often associated with purple color and oxidized beef associated with brown or gray color has been implicated as a negative influence on consumer-buying habits (Jeremiah et al., 1972). Time and exposure of beef muscle to oxygen is critical when displaying beef products for retail sales. From previous studies, meat in vacuum and modified atmosphere packaging exhibit similar bloom characteristics. Studies have also shown incandescent lighting to be optimal for influencing redness appearance of beef.

The impact of a radio frequency identification (RFID) transponders on perishable meat products has not been studied. The RFID is being recognized as an alternative to bar coding in the supply chain for tracking and monitoring of perishable food and pharmaceutical products (Barry, 2001). Very little research has been done on the impacts of an RFID transponder on perishable products. Current research is focusing on transponder performance from a readability and cost prospective. The RFID has potential to track perishable food and pharmaceutical items from raw materials to retail with the added ability to perform quality monitoring functions such as temperature profiling and gas exchange (Brody, 2001).

The objective of this study was to evaluate the effects of transponders on bloom time when adhered to the primary film of retail packaged steak. This was achieved by using a commercially available 13.56 MHz RFID transponder with a common polyethylene terephthalate (PET) substrate. Prior to this study, there has been no research on the effects of RF transponders on bloom time of red meats.

# MATERIALS AND METHODS

## Study 2

The effects of Radio Frequency Identification (RFID) transponders on bloom time of beef muscles were studied using tray-packed strip loin muscles. Each beef sample received treatments of a transponder attached to the primary overwrap film. Color measurements were taken directly beneath the transponder areas of the beef muscle and the control areas in absence of a transponder during exposure to 0.21 atm of oxygen. Analyses of bloom time were performed between 2-3° C under incandescent lighting.

### Transponder preparation

Transponders used for study 2 were the same 13.56 MHz transponders provided by Texas Instruments (Plano, TX) used in study 1 for development of a testing protocol. Transponders were cut to a uniform length and width of 7.6 and 4.8 cm, respectively. Application of the transponder to the primary meat film was performed using an adhesive coated pressure sensitive paper label typical of any used in retail meat counters. The transponder was applied to the label with the exposed area of the label and adhesive being applied to the primary film. The dimensions of the paper label were a length of 8.4 cm, width of 6.7 cm, and 3 mils thick. The label dimensions allow for a 1.52 $cm^2$ area of exposed adhesive coated paper for application to the primary film. Applying a transponder to a paper label replicates that of a smart label commonly found in grocery products. This paper label provides a printable surface for product description, ingredients, and nutrition labeling to be read by the consumer as well as an adhesive for the transponder to the film.

**Preparation of tray-packed beef loin muscles**

A random sample of USDA Select strip loin muscles (180, NAMP 1997) was obtained approximately 2-4 days post mortem from a Lansing distributor, vacuum packed and boxed. Whole meat cuts were then refrigerated in the box between 2-3° C for approximately 6 days until being tray-packed to simulate normal distribution time and retail warehousing. Vacuum packed beef subprimals were removed from the box and vacuum packaged prior to slicing to 0.64-0.95 cm thick. Slices were then placed on the tray in a top to bottom or medial to lateral configuration to ensure consistency in light measurements taken from both ends of the strip loin. The fat was placed on the outside edge and consecutively cut steaks were used in each package to allow the cut surface as the testing surface for each steak and minimize marbling effects on color scores.

An Adams 4-S (R.L. Adams Plastics Inc., Wyoming, MI) expanded polystyrene tray with a length, width, and thickness of 23.5 cm x 18.4 cm x 0.53 cm was used for meat display package and protection. A Dri-Loc™ absorbent pad manufactured by the Sealed Air Corporation (Saddle Brook, NJ) was placed under the tray to reduce any visual purge or excess blood seeping from the meat into the package. The product number for this pad is AC-25 with a size of 10.16 cm x 17.8 cm and an absorbency of 40-50 grams. This tray and pad configuration is commonly found in retail meat applications. A low oxygen barrier film of 0.5 mil in thickness, manufactured by Cryovac (Duncan, SC), was used as the primary overwrap. This low oxygen barrier film allows for the bloom of meat or conversion of myoglobin to oxymyoglobin through the diffusion of oxygen into the package. Transponders were attached to this film. The film was identified as highly plasticized PVC using a Fourier Transform infrared spectrometer (Perkin-Elmer Co., Norwalk, CT). A high oxygen barrier nylon pouch with a thickness of 2.75 mil purchased from Koch supplies (North Kansas City, MO) was used as a secondary barrier to prevent oxygen diffusion and inhibit conversion of myoglobin to oxymyoglobin. This pouch was used to replicate a case ready meat application until the secondary high barrier film was removed to allow for conversion of myoglobin to oxymyoglobin or bloom of meat.

**Preliminary research on bloom time of beef round steak**

Preliminary research was performed using beef round steak (171B, NAMP 1997) sliced in a top to bottom or medial to lateral configuration with the fat placed on the outside edge to determine bloom time performance of the packaging configuration. The tray-packed steak configuration used in the preliminary study was comprised of the same materials seen in the final study. All beef was received from the same Lansing, Michigan distributor with the same packaging and time parameters. Differences between studies can be found in transponder treatments, beef selection, and tray size. Polystyrene trays supplied by Koch Supplies (Koch, North Kansas City, MO) with length, width, and depth dimensions of 31.1 cm x 23.5 cm x 0.4 cm were used. After being tray-packed and overwrapped, each beef sample received three transponder treatments. The first transponder treatment was covered in aluminum foil to eliminate any oxygen transfer through the transponder substrate material. A second treatment was designed to replicate a smart label by applying the transponder to a paper based adhesive label. The final treatment was to directly apply the transponder to the primary film with a thin layer of adhesive tape on all 4 edges.

**Color measurements**

Color measurements were taken using a HunterLab MiniScan XE Spectrocolorimeter (Hunter & Assoc., Reston, VA). A 2.5 cm port with glass cover was utilized and calibrations performed against black and white tiles according to manufacturer's specification with a 10° standard observer and $D_{65}$ illuminant. Incandescent lighting measured at 60 foot candles using a GE type 217 light meter (GE, Cleveland, OH) was used to simulate a common retail display case. To correct for color measurements taken through the overwrap and once the overwrap was removed, film was wrapped around the port. This was done to maintain consistency and minimize potential color score errors as a result of reading through the film overwrap.

Each of the tray-packed samples was removed from the nylon pouch and placed in incandescent lighting to replicate a retail meat case. An initial a* value was taken through the primary film at time 0 upon removal from the nylon bag serving as a control. After determination of full bloom (stabilization of a* values), the primary overwrap film with the attached transponder was removed. Immediately following the removal of the overwrap and transponder, a color measurement was made directly below the transponder area of the meat as a control reading. To obtain consistency between muscles, color values were obtained from each untagged control area allowing each steak sample to act as an internal control.

