Influence of Packaging Methodology on the Quality Characteristics of Fresh Pork Chops

by

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ABSTRACT

Global consumption of pork is increasing and is projected to increase through 2030. To meet the increasing demand for pork products, it is imperative that the meat industry is able to extend the shelf life of pork products while maintaining the quality attributes over a longer period. Applying different packaging methodologies is one method that is used to extend the shelf life of meat products in the meat industry. Packaging methodologies can vary between traditional oxygen permeable to anaerobic methods when storing products under vacuum. To understand the impact that packaging methodology can have on the quality of pork products, two studies were designed and conducted using pork loin chops and stored under retail settings. Study one utilized pork loin chops (n = 300) packaged in either vacuum packaging and polyvinyl chloride overwrap (PVC) in a six-day retail display period to investigate the impact of packaging on surface color, warner-bratzler shear force, lipid oxidation, cooked color, and the objective flavor and aroma profiles which were evaluated using the electronic tongue and electronic nose. In study one, over a 6-day retail display period, pork chops packaged in PVC were redder ($p < 0.0001$) and more yellow ($p < 0.0033$) than vacuum packaged chops. Furthermore, PVC packaged chops had a more vivid surface color ($p = 0.0001$) compared to vacuum. Vacuum packaging of chops led to a more stable overall surface color throughout the display period. Within the 6-day storage period, assessment by electronic tongue and electronic nose show that both packaging method and time in storage affect the objective flavor and aroma profiles of pork chops. Pork chops packaged in vacuum had greater ($p \leq 0.0001$) sourness values than PVC chops, while PVC chops had greater relative values for 1-propanal ($p < 0.0252$) and Butane-2-3-Dione ($p < 0.0017$).The second study utilized pork loin chops (n = 1008) packaged in one of three different vacuum packaging films, or PVC to investigate the impact whether vacuum

packaging impacted the quality of pork loin chops. The three different vacuum packaging films used had varying composition, oxygen transmission, and vapor transmission rates. During study two over a 15-day storage period, PVC packaged chops had a redder ($p < 0.0001$) and more vivid ($p < 0.0001$) surface color compared to vacuum packaged chops. Not surprising, the aerobic nature of PVC packaging pork chops led to greater lipid oxidation in both a 6-day ($p = 0.0027$) and 15-day ($p < 0.0001$) storage period across both studies. Packaging method nor storage day impacted objective tenderness within a 6-day period ($p = 0.1275$), however, PVC packaged chops became more tender ($p < 0.0040$) compared to vacuum on day 10 of storage. Results of the current studies suggest that packaging can impact the surface color of pork chops namely redness, and more importantly can alter lipid oxidation, and the electronic assessment for flavor and aromatic profiles of pork chops. As electronic sensor technology continues to improve, the application to shelf-life research of meat products will be beneficial in defining the impact of packaging on the changes in flavor and aroma during prolonged storage.

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War Damn Eagle!

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LIST OF ABBREVIATIONS

PVC	Polyvinyl chloride
VP	Vacuum Packaging
VSP	Vacuum Skin Packaging
MAP	Modified Atmosphere Packaging
TBARS	2-thiobarbituric acid reactive substances
WBSF	Warner-Bratzler Shear Force
L*	Lightness
a*	Redness
b*	Yellowness
SEM	Standard Error of the Mean
HA	Hue Angle
CHMA	Chroma
RTB	Red-to-Brown
OTR	Oxygen Transmission Rate
VPR	Vapor Transmission Rate
%RSD	Percent Relative Standard Deviation

CHAPTER I
LITERATURE REVIEW

1.0 INTRODUCTION

An evolution of packaging technology in the meat industry occurred to extend the shelf-life of meat products, inhibiting the oxidation of lipids and proteins, and improving the surface color of meat products (McMillin, 2017). Changes in packaging technology are driven in part by the demands of retailers and consumers and the desires for meat and food purchased to achieve maximum storage potential in a retail setting (Troy and Kerry, 2010). Traditional packaging technology consisted of polyvinyl chloride overwrap (PVC). Packaging meat using PVC methods occurs by placing meat cuts on a tray (cardboard or expanded polystyrene) and is then covered with an oxygen permeable film (Brody, 2005). Packaging technology has continued to advance and includes methods such as vacuum packaging (VP), modified atmosphere packaging (MAP), and vacuum skin packaging (VSP). Vacuum packaging creates a seal between products and the outside environment, and the utilization of a vacuum removes the air from inside the package and seals the product in an anaerobic environment (Grispoldi, et al., 2022). Modified atmosphere packaging utilizes gas flushing to manipulate the atmosphere surrounding the meat products and replace it with either a single or a mixture of gases (Djenane, 2018). Vacuum skin packaging consists of a film being heated then tightly wrapped around the product being packaged under vacuum (Kamenik, et al., 2014). Vacuum pouch, thermoforming and vacuum skin packaging utilize a vacuum chamber to package meat products in an anaerobic environment, while modified atmosphere packaging uses gas flushing to manipulate the atmosphere around meat products.

Dos Santos-Donado, et al. (2021), conducted a study investigating both MAP and VP, and reported greater stability of lipid oxidation in beef steaks between day 7 to 28 for all MAP

systems tested compared to VP. Additionally, results also concluded that VP reduced levels of lipid oxidation causing less microbial spoilage in products packaged under vacuum. Additionally, Łopacka et al. (2016) concluded that MAP and a vacuum skin packaging using a permeable film inside a modified atmosphere package improved surface color of beef steaks resulting in greater objective surface redness when compared to beef steaks packaged using vacuum skin. Throughout the documented literature, it has been concluded that gas packaging technologies can improve the fresh quality traits of stored meat products, but this improvement will only be realized if new packaging techniques are acceptable to consumers (McMillin, 2008). Evaluating consumer perception of new packaging technologies, Grebitus et al. (2013) conducted a study assessing the consumers knowledge of packaging technologies and their willingness to pay greater prices for meat products in alternative packaging utilizing carbon monoxide (CO) and MAP. Consumer willingness to spend money on products with a shelf-life up to 14 days, increased by $0.13/lb for products packaged using CO. Whereas consumers were willing to pay $0.36/lb more for products packaged in MAP with a shelf-life of 14 days after receiving information on MAP technology. Grebitus et al. (2013) reported that shelf-life extension through alternative packaging methodologies such as MAP and vacuum packaging versus overwrapping was only beneficial to consumers who possessed knowledge on packaging technology resulting in their willingness to pay greater prices for meat at the retail counter. Education of consumers is still lacking and remains a focus of industry stakeholders like National Cattlemen's Beef Association, National Chicken Council, and Pork Board to increase consumer knowledge of packaging technology and have a greater understanding of production agriculture.

2.0 PACKAGING METHODOLOGY

Originally, meat products were placed into a package with the intent of protecting meat products from degradation, but over time the purpose of packaging has expanded, and now different packaging methods are utilized to alter quality attributes of the meat products (McMillin, 2017). Wang et al. (2018) conducted a study on consumer willingness-to-pay (WTP) using methods of packaging, preservation, and marketing, and determined that educating consumers on packaging methods had a positive effect on WTP for pork products packaged in VP compared to plastic-packed or unpacked pork. Technology for manufacturing packaging materials, packaging machines, and a greater understanding of meat storage has afforded the industry improvements in delaying the deterioration of fresh and even frozen meats.