**Statistical Analysis**

Replication of beef samples was performed by whole muscle (animal). Each replicate consisted of 6 tray-packed samples of 2 steaks per tray. A total of 3 whole muscles (animals) were used. Results were analyzed using Mixed Procedure for variance according to the Statistical Analysis System (SAS, 1996). The least squares means procedure was performed on all means and significance determined at $P<0.05$ and $P<0.0001$.

# RESULTS AND DISCUSSION

## Preliminary study on bloom time of beef round steak

Preliminary research using three transponder treatments indicated a full bloom or completely oxygenated muscle after 40 min of exposure to air at 0.21 atm of oxygen at 2.7°C. Color measurements were taken from 0-40 min in 5-min intervals. After reaching full bloom as seen by a stabilization of CIE L*,a*, and b* values, the overwrap was removed. Initial findings show a darker color or deoxygenated muscle tissue directly below the transponder areas of the film. No significant difference was found between transponder treatments. Transponder areas returned to full bloom after an additional 40 min of exposure to air at 0.21 atm of oxygen between 2-3 °C. This preliminary study provided insight on effects of transponder treatments to bloom of red meat. Knowledge gained from this study was used for selecting the smart label configuration for the transponder to replicate retail applications as a result of no difference being observed between transponder treatments. Further evaluations indicated a full bloom or stabilization of a* values modeling the same curve of time versus a* values at 40 min for all samples. This observation resulted in reduced sampling on replicated studies with color measurements being taken at 0, 20, and 40-min intervals. Subsequent studies were performed using a smaller tray size to better represent retail meat case applications.

**Bloom time of beef loin muscle**

Once the beef loin muscle was removed from the nylon pouch and exposed to 0.21 atm of oxygen between 2-3 °C, a stabilization of a* values was seen at the 40 min time mark. A graphical representation better illustrates this plateau or stabilization of a* values (Appendix 5). After reaching full bloom, the low barrier PVC overwrap was removed. Initial findings show a darker color or deoxygenated muscle tissue directly below the transponder areas of the film similar to results found in the preliminary study. This is an expected result and a common concern in the meat packing industry when using adhesive labels applied to the primary meat wrap. Subsequent replicate values were taken at 0, 20, and 40 min displaying the same bloom times for both the control and transponder areas of the muscle tissue.

The tables 1-3 represent mean color values for each of the treatments at each L*, a*, and b* value.

Table 1: CIE L* Values of beef loin muscles.

| Time | Treatment[1] | Mean Value[2] | Mean Standard Error |
|---|---|---|---|
| 0 | 0 | 37.67*,+ | ±0.34 |
| 0 | 1 | 36.09*,+ | |
| 20 | 0 | 37.94* | ±0.34 |
| 20 | 1 | 36.98* | |
| 40 | 0 | 37.95* | ±0.34 |
| 40 | 1 | 37.06* | |

[1] Treatment 0 indicates control area without transponder, Treatment 1 indicates area under transponder.

[2] Number of observations, N = 292.

* Means ± standard deviations in the same column at the same time followed by the asterisks are significantly different ($P<0.05$).

+ Means ± standard deviations in the same column at the same time followed by the plus are significantly different ($P<0.0001$).

Table 2: CIE a* Values of beef loin muscle.

| Time | [1]Treatment | [2]Mean Value | Mean Standard Error |
|---|---|---|---|
| 0 | 0 | 19.23*,+ | ±0.35 |
| 0 | 1 | 15.55*,+ | |
| 20 | 0 | 20.39* | ±0.35 |
| 20 | 1 | 19.04* | |
| 40 | 0 | 21.45* | ±0.35 |
| 40 | 1 | 20.67* | |

[1] Treatment 0 indicates control area without transponder, Treatment 1 indicates area under transponder.

[2] Number of observations, N = 292.

* Means ± standard deviations in the same column at the same time followed by the asterisks are significantly different ($P<0.05$).

+ Means ± standard deviations in the same column at the same time followed by the plus are significantly different ($P<0.0001$).

Table 3: CIE b* Values of beef loin muscles.

| Time | [1]Treatment | [2]Mean Value | Mean Standard Error |
|---|---|---|---|
| 0 | 0 | 19.08*,+ | ±0.23 |
| 0 | 1 | 15.72*,+ | |
| 20 | 0 | 19.63*,+ | ±0.23 |
| 20 | 1 | 18.66*,+ | |
| 40 | 0 | 19.00* | ±0.23 |
| 40 | 1 | 19.52* | |

[1] Treatment 0 indicates control area without transponder, Treatment 1 indicates area under transponder.

[2] Number of observations, N = 292.

* Means ± standard deviations in the same column at the same time followed by the asterisks are significantly different ($P<0.05$).

+ Means ± standard deviations in the same column at the same time followed by the plus are significantly different ($P<0.0001$).

All of the treatment values display a significant difference from the control values ($P<0.05$). The largest difference is seen in a* and b* values. Although all of the values show a statistical difference, a difference of 2-3 CIE intensity values cannot be visually distinguished in our laboratory. A smaller mean difference of L* values was observed for control and treatment areas when compared to a* and b* values. This follows closely with published data suggesting the L* value has little or no significance on bloom time of beef carcasses (Wulf et al., 1999).

Color values found in this study for vacuum-packed beef can also be applied to modified atmosphere packaging (mixture of $CO_2$, $O_2$, and $N_2$). A relationship of vacuum to modified atmosphere packaging of beef muscle for effects on bloom have been evaluated in previous studies. Vacuum and modified atmosphere packaging was found to have similar effects on beef redness and lightness (Insausti et al., 1999). A difference in L* values was observed on meat with modified atmosphere packaging with lighter values. This was explained by the higher oxygen concentration around the beef samples.

Insausti et. al., (1999) suggested that consumers prefer steaks that are neither very light nor dark. Results from this study show a significant difference between treatments after exposure to air and removal of primary overwrap with adhered transponder at time 0 ($P<0.0001$). After continued exposure to air this difference is less noticeable and thus not as statistically significant ($P<0.05$). After 40 mins of exposure to oxygen the beef muscle was at full bloom for both the transponder and control areas and was not visually detected. The variation seen at time 0 for transponder areas could result in lower consumer acceptance when compared to the control areas in absence of the transponder.

The lighter beef color of the control areas when compared to the darker transponder areas can influence purchase decisions of the consumer. Studies have indicated a consumer preference for bright red beef over darker beef when large variations are visible (Lynch et al., 1986).