2.1 POLYVINYL CHLORIDE OVERWRAP

Polyvinyl chloride overwrap is a packaging technology that utilizes air-permeable plastic film wrapping around meat products for retail display and typically using an expanded poly styrene tray. Permeability of the packaging film allows for oxygen binding that affects the surface color of meat products containing greater concentrations of myoglobin resulting in a conversion of the surface color to a bright cherry red as determined to be linked with freshness by consumers (McMillin, 2017). Investigating the shelf-life of PVC films, Peterson and others (2004) conducted a study comparing PVC to other common plastic packaging films composed of polyethylene, polyolefins, polystyrenes, or polybutadiene, and concluded that surface color became unacceptable due to increased browning at day three of refrigerated storage. More specifically, surface color of individual samples became inconsistent at day five and six of storage. In addition, Lorenzo and Gómez (2012) concluded that products packaged in PVC had consistent color values until day four of storage, then reported a decrease in redness. Oxygen availability when using PVC film can create a more desirable surface color. However, Cassens

and others (2021) concluded that pork packaged in PVC had less surface redness compared to pork packaged in high oxygen MAP after two days of retail display. In addition to less redness, Cassens et al. (2021) concluded that pork packaged in PVC had greater lipid oxidation compared to pork packaged in MAP and attributed this increase in lipid oxidation to the oxygen availability of the PVC packaged samples. Narváez-Bravo et al. (2017) concluded that the overall change in meat color was greater for PVC packaged meat products compared to other vacuum packaging methods at nine days of storage, further supporting evidence that PVC only provides short-term color stability, and when compared with other packaging methods such as MAP or vacuum packaging it has a shorter shelf-life.

Narváez-Bravo et al. (2017) evaluated microbial growth in meat products packaged in PVC to other packaging technologies and found that steaks packaged in PVC had greater coliform counts from two to nine days of storage compared to vacuum skin packaged steaks.

2.2 VACUUM PACKAGING

The reason for creating vacuum packaged meat and food is to remove as much air as possible surrounding the product. Vacuum packaging is accomplished by placing the product in a pouch or pocket of film, removing the air surrounding the product, and sealing the package with heat. Films used in vacuum packaging are designed to minimize gas exchange between the environment and the product within the package. Removing the atmospheric gases within a package and using films that minimize gas exchange can be done to extend the shelf-life and preserve the quality of products by limiting oxidation and degradation caused by oxygen encountering the product (Strydom and Hope-Jones, 2014).

A packaging environment void of oxygen such as vacuum packaged products can support improvements in meat tenderness throughout the storage period (Lagerstedt et al., 2011).

It has been reported that shear force values decrease when stored in vacuum packaging compared to products packaged within environments containing greater oxygen (Lagerstedt et al., 2011). Vacuum packaging can also slow lipid oxidation better than aerobic packaging during refrigerated storage according to Park and others (2008). Lipid oxidation is affected by the presence of oxygen, so the anaerobic nature of vacuum packaging is beneficial in reducing lipid oxidation. Investigating instrumental color, Berruga et al.(2005) concluded that redness values were more stable in products packaged in vacuum packaging. Vacuum packaging provides color stability, increasing storage time that can improve tenderness through enzymatic degradation, and reduces lipid oxidation which are all positive impacts on meat quality.

2.3 MODIFIED ATMOSPHERE PACKAGING

Modified atmosphere packaging technology employs gas flushing packages to control the atmosphere surrounding meat products. A meat product is placed in a pouch or on a tray then the air surrounding the product is evacuated and a predetermined combination of gases is flushed into the available space surrounding the meat product. A plastic film is then sealed over the pouch, sealing the product with the combination of gases forming the surrounding atmosphere. Gases used in MAP varies, but is consistently comprised of any combination of oxygen, nitrogen, carbon dioxide, or even carbon monoxide and there remains a focus throughout the literature to determine which combinations of gases can extend shelf-life and promote quality traits in meat products. Łopacka et al. (2017) utilized varying levels of oxygen in MAP to study quality traits such as color and lipid oxidation and concluded that varying levels of oxygen inclusion did not alter surface color of beef steaks. In contrast, Lai and others (2022) reported that redness values were greater in steaks packaged using high oxygen MAP and attributed the elevated redness to oxymyoglobin formation on the surface of the meat. Implementing MAP can

be used to elicit desired surface color changes in meat products while still maintaining other quality attributes in products.

MAP packaging can also impact lipid oxidation in meat products based on results reported by Łopacka and others (2017) when oxygen inclusion increased, lipid oxidation also increased throughout a 12-day storage period. Lipid oxidation in meat products is affected by the presence of oxygen which reacts with meat. Oxygen reacts with free radicals in lipids leading to the oxidation and degradation of the lipids in meat products. Lai and others (2022) concluded that beef packaged in high oxygen MAP increased lipid oxidation beyond acceptable levels by day 15 of storage, but products packaged in low oxygen MAP displayed lipid oxidation values like vacuum packaged products. Modified atmosphere packaging using variable oxygen levels maintained quality traits of pork such as redness and reduced purge loss when compared with vacuum packaging, but greater oxygen inclusion had a negative effect on tenderness (Li et al., 2022). Modified atmosphere packaging has been reported to maintain quality traits of meat products, especially meat color and lipid oxidation when extended shelf-life periods are needed for fresh and frozen meats.

2.4 MOTHER BAGS

Mother bags, also referred to as master packaging, or master bags, place multiple retail packages with greater film packaging permeability under identical packaging atmospheric conditions prior to retail display. Mother bags are constructed using a plastic film with reduced oxygen transmission rates. Retail cuts are packaged and placed in the master bag, then a mixture of gas is flushed into the bag around the retail products (Kennedy et al., 2005). Mother bags provide a uniform atmosphere for multiple meat products. Atmospheric conditions within the mother bag may consist of a gas mixture that includes oxygen, nitrogen, carbon dioxide, or

carbon monoxide and a goal of extending the shelf-life of products is applied prior to retail display of the packaged meat products. Venturini and others (2006) concluded that the removal of oxygen and flushing of mother bags with carbon dioxide can extend the shelf-life of meat products prior to retail display and maintain the quality characteristics of fresh meat products considered desirable to consumers. Previous results agree with other research (Wilkinson et al, 2006, Scholtz et al, 1992, Limbo et al., 2013) investigating mother bags that afforded an extension to the refrigerated shelf-life of meat products including pork and beef prior to retail display without compromising the quality of the products within the packaging.

Literature has shown that mother bags have the capacity to not only extend the shelf-life of meat products but can also preserve the quality of the meat products. Yang and others (2022) concluded that beef packaged in mother bags containing a carbon dioxide gas flush reduced purge loss and maintained a more desirable red color. Mother bags using a gas composition can utilize oxygen scavengers as a method to offset oxygen permeability of the mother bag in an effort to preserve the gas atmosphere and protect the quality traits of fresh meat products such as color. Tewari and others (2002) concluded that the use of oxygen scavengers in mother bags preserved the color of meat products, but the impact of oxygen scavengers on surface color is dependent on the meat product due to differences in susceptibility to oxidation in beef vs. pork.