The cherry red color traditionally associated with fresh red meat has been indicated as a major determinate in meat purchasing habits. Values for the redness commonly associated with the a* colorspace have been perceived as one of the greatest determinants of consumer acceptance for fresh red meat products (Brewer et al, 2001). Studies have also indicated a closer relationship of L*and a* values affecting carcass grade quality (Wulf et al., 1999). The redness of ground beef patties associated with a* values has also been shown to affect premature browning when cooked. A higher a* value in cooked patties showed lower incidence of premature browning in the cooked beef patties (Killinger et al., 2000). Results for a* values in this study show a large difference between treatments at time 0 once the overwrap was removed ($P<0.0001$). This difference is less significant after continued exposure to air for 40 mins ($P<0.05$). This supports the relationship of L* and a* values on perceived bloom of red meat. This also indicates a consumer concern when comparing the darker more purple areas beneath the transponder to that of the lighter, redder areas in the areas around the transponder. Another explanation may be pigment change due to light intensity during testing.

The yellow b* values have not been well reported in literature for application and effects to bloom time of red meat. Past studies have reported b* to be a better predicator of meat color than a* (Jeremiah et al., 1972). Recent studies have indicated a significant role of b* values on beef color (Insausiti et al., 1999). The significance of b* to bloom time of beef muscle is not well understood. Traditionally, b* values have been used in the poultry industry as an indicator of freshness and quality (Fletcher, 1998). The b* values presented in this study show a significant difference at time 0 for transponder and control areas once the overwrap was removed ($P<0.0001$). This mean difference was similar to a* values with a larger range than L* values. Similarly to L* and a* values, b* values stabilized and were not as significantly different from control areas after 40 mins of exposure to air ($P<0.05$). This data suggests a strong relationship of a* and b* values when predicting initial bloom of red meat at time 0 or immediate removal from overwrap. This follows closely to Jeremiah and Carpenter (1972) when suggesting the importance of the b* values on meat color. These results indicate a greater impact of the transponder on a* and b* values affecting the color of red muscle.

New findings in this research are the observation of the formation of brown areas seen in the vacuum packed trays at various areas around the transponder and the heat sealed edge of the tray. These brown areas are commonly associated with metmyoglobin where the iron portion of the pigment goes from red to brown over continued oxygen exposure (Aberle et al., 2001). This brown pigment formation occurred after the meat was tray-packed, overwrapped, and placed in the high oxygen barrier nylon bag. These brown, presumably metmyoglobin, areas were in portions of each sample of the total lot. Future research needs to be done to further explain this formation of isolated metmyglobin areas seen in the affected beef samples. Some speculation can be made suggesting pockets of air being trapped in certain areas between the beef and film occurred at the label edge resulting in the conversion of red oxymyoglobin to the brown metmyoglobin.

## Summary

The effects of an adhered transponder to the primary film on the bloom time of fresh red meat demonstrated little change in overall performance of the package. Meat was found to bloom in 40 min once the primary film was removed for both control and transponder areas. The strip loin muscles responded similarly to transponder treatments with a bloom time of 40 min. Preliminary results also suggest similar performance for all beef muscle types with transponders utilized in the primary packaging. Results with Select Beef Strip loin muscles did show a statistical difference ($P<0.05$) but consumer perception of this difference is not distinguishable so that the difference in meat color will affect buying habits. It was shown in this study that transponders did not effect bloom time. Deoxygenated areas below the transponder areas were seen upon removal of the primary PVC overwrap at time 0. These areas were significantly different for L*, a*, and b* values. This can be the greatest determinant of consumer acceptance. Most consumers will use the meat product upon direct removal from its package or at time 0 when the greatest difference between transponder and areas around the transponder are seen.

# CONCLUSIONS

It was the goal of this research to provide a method for design and application of products utilizing a radio frequency transponder. Designing a material testing protocol for the transponder, identifying a perishable product application, and measuring the effects of the transponder on the package system accomplished this goal. Methods used in this research such as substrate identification, quantification of barrier and mechanical properties, and interaction in the package system can be utilized for numerous products and transponders alike.

Study 1 developed a transponder testing protocol for packaging professionals to identify key properties necessary for successful package performance. In such instances where specific properties of the transponder are not given, a product designer can utilize similar methods given in this research for development of a transponders specification specific to their application. Results indicated good oxygen and water barrier properties for the transponder. Mechanical properties of the transponder provided sufficient strength for most perishable food applications. Samples utilized for this research had to be scrutinized for pinholes incurred during the manufacturing process. This is seen as the greatest concern for integration of transponder substrates into primary perishable packaging when gas transfer is a determinant of quality and freshness.

Study 2 investigated the effects of a transponder on bloom time of red meat when applied to the primary film overwrap. Beef strip loin muscles were exposed to air to allow for bloom. Bloom time was most affected when the transponder was removed after exposure to air for 40 mins. Measurements of L*, a*, and b* for transponder areas were significantly different ($P<0.0001$) from control areas without a transponder. This difference was not only statistically significant but also visibly different. After 40 min, there was no visible difference of transponder and control areas but a statistical difference ($P<0.05$) was still found.

# FUTURE RESEARCH

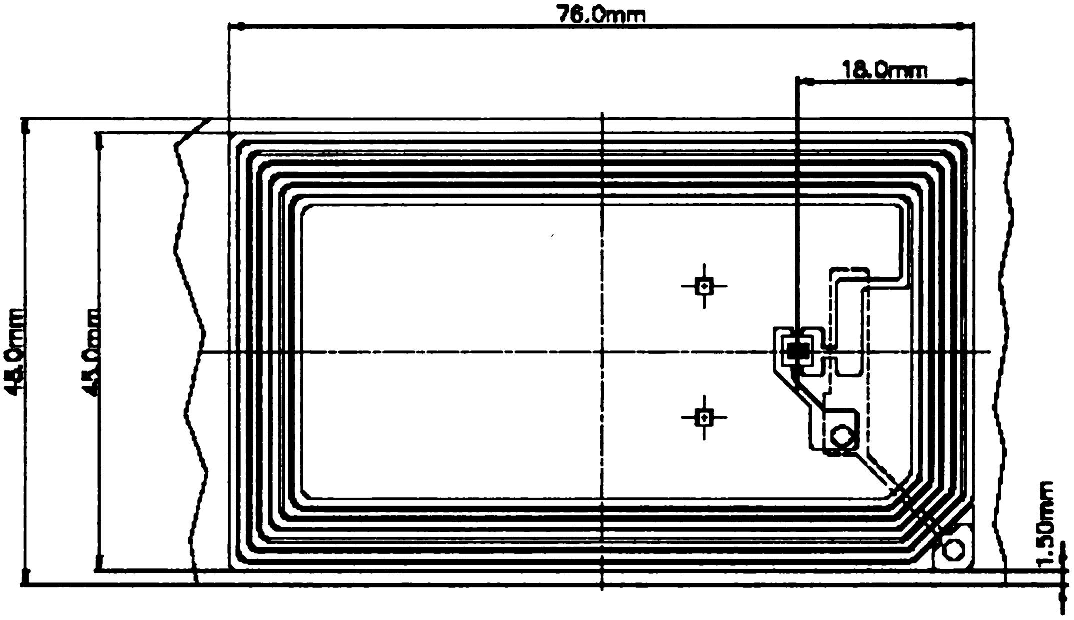
The method of addressing all potential transponder and product interactions is significant. Very little work has been done on the impact of radio frequency transponders or perishable products. The majority of research currently being done by manufacturers is to measure performance of the transponder and not physical properties or impact to the product. Future research will need to quantify the effects of temperature and product composition on migration of organic compounds. This will become increasingly important with the use of transponders on primary packaging of pharmaceutical products. Other future areas of research include mechanical properties to ensure proper product performance. The impact of manufacturing methods on transponder performance will also need to be evaluated. As discussed in this research, the manufacturing of transponders is not controlled well enough to utilize barrier and mechanical properties of the transponder.