3.0 MEAT COLOR

Surface color of meat serves as an indicator to consumers of the freshness and quality of meat when making purchasing decisions. Consumers assess the surface of meat products before other quality traits which is why color is so influential in consumers' purchasing behaviors (Mancini and Hunt, 2005). Surface color can be affected by the oxidation state of

myoglobin in the meat. There are three myoglobin forms commonly assessed in research: deoxymyoglobin, oxymyoglobin, and metmyoglobin, associated with purple/red, cherry red, and brown colors, respectively (Danijela et al., 2013). Instrumental color is analyzed by measuring the absolute lightness, redness, yellowness, hue, and chroma from the surface of meat products. Packaging systems can alter the surface color of meat products when atmospheric gases are used within the packaging method (Tomasevic et al., 2021). Yang et al. (2016) concluded that steaks packaged in MAP had greater surface lightness and redness than products packaged using vacuum. In addition, Lu and others (2020) concluded that steaks packaged in MAP had greater lightness values when oxygen inclusion within the package was greater than 20%. Meat packaged in MAP with a greater oxygen content have resulted in greater oxymyoglobin values than vacuum packaging throughout storage (Li et al., 2012, Lu et al., 2020). Troy and Kerry (2010) concluded that consumer expectations for the color of meat products can vary between species and leads to differing demands on surface color of products in the retail setting. Surprisingly, Troy and Kerry (2010) report that surface redness is the most important color characteristic in beef but contradicts results of Holman and others (2016) that identified lightness of the beef surface was more important than redness to consumers.

4.0 LIPID OXIDATION

Lipid oxidation has been widely defined throughout extensive literature as the formation of free radicals, which then bind with lipid molecules in meat products oxidizing those lipids. Lipid oxidation is an area of interest in meat research due to the negative impacts that lipid oxidation can have on meat products, which is known from extensive research to be the production of off odors and off flavors in meat products. A preferred evaluation for lipid oxidation is the 2-thiobarbituric acid reactive substances test (TBARS), with greater values

indicating greater lipid oxidation. Sørensen and Jørgensen (1996) describe the common methods of performing TBARS such as distillation or extraction. Distillation involves distilling an acidic sample to separate the TBARS from the food matrix. Clausen and others (2009) concluded that meat products packaged in atmospheres containing greater percentages of oxygen lead to increases in lipid oxidation than when meat products were packaged anaerobically. These results support the findings of Orkusz et al. (2017) who concluded that samples packaged in MAP compared to vacuum packaging had greater lipid oxidation. With regards to shelf-life, the inhibition of lipid oxidation can extend shelf-life and maintain the quality characteristics consumers use in determination of freshness in products (Dominguez, et al., 2019). Jongberg et al. (2014) concluded that chicken products packaged in vacuum had significantly lower levels of lipid oxidation than those packaged in high-oxygen MAP. A relationship observed between MAP and greater lipid oxidation correlated with a greater perception of rancid odor in meat products. Research by Maqsood et al. (2016) further supported that lipid oxidation is reduced in meat products packaged using vacuum over nine days of storage however, lipid oxidation in products stored in oxygen rich atmospheres significantly increased at day 14 of storage. An increase was the result of the meat products reaching their oxidation threshold and beginning to decompose. It has been reported that between day 14 and 21 of storage, lipid oxidation values do not significantly increase for products packaged using vacuum methods (Brenesselová et al, 2015). Brenesselová et al. (2015) also concluded that lipid oxidation of products packaged in an aerobic atmosphere increased throughout a 21-day storage period investigated providing further evidence that packaging methods reducing exposure to oxygen deterioration can reduce lipid oxidation.

5.0 MEAT TENDERNESS

Tenderness in meat products is a key component to consumer satisfaction (Garmyn, 2020). Unlike surface color which can be assessed by consumers at the retail level, tenderness is assessed at the time of consumption. For this reason, research investigating the impact of factors such as packaging and aging on tenderness of products is necessary to predict consumer satisfaction. Conducting consumer testing on meat products is not always available in research, therefore the establishment of an objective measurement device allowed for tenderness to be measured without the use of a human consumer or trained panel (Destefanis, et al., 2008). Warner-Bratzler Shear Force (WBSF) is considered the most popular method of determining objective tenderness in meat products (Ruiz de Huidobro et al., 2005). To investigate the correlation between measuring tenderness using WBSF and using a consumer panel, Choe and others (2016) utilized both objective and subjective evaluations on the tenderness of pork products and reported a strong correlation between the evaluation of trained sensory panelists and tenderness values obtained by Warner-Bratzler shear force. Objective tenderness evaluation can accurately determine the impact of factors like aging, packaging, and cookery method on meat products. An aging period of at least six days has been reported to improve tenderness in pork (Tarsitano et al., 2013). Similarly, Moloney and others (2020) concluded that increased aging in beef steaks decreased Warner-Bratzler shear force values, thereby improving tenderness, and steaks aged for 28 days had significantly reduced shear force values more than steaks aged for 14 days. Colle and others (2015) investigated aging on the tenderness of beef steaks, utilized two different muscles, and concluded that aging did impact tenderness of steaks from the *Longissimus lumborum*, but aging did not impact steaks from the *Gluteus medius*. Aging has reportedly impacted tenderness, however the effect that packaging methodologies can have on tenderness improvement is less understood. Variation in tenderness for beef steaks

packaged in high oxygen MAP, vacuum packaging, and carbon monoxide MAP was investigated by Grobbel and others (2008) and reported that tenderness did not differ between packaging methods at day 14, but vacuum packaged steaks were more tender at day 28 of display than those packaged in MAP for 18 days.

6.0 ELECTRONIC SENSORY PERCEPTION IN MEAT PRODUCTS

Evaluating products using artificial senses such as the electronic tongue and nose is a technology that has been under development for the last few decades (Hayashi et al., 1990). Electronic tongues consist of eight sensors designed to mimic human perception of basic tastes (Vlasov et al., 2002). Assessment of meat and food using an electronic tongue mimics the tastes factors but, the electronic nose is designed to replicate the human olfactory system. Sensors in the electronic nose identify volatiles present in samples, and transmit those signals for processing (Munekata et al., 2023). Surányi and others (2021) investigated the ability of the electronic tongue to accurately distinguish meat products from different breeds of cattle and the electronic tongue was capable of independently distinguishing two of five breeds. Kim and others (2017) used the electronic tongue to investigate the impact of wet versus dry aging on beef products and reported that dry aging enhanced umami and salty flavors, but reduced values for sourness when compared to wet aging. Using an electronic nose can identify volatiles present in samples, and certain volatiles can be indicative of processes that have taken place within meat products. During development of an electronic nose system, Hansen et al. (2005) evaluated pork meat loaf comprised of different pork sources and reported that the electronic nose successfully identified products that were unacceptable to consumers. However, there are limitations to using an electronic nose system and the technology will not always successfully identify all unacceptable products. Electronic assessment of meat and food is relatively new and multiple extraction

methods for analyzing samples can be used. Tian et al. (2013) conducted a study using pork adulterated mutton to identify the best extraction method and concluded that stepwise discriminatory analysis was the most effective. Electronic nose assessment has also been utilized to determine the freshness of meat products and olfactory profiles of meat products changes during storage. Chen and others (2019) analyzed pork, beef, and mutton across varying storage times using the electronic nose and, concluded that the electronic nose was able to accurately distinguish individual meat sources and storage times. In measuring signal response strength of the volatiles generated, pork and beef reached their respective maximum signal strength faster than mutton which took an additional 100 seconds to reach its maximum strength (Chen et al. 2019).

7.0 CONCLUSION

Extending the shelf life of meat products is and will continue to be an area of interest for the meat industry. Packaging meat in an anaerobic environment and manipulating the gas atmosphere around products in packaging has improved shelf life. While new packaging technology can extend the shelf life of products, the impact these technologies have on the quality characteristics of meat products must also be understood. Qualities like surface color, lipid oxidation, and tenderness can be impacted by packaging technology. These qualities are indicative of consumer acceptability, satisfaction, and spoilage, therefore, as packaging technologies evolve, the impact on quality in meat products must be understood to utilize packaging methodologies to minimize quality deterioration.