The effects of the transponder on the primary package of a perishable product resulted in some areas of future research. Reducing the initial darker color seen in the areas beneath the transponder could prove valuable to consumer acceptance. Other concerns were seen with the brown metmyoglobin areas found around the transponder and seal areas of the film to the tray. These observations may be attributed to small amounts of oxygen being trapped in between the film and meat. Examining these effects could result in improved tray packaging methods and attachment of transponder.

These are few examples of future research to be done for a complete understanding of radio frequency transponders in a perishable product environment.

# APPENDICES

**Appendix 1. Material properties of radio frequency transponder inlay**




| | |
|---|---|
| Recommended Operating Frequency * | 13.56 MHz |
| Data Retention Time * | > 10 years |
| Simultaneous Identification of Transponders * | ≥ 50 transponders per second |
| Antenna Size * | 45 mm x 76 mm |
| Foil Width * | 48 mm ± 0.5 mm |
| Foil Pitch * | 96 mm ± 0.1 mm |
| Thickness minimum (substrate) | 1.6 mil ± 0.05 mil |
| Thickness maximum (chip) | 13.0 mil ± 0.05 mil |
| Substrate Material | Polyethylene terephthalate |
| Permeability Coefficient of Oxygen | 4.23 ± 0.3 (cc mil/100 $in^2$ d atm) |
| Permeability Coefficient of Water Vapor | 0.576 ± 0.02 (g mil/$m^2$ d mmHg) |
| Antenna Material | Aluminum |
| Surface Tension | 46 ± 2.0 (dynes/cm) |
| Tensile Strength | 16400 ± 300 (psi) |
| Operating Temperature (single inlay) * | -25° C to 70° C |
| Storage Temperature (on reel) * | -40°C to 85°C |
| Quantity Per Reel * | 5000 |

[1]* Provided by Texas Instruments (Plano, Texas)

## Appendix 2. FT/IR film identification

Figure 1: Transponder Substrate: Polyethylene terephthalate (PET)

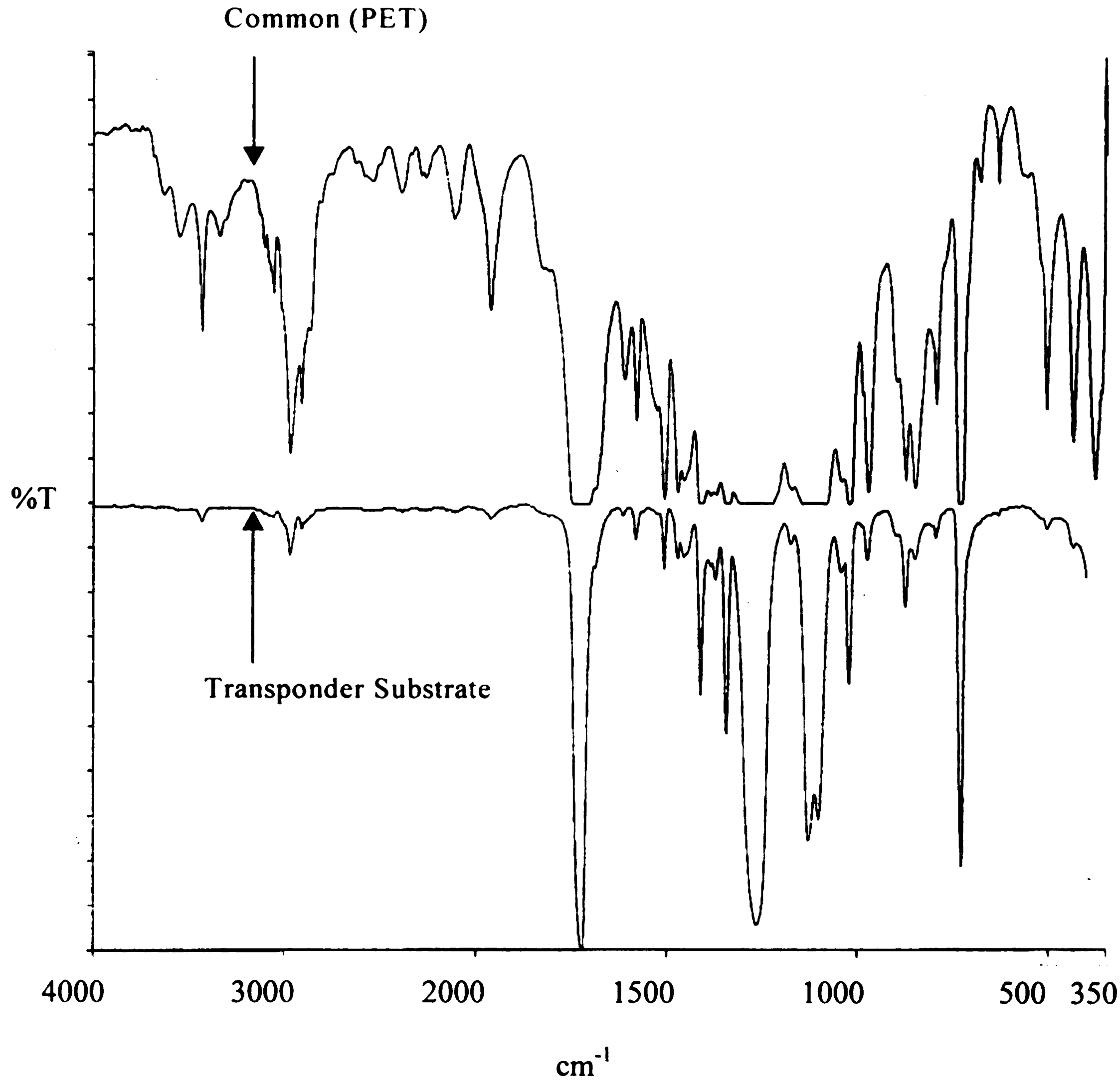



Figure 2: High Barrier Nylon Pouch

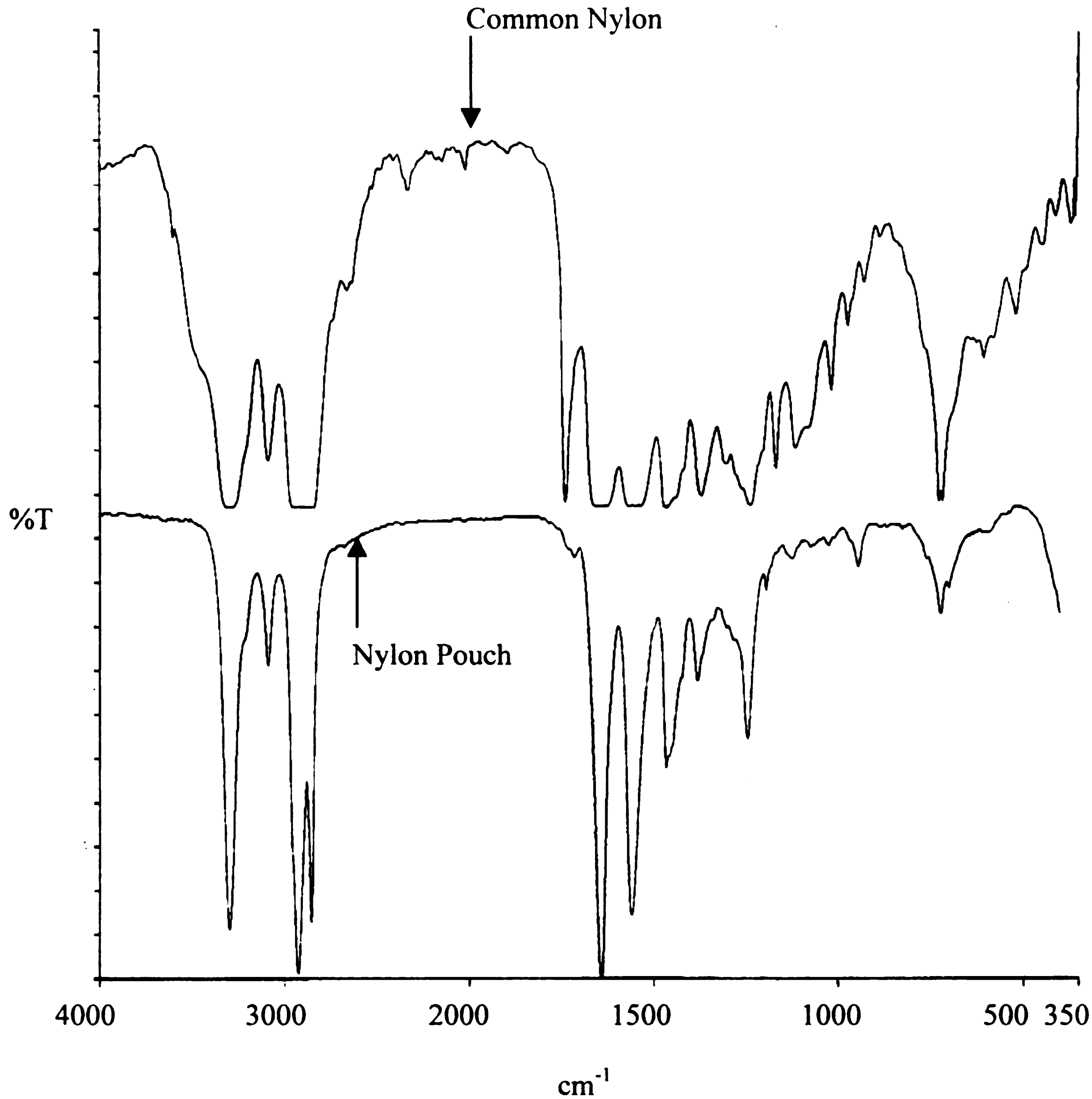
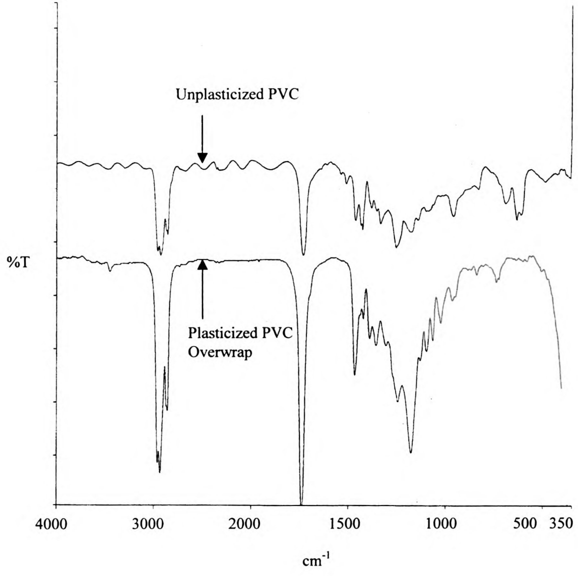

Common Nylon
%T
Nylon Pouch
4000
3000
2000
1500
1000
500
350
cm-1

Figure 3: Primary Low Barrier Overwrap: Plasticized Polyvinyl Chloride



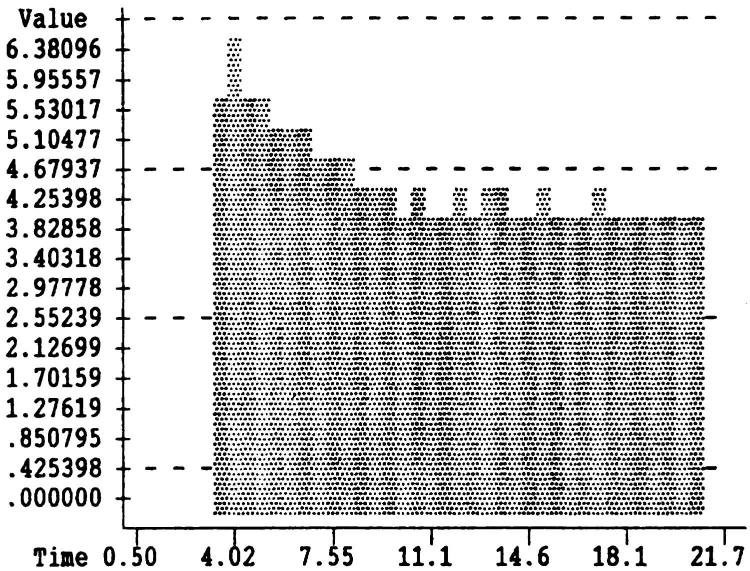
## Appendix 3. Water vapor transmission rate of radio frequency transponder

PERMATRAN-W 3/31 12/09/01 18:38

Setup Information

| Cell No | Material Identity | Type/Area F/P cm² | Thick mil | Indiv. Zero | Cycle Count | Cond Hr. | Status | Elapsed Time |
|---|---|---|---|---|---|---|---|---|
| 1B | TRPVIII | Film 5 | 1.6 | No | Inf | 3.00 | Test | 20.7 |

Remarks: A 1-1.1
B 1.1-1.2




Module 1 Parameters

Exam=10 min, ReZr=2/4
Temp=23.8, SetPt=23.8
Cell Rh% A=42, B=49
N2 Flow = 100.6 sccm