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CHAPTER II

Influence of packaging on quality and electronic sensory assessment of pork loin chops

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Abstract:

Packaging methodology can influence the quality characteristics of meat products throughout retail display thereby impacting consumer purchasing decisions and satisfaction. Whole boneless pork loins (N = 20) were fabricated into 2.54 cm thick individual chops (n =300) and assigned randomly to either polyvinyl chloride overwrap (PVC) or vacuum packaging (VP). Chops (n = 150/treatment) were placed into a lighted retail case for six days, and analysis was completed for instrumental surface color (n = 20/treatment), internal cooked color (n = 30/treatment), 2-thiobarbituric acid reactive substance (TBARS; n = 30/treatment), warner-bratzler shear force (WBSF; n = 30/treatment), electronic tongue (E-tongue; n = 6/treatment), and electronic nose (E-nose; n = 6/treatment). Data was analyzed as a completely randomized design with individual chop serving as the experimental unit for all laboratory analysis. Treatment and day were considered as fixed effects and significance was declared at an α of 0.05. Pork chops packaged in PVC were redder ($p < 0.0001$) and more yellow ($p \leq 0.0033$) than VP chops throughout the storage period. Chops stored in PVC had greater calculated spectral values for hue angle ($p = 0.0003$), chroma ($p = 0.0001$), and red-to-brown ($p = 0.0001$). As expected, TBARS values were greatest ($p = 0.0027$) on day 6 for loin chops stored using PVC methods, and internal cooked color of pork chops were redder ($p = 0.0068$) on day 0 when using PVC packaging. Electronic tongue detected greater ($p = 0.0001$) sourness in vacuum packaged chops, whereas the e-nose identified several volatile compounds linked to cookery in packaged chops. Results of the current study indicate that packaging methodology can impact fresh and cooked pork chop characteristics. Furthermore, technology assessment of pork using e-tongue and e-nose tools may be a useful tool for capturing greater knowledge of pork sensory attributes, but more research is needed.

Keywords: electronic nose, electronic tongue, polyvinyl chloride overwrap, pork, surface color, vacuum

1. Introduction

Packaging methodologies can impact the quality characteristics of fresh meat including shelf life, instrumental color, lipid oxidation, and objective tenderness [1]. It is well known that fresh meat characteristics influence consumer purchasing decisions at the retail counter and are used as the indicator of freshness [2]. Not all indicators of meat freshness are visible, but without access to destructive methods such as objective color, pH, and objective tenderness at retail, consumers rely heavily on the visible cues such as surface color deterioration. Consumer ratings of the surface attributes such as color and fat quantity on pork chops when packaged using vacuum were improved over ratings for pork chops packaged in polyvinyl chloride overwrap (PVC) or modified atmosphere methods [3]. To increase consumer demand for pork, improvements in packaging methods are needed. Packaging is the final step of food protection in the gate to plate cycle of animal proteins, and as packaging technology evolves, a greater understanding of the impact on consumer acceptability and quality characteristics is needed. Increasing percentages of packaged meat discarding or price reduction at the retail counter remains a concern for retailers in the United States [4]. It is well documented throughout the literature that greater oxygen levels can negatively influence lipid oxidation in pork products resulting in altered storage periods and deterioration of surface color in fresh meats [5].

Extending the storage period of fresh meat allows retailers to market meat longer, limiting the potential for markdowns and throwaways that are often caused by surface color deterioration. In addition to increased storage time in retail, improved packaging methods may afford consumers an opportunity to store fresh meat longer after purchase due to possible reductions in

purge loss, fewer color changes, and minimizing spoilage organism growth [4]. In 2021, the USDA estimated that 21% of meat products are wasted after consumers purchased products from retailers and transferred those products into homes [6]. Increasing the storage duration of fresh meat may reduce product wastage and lead to possible improvements in production efficiencies throughout the meat industry resulting in improved sustainability efforts and reduce the need to discount or discard products. In the US, packaging of fresh pork traditionally uses polyvinyl chloride overwrap (PVC), modified atmosphere packaging (MAP), or vacuum methods. Storage studies have concluded that altering packaging atmospheres during storage can increase shelf-life of pork products up to 14 days [7]. Vacuum packaging is a method that has resulted in causing less lipid oxidation than aerobic packaging methodologies when storing fresh pork using consumer household refrigeration [8]. Improvements in plastic manufacturing for use in vacuum packaging can drive the pursuit of new information on storing meat products and subsequent decline of fresh or cooked meat characteristics.

Deterioration of fresh meat is well documented throughout the literature, however, limitations on the use of non-destructive and rapid technology assessment such as electronic sensing (e-tongue/e-nose) for evaluating fresh meat characteristics requires additional investigation. Previous results on braised chicken using electronic nose and tongue have identified compounds such as sulfur, nitrogen, and flavors of saltiness, and richness without using trained or consumer panels [9]. Impacts of cookery method on the sensory characteristics of lamb meat measured using the electronic nose and tongue concluded that superheating of lamb meat resulted in greater saltiness and sourness values compared to using a heat source such as charcoal grilling [10]. Additionally, the electronic nose and tongue are even capable of evaluating freshness indicators of ground beef, pork, mutton, goat, and poultry and their origins

[11-14]. Using an electronic tongue to assess beef steaks has indicated that aging can alter the flavor profiles for saltiness, umami, and sourness [15]. Improving technological assessment affords a greater understanding of chemical components that may change during storage allowing for new methods to protect and reduce deterioration of fresh meat. Historically, sensory evaluation using consumers or trained methodologies required an extensive consumption of time and resources. Development of methods for evaluating odor, and taste characteristics may enhance foundational knowledge of cooked pork characteristics.

Therefore, the objective of this study was to investigate the impact of packaging methodology (PVC overwrap vs. vacuum) on the fresh and cooked characteristics including electronic analysis of the flavor and aroma profiles of pork loin chops during a 6-day storage period.

2. Materials and Methods

2.1 Sample Preparation

Whole boneless pork loins (n = 20; Institutional Meat Purchasing Specifications No. 413) were purchased from a commercial retailer and transported to the Auburn University Lambert Powell Meat Laboratory and placed in refrigerated (2 °C ± 1.25 °C) storage (Model LEH0630, Larkin, Stone Mountain, GA, USA) for 15 days in the absence of light. Pork loins (n = 20) were cut into individual chops (n = 15/loin) 2.54 cm thick using a BIRO bandsaw (Model 334, Biro Manufacturing Company, Marblehead, OH, USA). After fabrication, individual chops were randomly assigned to one of two packaging methods (treatment), either vacuum packaging (VP; n = 150 chops) or polyvinyl chloride overwrap (PVC; n = 150 chops). Loin chops assigned to PVC were placed on a styrofoam tray (1S, GENPAK, Charlotte, NC, USA) with an absorbent pad (DRI-LOC AC-50, Novipax, Oak Brook, IL, USA), and hand wrapped with a PVC film (O_2

transmission rate = 14,000 cc O_2/m/24 h/atm). Vacuum packaged loin chops were placed into a 25.40 cm × 15.24 cm (l × w) vacuum pouch (3 mil, nylon/polyethylene, O_2 transmission rate = 7.5 cc/100 in^2/24 h/atm, Prime Source, St. Louis, MO, USA) and sealed with a double-chamber vacuum packager (Model UV2100-C, Koch Equipment LLC, Kansas City, MO, USA). Within each treatment, chops were randomly assigned to analysis (instrumental color, n = 20; WBSF, n = 30; TBARS, n = 30; cooked color, n = 30; electronic tongue, n = 6; electronic nose, n = 6).