Cell B - TRPVIII

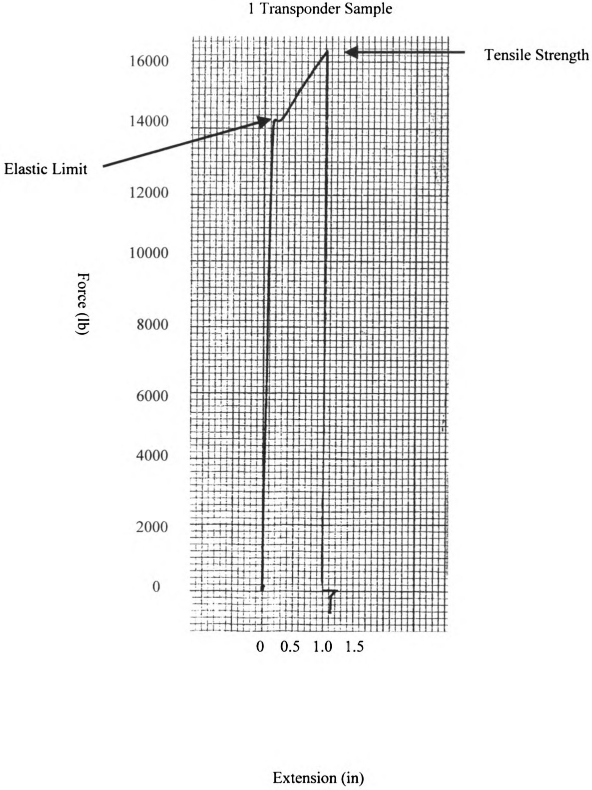
Permeation Test Result

gm/m²/day 3.895
gm/100in²/day 0.2513

Start = 12/08/01 21:55
Elapsed test = 20.7 hr

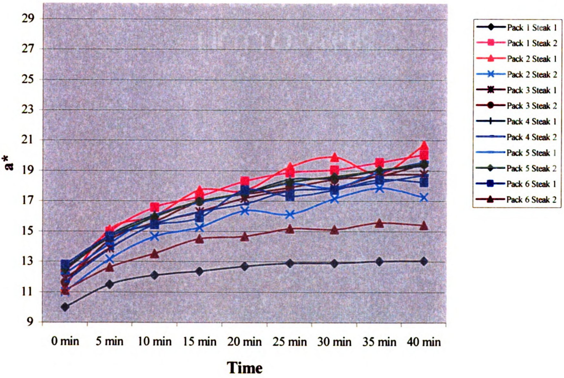
Test Progress Results (Values are expressed in gm/m²/day)

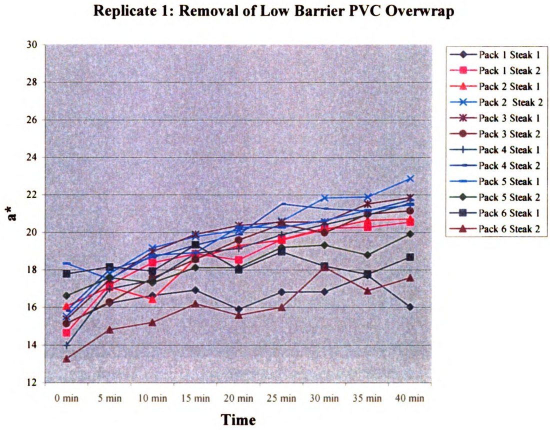
**Appendix 4. Tensile strength of radio frequency transponder**



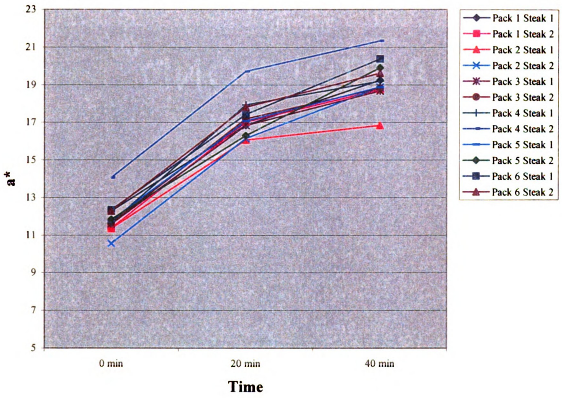
## Appendix 5. Bloom time of beef loin muscle

### Replicate 1: Removal of High Barrier Nylon Pouch

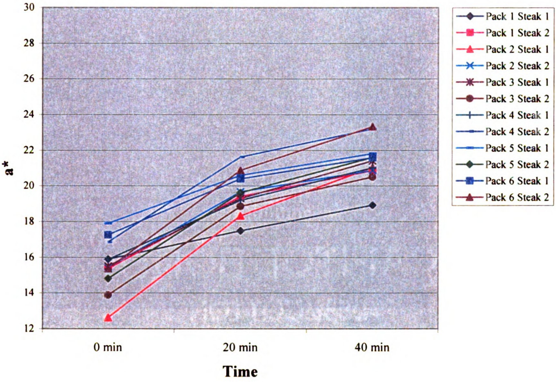



Replicate 1: Removal of Low Barrier PVC Overwrap
30
28
26
24
22
20
18
16
14
12
a*
0 min
5 min
10 min
15 min
20 min
25 min
30 min
35 min
40 min
Time
Pack 1 Steak 1
Pack 1 Steak 2
Pack 2 Steak 1
Pack 2 Steak 2
Pack 3 Steak 1
Pack 3 Steak 2
Pack 4 Steak 1
Pack 4 Steak 2
Pack 5 Steak 1
Pack 5 Steak 2
Pack 6 Steak 1
Pack 6 Steak 2

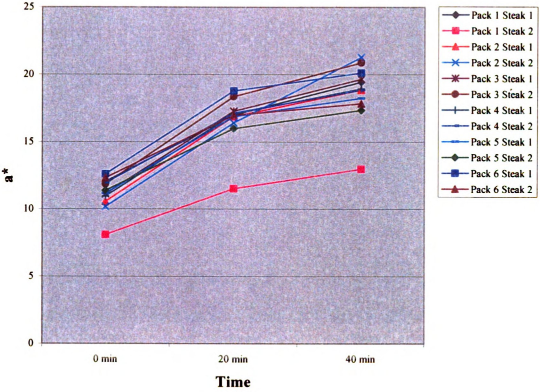
## Replicate 2: Removal of High Barrier Nylon Pouch



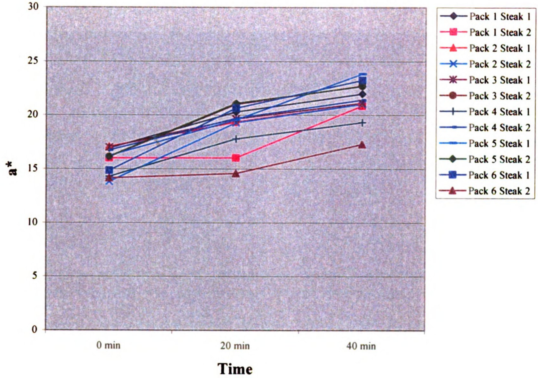
## Replicate 2: Removal of Low Barrier PVC Overwrap



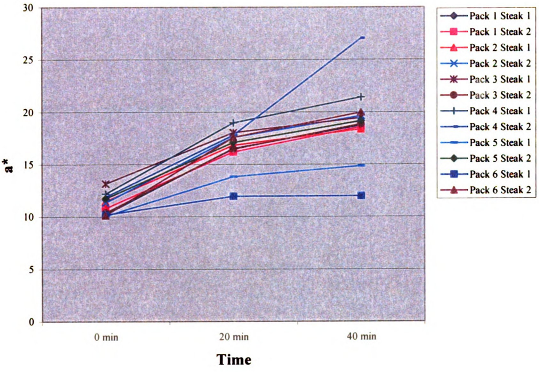
## Replicate 3: Removal of High Barrier Nylon Pouch



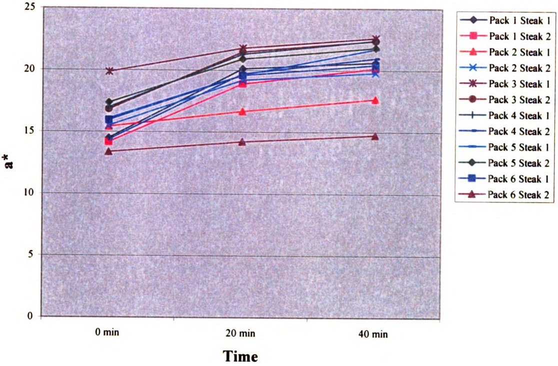
## Replicate 3: Removal of Low Barrier PVC Overwrap



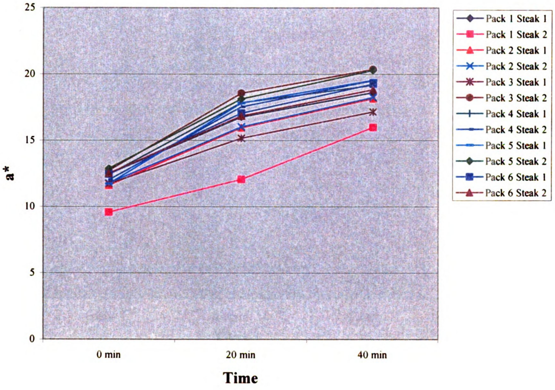
## Replicate 4: Removal of High Barrier Nylon Pouch

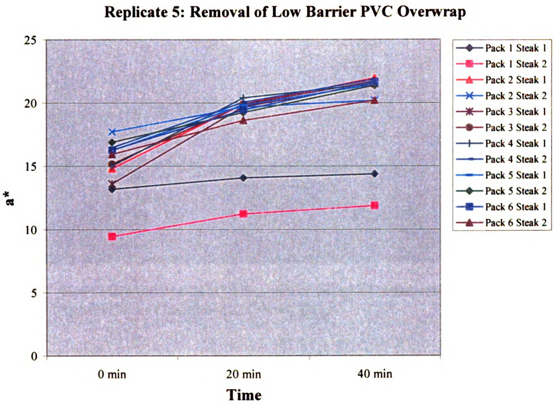


## Replicate 4: Removal of Low Barrier PVC Overwrap



## Replicate 5: Removal of High Barrier Nylon Pouch




Replicate 5: Removal of Low Barrier PVC Overwrap
25
20
15
10
5
0
a*
0 min
20 min
40 min
Time
Pack 1 Steak 1
Pack 1 Steak 2
Pack 2 Steak 1
Pack 2 Steak 2
Pack 3 Steak 1
Pack 3 Steak 2
Pack 4 Steak 1
Pack 4 Steak 2
Pack 5 Steak 1
Pack 5 Steak 2
Pack 6 Steak 1
Pack 6 Steak 2

## Appendix 6. Photos of materials and equipment

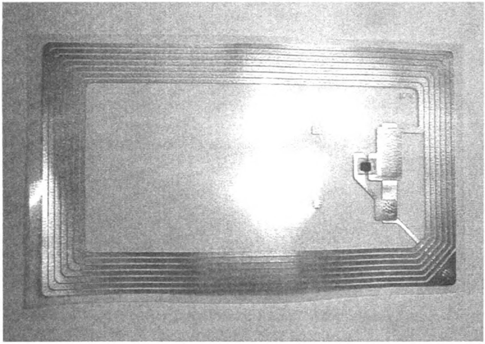


Figure 1. 13.56 MHz Passive RFID Transponder with PET substrate and Aluminum Antenna, Texas Instruments; (Plano, TX).

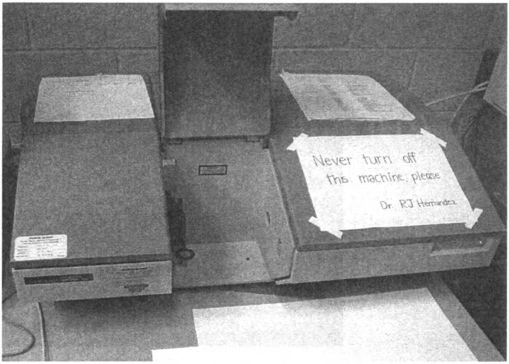



Figure 2. FT-IR (Fourier Transform Infrared) Spectrometer, Perkin-Elmer Corporation; (Norwalk, CT).

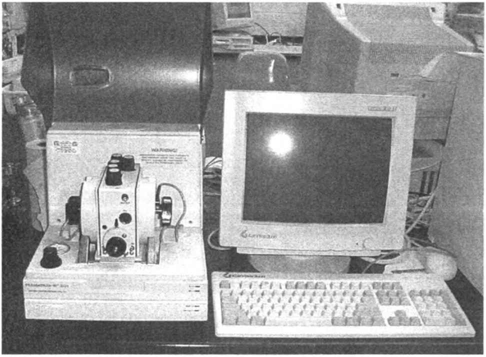



Figure 3. Permatran W3/31 Water Vapor Transmission Rate Analyzer, Modern Controls Incorporated; (Minneapolis, MN).


Figure 4. Oxtran 2/60 Oxygen Permeability Analyzer, Modern Controls Incorporated; (Minneapolis, MN).

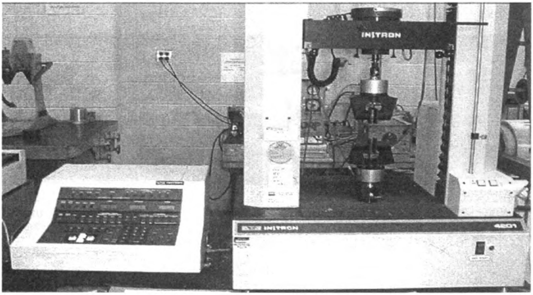



Figure 5. Instron 4201 Tensile Tester, Instron Corporation; (Canton, MA).