2.2 Simulated Display

Packaged loin chops (N = 300) were placed in an LED lighted refrigerated, 3-tiered case (Model TOM-60DX-BN, Turbo Air Inc., Long Beach, CA, USA) to simulate a fresh retail display setting. Temperature inside the retail display cases was recorded using data loggers (ThermoData WiFi Loggers, Thermoworks, American Fork, UT, USA) within the cases (4.6 °C ± 2.6 °C). During display, packaged loin chops were placed on all shelves and rotated daily on the shelves to simulate consumer movement in a retail setting.

2.3 Instrumental Color

Throughout the 6-day display, instrumental surface color was measured with a HunterLab MiniScan EZ colorimeter, (Model 45/0 LAV, illuminant D65, Hunter Associates Laboratory Inc., Reston, WV, USA) on packaged chops (n = 20/treatment). Prior to collecting surface color readings, the colorimeter was standardized using a black and white tile. For each day of analysis, three individual readings were measured on the surface of each chop through the packaging film, and a mean of these readings was calculated for statistical analysis. Objective color readings of the pork chops were evaluated for surface lightness (L*), redness (a*), and yellowness (b*). Using the L*, a*, and b* readings, hue angle (HA), chroma (CHMA), and red-to-brown (RTB) were calculated for each chop. Hue angle is the changing of meat surface color from red to

yellow and calculated using $\tan^{-1}(b^*/a^*)$ with a larger value representing a greater shift from the true red axis. Chroma was calculated using $\sqrt{a^{*2} + b^{*2}}$ and a larger chroma value indicates a more vivid surface color. Red-to-brown was calculated using measured reflectance ratios of 630 nm:580 nm. Relative values for myoglobin percentages were calculated as deoxymyoglobin (%DMb = {2.375 × [1 – ({A473 – A700})]} × 100), metmyoglobin (%MMb = {[1.395 – ({A572 – A700}÷{A525 – A700})]} × 100), and oxymyoglobin (%OMb = 100 – (%MMb + %DMb).

2.4 Warner Bratzler Shear Force

Warner-Bratzler shear force (WBSF) was used to measure objective tenderness on day 0, 3, and 6. Chops assigned to WBSF were removed from their respective packaging (n = 30/treatment; n = 10/treatment/day), blotted dry with a paper towel to remove excess surface moisture, then cooked in a convection oven (Vulcan, Baltimore, MD, USA) preheated to 232.2 °C until an internal temperature of 73.9 °C was achieved. Chops were removed from the oven and allowed to cool to room temperature prior to removing six 1.27 cm diameter cores parallel to the muscle fiber by hand. Warner-Bratzler shear force was measured using a texture analyzer (Model TA-XT Icon, Texture Technologies Corp., New York, USA). Cores were sheared perpendicular to the muscle fiber according to previously established methods [16]. Each core was sheared once using a load cell of 294 N and a crosshead speed of 50 mm/min. Maximum peak force values for all cores of a chop were averaged to obtain the average peak force value.

2.5 Lipid Oxidation

Lipid oxidation was analyzed by evaluating 2-thiobarbituric acid reactive substances (TBARS) on day 0, 3, and 6. Chops assigned to TBARS (n = 30/treatment; n = 10/treatment/day) were removed from their respective packaging, and approximately 2 g of meat was taken from each chop and homogenized with 8 mL of cold 50 mM phosphate buffer (pH of 7.0) and 2 mL of

Trichloroacetic acid. After homogenization, samples were filtered through Whatman No. 1 filter paper, and the filtrate was separated into duplicate 2 mL aliquots in 10 mL borosilicate tubes. 2 mL of 0.02 M 2-thiobarbituric acid reagent was added to each tube, boiled in a water bath for 20 min, and chilled in an ice bath for 15 min. Absorbance at 533 nm was measured with a spectrophotometer (Model UV-1600PC, VWR International LLC, Randor, PA, USA) and values multiplied by a factor of 12.21 to be recorded as mg MDA/kg of fresh meat as previously described [17].

2.6 Cooked Color

Chops (n = 30/treatment; n = 10/treatment/day) were cooked and cooled according to procedures described previously on days 0, 3, and 6 then cut horizontally through the geometric center to measure objective color as described previously. Three readings were measured on the internal surface of the cooked chop and objective color values were determined using illuminant D65 and a 10° observer for lightness, redness, and yellowness using a HunterLab MiniScan EZ colorimeter. Colorimeter was calibrated prior to measuring cooked color using the methods described previously for fresh surface color.

2.7 Electronic Tongue

During storage, chops assigned to electronic tongue analysis (n = 6/treatment; n = 2/treatment/day) were removed on day 0, 3, and 6 from refrigerated storage for analysis by electronic tongue (e-tongue). Fresh chops were removed from packaging and diced into a 20 g sample representative of the entire chop, and homogenized using a mechanical blender (Model 38BL54, Waring Products, Connecticut, USA) with 100 mL of deionized water for 60 seconds. Homogenate was centrifuged (Model D-37520 Osterode, Thermo Electron Corporation, Karlsrube, Germany) for 15 minutes at 1500 × g (Model D-37520 Osterode, Thermo Electron

Corporation, Karlsrube, Germany), centrifuged samples were filtered using a 0.45 μm PES filter (VWR Internation, LLC, Radnor, PA, USA) under vacuum (Vacuum Technology, East Hanover, NJ, USA) and analyzed by e-tongue (α-Astree II Electronic Tongue, Alpha MOS, Toulouse, France). Electronic tongue consists of seven sensors sourness (AHS); general purpose (PKS); saltiness (CTS); umami (NMS); general purpose (CPS); sweetness (ANS) and bitterness (SCS) as defined by the product manufacturer. Samples were analyzed by each sensor for 120 seconds to record values. Sensors were subjected to a cleaning solution of deionized water for 10 seconds after each sample.

2.8 Electronic Nose

Chops assigned to electronic nose analysis (n = 6/treatment; n = 2/treatment/day) were removed from refrigerated storage on day 0, 3, and 6 for analysis by electronic nose. Electronic nose samples were prepared for objective analysis inside of a laboratory hood to reduce the influence of volatiles present in the atmosphere within the laboratory. Pork chops were removed from their respective packaging and diced by hand into a 2 g sample representative of the entire chop, placed into a 20 mL e-nose vial and capped in triplicate. An empty vial served as a blank to account for the volatiles present in the atmospheric air surrounding samples in the vials. Prepared sample vials were analyzed by e-nose (Heracles Neo e-nose, Alpha MOS, Toulouse, France). Vials were agitated at 500 rpm and incubated at a temperature of 50.0 °C for 20 minutes to generate volatiles within the headspace of each vial. Following incubation, the autosampler injector of the e-nose inserted 5000 mL of the headspace gas at a rate of 125 mL/s. Trapping conditions were maintained at 40.0 °C for 50 seconds. Volatiles were carried via hydrogen gas (flow rate 1 mL/min) through the non-polar (MXT-5) and polar (MXT-1701) capillary columns for flash chromatographic analysis. Chromatographic analysis was completed by two parallel

flame ionization detectors (FID1 and FID2). Temperature of the sample was increased to 250 °C at a rate of 1 °C/s from the initial 40.0 °C. Volatile peaks were identified by comparing the retention time and retention indices of each compound.

2.9 Statistical Analysis

The current study was analyzed as a completely randomized design using the GLIMMIX procedure of SAS (version 9.2; SAS Inst. Cary, NC, USA). Treatment and day were fixed effects with individual sample replication and error as the random effects. Least squares means were computed for all variables and significant ($p < 0.05$) means were separated using pairwise *t*-tests (PDIFF option).

3. Results and Discussion

3.1 Instrumental Color

Instrumental fresh color of pork chops was evaluated throughout the six-day retail display period (Table 1). There was no treatment × day interaction ($p = 0.2936$) for surface color lightness (L*) regardless of packaging treatment or day of storage. In addition, main effects for storage day ($p = 0.5259$) and treatment ($p = 0.6756$) did not differ for lightness values of pork chops. Results of the current study do not agree with previous literature that reports L* values in vacuum packaged pork increased during display [18]. Furthermore, the lack of difference in surface lightness values between packaging treatments in the current study differs from the results of previous research which reported vacuum packaged pork can have greater L* values than PVC packaged pork [19]. It is plausible that the difference observed between the current study and that of previous literature is due to the variation in oxygen permeability of the packaging films used between studies.

Interactive effect of packaging treatment and storage day for redness was greater ($p < 0.0001$) when using PVC compared with chops packaged in vacuum over a 6-day retail display period (Table 1). Differences in redness values between packaging treatments on day 0 can be attributed to the time between packaging and color readings being collected allowing an interaction to occur between pork chops and the aerobic atmosphere in PVC. Greater redness values agree with previous results that recorded increased surface redness when using oxygen permeable overwrapping instead of vacuum packaging for pork [20]. In addition, results of previous literature conclude that packaging does alter redness in beef steaks over a display period of 13 days [21].

The interactive effect resulted in overwrapped pork chops being more yellow ($p \leq 0.0033$) than chops stored in vacuum packaged (Table 1) during the storage period. Current results of PVC pork chops with greater yellowness support previous research results when using PVC packaging for beef [22]. Furthermore, it is well documented in the literature that b* values of meat stored in vacuum remain unchanged during storage [23]. It is plausible from the results of previous literature that the decline in b* values for PVC chops observed in the current study can be explained by an increase in metmyoglobin, supported by the increase in relative metmyoglobin levels of PVC chops in the current study [22].

There was an interaction between packaging treatment and day of simulated retail display for hue angle ($p \leq 0.0003$), chroma ($p < 0.0001$), and red to brown ($p < 0.0001$) changes in surface color of pork loin chops (Table 2). Hue angles were greater ($p < 0.0001$) on day 3 and 6 for PVC chops and is likely a relationship caused by the greater permeability of the packaging film to atmospheric exposure to oxygen. Previous literature supports the current study in that aerobic packaging environments (PVC) lead to greater discoloration than anaerobic

environments ultimately causing greater discoloration in overwrapped pork loins [24]. In addition, results of the current study support previous literature, that packaging method impacts calculated relative values for hue angle and overall discoloration in fresh meat products such as redness and chroma [25].

Calculated CHMA values representing surface vividness were greater ($p < 0.0001$) for the interactive influence PVC overwrap throughout the six-day simulated display (Table 2). Surface color intensity on the chop surface declined after day 0 for both PVC and vacuum packaged chops but surface color was objectively duller ($p \leq 0.0002$) on pork chops in vacuum than PVC regardless of day. A decline in surface vividness of pork chops in the current study tends to agree with previous research reporting chroma values of overwrapped beef that also declined [26]. In addition, results of the current study differ from those of previous literature reporting objective intensity of vividness on the surface of vacuum packaged pork can increase [18].

Changes in surface color during storage can be difficult to visualize or measure. Calculations of spectral values for changes in overall redness using RTB assist with interpretation of surface color changes (Table 2). Fresh chop surface color was objectively redder when using PVC packaging than chops packaged in vacuum ($p < 0.0001$). Variation in objective color measurements and calculated relative values of spectral color for fresh pork throughout the literature is limited especially when using vacuum packaging.

An interactive effect of packaging treatment × day occurred ($p < 0.0001$) for relative values of myoglobin measured objectively during storage (Table 3). Calculated relative deoxymyoglobin values were greater ($p < 0.0001$) when packaged in vacuum regardless of storage day. As expected, deoxymyoglobin values of PVC packaged chops were lower ($p <$

0.0001) as storage day increased, compared to chops packaged in vacuum which had greater deoxymyoglobin values as day of display increased. Oxygen transmission rate of packaging films may alter the partial pressure of the chops and limit binding of oxygen with the surface myoglobin. Therefore, variation in calculated values of deoxymyoglobin is likely the result of film permeability to atmospheric exposure to oxygen. It is well known from previous literature that packaging atmospheres with lower oxygen content can promote greater deoxymyoglobin [27].

Relative values for oxymyoglobin were greater ($p < 0.0001$) on day 0 for chops packaged in PVC overwrap but by day 6 packaging method did not influence oxymyoglobin spectral values (Table 3). Not surprising, metmyoglobin values in pork chops packaged using overwrap increased ($p < 0.0001$) from day 0 through 6 of storage. Surface color changes reflected by relative values of calculated myoglobin highlight the color differences that are often recorded with objective measurement. Permeability and exposure to atmospheric gases during storage has been well discussed leading to altered surface color when low barrier packaging films have been selected for fresh meats. Change in oxymyoglobin and metmyoglobin values are indicative of the shift from a bright red surface color to an oxidized brown color in fresh meat [28]. Results of the current study support previous literature that oxymyoglobin values in vacuum packaged beef steaks do not change during storage [29]. Variation in oxymyoglobin and metmyoglobin of packaged chops suggests that vacuum packaging may have caused surface color stability than chops packaged in overwrap, current results agree with previous literature that concludes metmyoglobin values in vacuum packaged beef steaks remained lower than aerobically packaged beef steaks for 20 days of display [30]. More information regarding packaging of fresh pork using thermoforming vacuum is needed to understand the implications on surface color.

An interactive effect of packaging treatment × day of simulated retail display ($p \leq 0.0027$) was present in lipid oxidation of packaged pork chops (Table 5). Lipid oxidation of pork chops was similar ($p = 0.9131$) on day 0 regardless of packaging, however greater ($p = 0.0028$) oxidation occurred by day 6 in pork chops packaged using PVC compared to VP. Not surprising, more lipid oxidation in PVC packaged chops was likely a result caused by the permeability of packaging film and the lack of barrier properties often noted when using a oxygen permeable film such as PVC. It is more likely that the anaerobic environment that vacuum packaging afforded pork chops during storage hindered the oxidation often associated with stored meat products like pork. Current results observed for lipid oxidation of pork loin chops packaged in vacuum agree with previous research in pork occurring across similar storage days [18]. It is also documented that pork loin chops packaged in vacuum have reduced TBARS values, indicative of less lipid oxidation, during storage when compared to pork loin chops packaged under vacuum further supporting the findings of the current study [19].

3.3 Warner-Bratzler Shear Force

No interactive effect ($p = 0.1275$) of packaging treatment × day of simulated retail display was present, and neither storage day ($p = 0.9161$), nor packaging treatment ($p = 0.0716$) altered WBSF during the current study (Table 4). Loins were aged under vacuum for 15 days before the project commenced, but it is apparent based on these results that neither retail storage of 6-days nor packaging method influenced objective tenderness. It is documented that postmortem storage can improve objective tenderness when using vacuum packaging methods [31]. It is plausible that vacuum packaging limits the evaporative losses of meat during storage and the greater moisture within the meat as a result is not lost during cooking. Furthermore, previous literature has concluded that as storage time increases, WBSF values of low-oxygen

packaged pork decreased, while high-oxygen packaged pork values increased [32]. Nevertheless, literature has supported the amount of oxygen present in aerobic packaging of pork impacts tenderness [33].