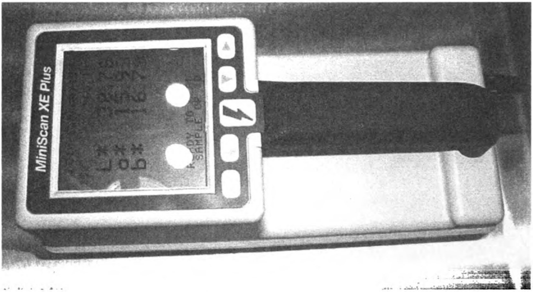



Figure 6 HunterLab MiniScan XE Spectrocolorimeter, Hunter & Assoc.; (Reston, VA).

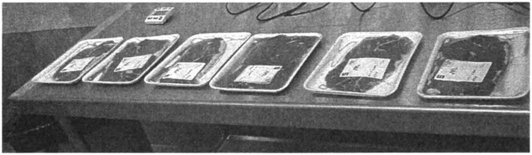


Figure 7 Tray-packed Meat with Transponder Located Beneath Label.

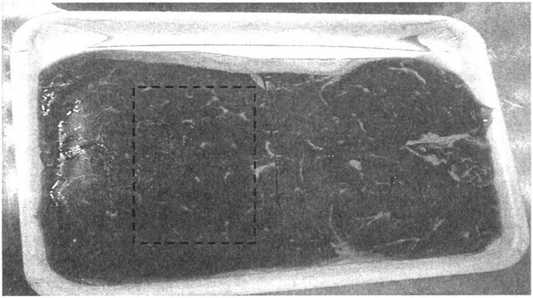


Figure 8 Deoxygenated Muscle Tissue Beneath Transponder Upon Film Removal (outline added for emphasis).

## REFERENCES


Anonymous. 2002. ActivePak showcased the diverse range of active packaging technologies to choose from. Packag. Strategies. 20:4-5.

Aberle, E.D., Forrest, J.C., Gerrard, D.E. and Mills, Edward W. 2001. _Principles of Meat Science,_ 4th ed. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Barry, C. 2001. RFID tracks packages 'speaks' to consumers. Food and Drug Packaging 65:53-56.

Burnell, J. 1999. RFID to grow not with a bang but with whispers. Automatic ID news 15:26-27.

Brewer, M.S., Zhu, L.G., Bidner, B., Meisinger, D.J., and McKeith, F.K. 2001 Measuring pork color: effects of bloom time, muscle, pH and relationship to instrumental parameter. Meat Sci. 57:169-176.

Brewer, M.S. and Wu, S.Y. 1993. Display, packaging, and meat block location effects on color and lipid oxidation of frozen lean ground beef. J. Food Sci. 58:1219-1223.

Brody, A.L. 2001. What's Active about Intelligent Packaging. Food Technology 55:75-78

Clarke, R. 2001. Radio Frequency Identification: Smart or Intelligent Packaging? J. Packaging Sci. and Tech. 10:233-247

Demetrakakes, P. 2002. Making a Case for Itself. Flexible Packaging 3:26-29.

Faber. J.M. and Dodds, K.L. 1995. _Principles of Modified-Atmosphere and Sous Vide Product Packaging,_ Tachnomic Publishing Company Inc., Lancaster, PA.

Fletcher, D.L., 1999. Broiler breast meat color variation, pH, and texture. Poultry Sci. 78:1323-1327.

Galoshich, A. 1999. Building a case for pre-packaged meats. National Provisioner 213:75-84.

Hernandez, R. J., Selke, S.E.M., and Culter, J. 2000. *Plastics Packaging Properties, Processing, Applications, and Regulation.* Hanser Publishers, Munich, Germany.

Hernandez, R.J. 2001. *Permeability and Shelf Life Modeling.* Michigan State University, School of Packaging. Michigan State Univ., E. Lansing, MI.

Hohberger, C.P. 2001. Smart labels must be engineered. Association for Automatic Identification and Data Capture Technologies Inc., (AIM), [On-line]. Available: http://www.aimglobal.org/technologies/rfid/smartlabels/smartlabelsfeb01_files/slide0198.htm.

Hickman, I. 1993. *Practical Radio Frequency Handbook.* Newnes, Woburn, MA.

Insausti, K., Barian, M.J., Purroy, A., Alberti, P., Lizaso, L. and Hernandez, B. 1999. Colour stability of beef from different Spanish native cattle breeds stored under vacuum and modified atmosphere. Meat Sci. 53:241-249.

Jeremiah, L.E., Carpenter, Z.L. and Smith G.C. 1972. Beef Color as Related to Consumer Acceptance and Palatability. J. Food Sci. 37:476-479.

Killinger, K.M., Hunt, M.C., Campbell, R.E. and Kropf, D.H. 2000. Factors affecting premature browning during cooking of store-purchased ground beef. J. Food Sci. 65:585-587.

Krizner, K. 2000. For Mercedes-Benz, the parts are always there. Frontline Solutions 1:9-10.

Kropf, D.H., Dikeman, M.E., Hunt, M.C. and Cross, H.R. 1984. Lighting type and intensity effects on beef carcass grade factors. J. Anim. Sci. 59:105-108.

Landt, J. 2001. *The History of RFID*. Association for Automatic Identification and Data Capture Technologies Incorporated. AIM Inc., Pittsburgh, PA.

Lynch, N.M., Kastner, C.L. and Kropf, D.H. 1986. Consumer Acceptance of Vacuum Packaged Ground Beef as Influenced by Product Color and Educational Materials. J. Food Sci. 51:253-255.

Mykytuik, A. 2002. RFID: An I.Q. Boost for Flexible Packaging. Flexible Packaging 3:22-28.

NAMP. 1997. *The Meat Buyers Guide*, North American Meat Producers Association, Reston, VA.

Rodriguez, F. 1996. 4th ed. *Principles of Polymer Systems*, Taylor and Francis, Washington, DC.

SAS Institute, Inc. 1996. *SAS User's Guide: Basic Statistical Analysis*, Version 6.12, SAS Institute Inc., Cary, NC.

Uniteq. 2001, March 1. Associated Grocers of Maine Revamps Supply Chain Systems. Press release submitted by: Uniteq.com, [On-line]. Available: http://www.isit.com, Article ID 2716.

Venture Development Corporation (VDC). 2001, December 15. Global Automatic Identification and Data Collection Market Contracts in 2001 – Rebound net expected until 2003. Submitted by: Venture Development Corporation, [On-Line]. Available: http://www.vdc-corp.com/autoid/press/01/pr01-48.html.

Wulf, D.M. and Wise J.W. 1999. Measuring muscle color on beef carcasses using the L*a*b* color space. J. Anim. Sci. 77:2418-2427.