3.4 Cooked Color

There was no interaction (packaging treatment × day) for objective lightness ($p = 0.2162$) or yellowness ($p = 0.7513$) values on cooked pork chops. However, an interaction ($p \leq 0.0068$) of packaging treatment × day of simulated retail display for redness values did occur (Table 5). It is likely that redness values differed among packaged chops due to cooking variation at the time of analysis. However, chops from all days and all treatments were cooked on the same day, suggesting variation in color may have been attributed to each cooking period within the day. As the ability to cook all chops within a single cooking cycle was not possible due to the number of samples and oven constraints. A limited variation in objective redness for cooked chops in the current study differs from previous literature, which reported as atmospheric oxygen exposure increased, redness decreased in beef patties after storage [34]. Furthermore, current results differ from previous literature that vacuum packaged beef had greater redness values in cooked patties than aerobically packaged patties throughout a 14-day storage period [35].

3.5 Electronic Tongue

Application of the electronic tongue can provide an objective evaluation of the taste profile of meat and other food products. An objective device such as the electronic tongue is designed to mimic the human perception of basic tastes, providing researchers with the ability to assess food products without the use of a human sensory panel. It has been documented that the electronic tongue is capable of differentiating meat samples by breed and differentiating adulterated meat products [36-37]. Use of the electronic tongue in shelf-life research has also

been used to compare aging methods and flavor profiles of meat [38]. Furthermore, previous literature has reported that the e-tongue has been used to show that overall flavor profiles of fish and individual flavors change during storage [39].

Results of the current study depict that the use of an electronic tongue was able to differentiate sensory variables of pork loin chops when using PVC and VP methodologies (Table 6). Results are presented as the mean percent relative standard deviation (%RSD) of each sensor. An interactive effect (packaging treatment × day) was present for sourness (AHS) ($p \leq 0.0001$) and general purpose (PKS) ($p \leq 0.0009$). Pork chops packaged in vacuum had greater ($p \leq 0.0001$) sourness values than chops packaged in overwrap on day 0, and at day 6 (Table 6). General purpose (PKS) values for vacuum packaged and overwrapped pork chops were similar ($p > 0.0009$) from day 0 through 3 of retail display, however PKS values for vacuum packaged loin chops increased ($p \leq 0.0009$) by the end of the display period.

The main effect of treatment impacted values for saltiness (CTS), umami (NMS), and sweetness (ANS). Values for CTS ($p = 0.0003$), NMS ($p = 0.0179$), and ANS ($p = 0.0408$) were greater in VP loin chops. The effect of day was also significant for NMS ($p < 0.0001$), CPS ($p = 0.0007$), and ANS ($p < 0.0001$). NMS and CPS values did not differ (NMS, $p = 0.3232$; CPS, $p = 0.8885$) from day 0 to 3, then both significantly increased (NMS, $p < 0.0001$; CPS, $p < 0.0007$) between day 3 and day 6. Whereas ANS values significantly increased ($p < 0.0001$) from day 0 to 3 but did not differ ($p = 0.6037$) at the conclusion of the storage period.

It is plausible that vacuum packaging and the respective barrier properties protected the evaporative losses sensory attributes measured by the electronic tongue. Results of the current study indicate the electronic tongue is capable of distinguishing that differences in flavor profiles of pork loin chops are altered by packaging methodology and duration of storage. However, the

application and use of an electronic tongue remains relatively new and thus the need for additional research in cooperation with consumer or trained sensory evaluation is needed. As technology improves, and the understanding of flavor profiles in fresh pork change during refrigerated retail storage, the application of the electronic tongue in shelf-life research could lead to a greater comprehensive understanding of meat products.

3.6 Electronic Nose

A similar objective tool to the electronic tongue, an electronic nose is becoming more popular for use in objectively measuring the olfactory profile of meat and food samples by identifying volatiles through flash gas chromatography (Table 7). Measured volatiles are often linked to cooked meat sensory taste anchors recording during trained sensory analysis. Loin chops packaged in PVC had greater relative area under the peaks formed for 1-propanal ($p < 0.0252$) and Butane-2-3-Dione ($p < 0.0017$) compared to vacuum packaged chops (Table 7). Volatile retention between days was not observed in the current study, however, use of the e-nose to assess the safety of pork products in shelf-life research has been documented in the literature [39]. Compounds such as alcohols, aldehydes, ketones, and alkanes have been identified as indicators of lipid oxidation in meat products [40]. There were 31 volatiles identified in the current study that were present in both treatment groups and repeated at least twice among samples within a treatment group. Alcohol is known to be indicative of lipid oxidation, and 1-propanol is also documented as a volatile present due to the production of lactic acid bacteria in stored pork [41]. Volatile evidence of lipid oxidation in the vacuum packaged chops could also be explained by the production of lactic acid under anaerobic conditions, which can produce sulfurous odors [42]. Alcohol can be products of lipid oxidation and more specifically, the Maillard reaction can produce 2-3 octanedione [43]. As technology evolves, the

application of electronic nose to rapidly measure volatiles in pork products regardless of packaging method could be very beneficial to shelf-life research in understanding the mechanism of aromatic profiles changes over time.

4. Conclusion

Understanding the impact of packaging methodology on the storage duration of pork products can support meat industry efforts to reduce deterioration of fresh meat and decrease the amount of waste at the retail level. Results of the current study indicate that vacuum packaging may afford longer storage periods, but within the current storage period of 6-days PVC packaging of loin chops produced a more desirable surface color. As expected, packaging methodology impacted lipid oxidation and may limit the deterioration of pork if storing longer than 6 days. These results indicate more research is needed on comparing vacuum packaging of pork products to overwrapped methodologies. Using e-sensors such as the electronic tongue and electronic nose could be beneficial in understanding how packaging and storage time impacts the flavor and aroma profiles of meat products in shelf-life research. As e-technology evolves, and the understanding of the correlation of e-sensor data to consumer perception enhances, its application in shelf-life research may increase.

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TABLES

Table 1. Objective fresh surface color on packaged pork loin chops during refrigerated storage.

	Treatment[1]			P-value		
	VP	PVC	SEM*[2]	Treatment	Day	Treatment × Day
Lightness (L*)						
0	59.23	61.20	0.763	0.5259	0.6756	0.2936
3	59.66	59.33				
6	60.00	59.56				
Redness (a*)						
0	11.88^{d}	18.01^{a}	0.388	<0.0001	<0.0001	<0.0001
3	12.21^{cd}	13.66^{b}				
6	12.18^{d}	13.16^{bc}				
Yellowness (b*)						
0	10.71^{d}	15.75^{a}	0.285	<0.0001	<0.0001	0.0033
3	9.89^{d}	13.80^{b}				
6	9.91^{d}	12.84^{c}				

[1]Packaging Treatment: VP (Vacuum Packaging), PVC (Polyvinyl Chloride Overwrap).
[2]SEM, Standard error of the mean.
[a-c]Mean values for the interaction of packaging and storage day within an objective color measurement lacking common superscripts differ ($p < 0.05$).

Table 2. Calculated relative spectral values on packaged pork loin chops.

	Treatment[1]			P-value		
Hue Angle (°)	VP	PVC	SEM*[2]	Treatment	Day	Treatment × Day
0	41.97^{bc}	41.19^{cd}	0.835	< 0.0001	0.6457	0.0003
3	38.99^{d}	45.66^{a}				
6	39.15^{d}	44.41^{ab}				
Chroma (C*)						
0	16.03^{d}	23.94^{a}	0.410	< 0.0001	< 0.0001	< 0.0001
3	15.74^{d}	19.47^{b}				
6	15.74^{d}	18.44^{c}				
Red:Brown						
0	1.65^{c}	2.50^{a}	0.054	< 0.0001	< 0.0001	< 0.0001
3	1.82^{b}	1.90^{b}				
6	1.81^{b}	1.77^{bc}				

[1]Spectral Values: Hue angle (^{o}) represents the change from the true red axis (larger number indicates a greater shift from red to yellow); Chroma (C*), is a measure of total color (a larger number indicates a more vivid color). Red:Brown, calculated as 630 nm reflectance / 580 nm reflectance and represents a change in surface color from red to brown (larger value is a redder color).

[2]SEM, Standard error of the mean.

[a-d] Mean values for the interaction of packaging and storage day within a calculated spectral measurement lacking common superscripts differ ($p < 0.05$).

Table 3. Calculated relative values of myoglobin forms on pork loin chops during refrigerated storage.

	Treatment[1]			P-value		
	VP	PVC	SEM[2]	Treatment	Day	Treatment × Day
Deoxy						
0	22.51[b]	2.54[d]	1.171	< 0.0001	< 0.0001	0.0002
3	30.42[a]	5.83[d]				
6	30.92[a]	15.54[c]				
Oxy						
0	49.91[d]	83.70[a]	1.390	< 0.0001	< 0.0001	< 0.0001
3	55.05[c]	63.39[b]				
6	53.66[cd]	54.93[c]				
Met						
0	27.59[a]	13.76[b]	1.589	< 0.0001	0.4581	< 0.0001
3	14.71[b]	30.78[a]				
6	15.42[b]	29.52[a]				

[1] Spectral Values: Calculated % of metmyoglobin (MET), oxymyoglobin (OXY), and deoxymyoglobin (DEO) using spectral values.
[2]SEM, Standard error of the mean.
[a-d] Mean values for the interaction of packaging and storage day within a calculated spectral value row lacking common superscripts differ ($p < 0.05$).

Table 4. Effect of packaging and storage day on lipid oxidation and objective tenderness in pork loin chops.

	Treatment[1]			P-value		
	VP	PVC	SEM[2]	Treatment	Day	Treatment × Day
TBARS						
0	0.36^{bc}	0.37^{bc}	0.031	0.0005	<0.0001	0.0027
3	0.34^{c}	0.41^{bc}				
6	0.43^{b}	0.67^{a}				
WBSF (N)						
0	30.80	30.22	2.542	0.0716	0.9161	0.1275
3	28.98	31.37				
6	24.65	34.29				

[1] Packaging Treatment: VP (Vacuum Packaging), PVC (Polyvinyl Chloride Overwrap).
TBARS: 2-thiobarbituric acid reactive substances are reported as mg/kg malonaldehyde in fresh tissue. A larger value indicates greater oxidation.
WBSF: Warner-Bratzler shear force reported in Newtons.
[2]SEM, Standard error of the mean.
[a-c] Mean values for the interaction of packaging and storage day within an objective analysis lacking common superscripts differ ($p < 0.05$).

Table 5. Influence of packaging and storage period on internal cooked color of pork loin chops.

	Treatment[1]			P-value		
	VP	PVC	SEM[2]	Treatment	Day	Treatment × Day
Lightness (L*)						
0	77.72	76.87	0.718	0.4849	0.3554	0.2162
3	78.58	77.17				
6	77.83	78.85				
Redness (a*)						
0	10.22[b]	11.51[a]	0.286	0.2389	0.7668	0.0068
3	10.88[ab]	11.00[ab]				
6	11.02[ab]	10.44[b]				
Yellowness (b*)						
0	13.96	13.95	0.213	0.4581	< 0.0001	0.7513
3	12.94	13.03				
6	12.39	12.70				

[1]Packaging Treatment: VP (Vacuum Packaging), PVC (Polyvinyl Chloride Overwrap).
[2]SEM, Standard error of the mean.
[a-c] Mean values for the interaction of packaging and storage day within an objective color measurement lacking common superscripts differ ($p < 0.05$).

Table 6. Packaging method and storage day influence on pork loin chops using an electronic tongue.

	Treatment[1]			P-value		
	VP	PVC	SEM[2]	Treatment	Day	Treatment × Day
AHS[3]						
0	2.28[a]	0.51[d]	0.293	< 0.0001	< 0.0001	0.0001
3	0.86[cd]	1.47[bc]				
6	4.43[a]	1.99[b]				
PKS[4]						
0	2.57[b]	2.09[bc]	0.293	0.0020	< 0.0001	0.0009
3	1.23[c]	1.49[c]				
6	4.28[a]	1.92[bc]				
CTS[5]						
0	2.29	1.13	0.198	0.0003	0.0827	0.2134
3	1.52	1.04				
6	1.61	1.04				
NMS[6]						
0	2.06	1.69	0.350	0.0179	< 0.0001	0.1179
3	1.64	1.41				
6	4.29	2.67				
CPS[7]						
0	1.61	1.34	1.023	0.8364	0.0007	0.8911
3	1.28	1.38				
6	5.27	5.97				
ANS[8]						
0	2.74	1.58	1.292	0.0408	< 0.0001	0.0996
3	73.81	68.12				
6	1.53	1.42				
SCS[9]						
0	1.01	1.03	0.140	0.3979	0.4306	0.0536
3	0.97	1.17				
6	1.14	0.63				

[1] Packaging Treatment: VP (Vacuum Packaging), PVC (Polyvinyl Chloride Overwrap).
[2]SEM, Standard error of the mean.
[3]AHS (sourness)
[4]PKS (general purpose)
[5]CTS (saltiness)
[6]NMS (umami)
[7]CPS (general purpose)
[8]ANS (sweetness)
[9]SCS (bitterness)
[a-d] Mean values for the interaction of packaging and storage day within a sensor lacking common superscripts differ ($p < 0.05$).

Table 7. Relative area of volatile compounds on pork loin chops using an electronic nose.

Compound	VP	PVC	Sensory Descriptors[1]	SEM[2]	P-value
Alcohol					
1-propanal	6.04[b]	9.12[a]	alcoholic	1.784	0.0252
2-3 Butanediol	1.33	3.57	Creamy, Onion	1.124	0.2185
2-3 Octanedione	2.49	1.41	aldehydic	0.448	0.1495
Ethanol	9.76[a]	6.75[b]	Alcoholic	0.550	0.0310
Methanol	4.07	4.56	Alcoholic, Pungent	1.340	0.4482
Aldehyde					
Acetaldehyde	740.35	1230.72	aldehydic	157.900	0.0644
n-nonanal	0.75	0.99	Aldehydic	0.166	0.3275
Propanal	19.42	14.24	Acetaldehyde	3.465	0.2982
Alkane					
3-Ethylhexane	143.42	340.96	-	171.350	0.5006
3-Methylpentane	1007.76	4660.62	-	3526.810	0.4013
Hexadecane	1.00	0.33	Alkane, Fruity	0.386	0.3441
Hexane	13.85	12.14	Alkane, Gasoline	2.829	0.4051
Octane	5.02	2.09	Alkane	1.152	0.1115
Pentadecane	1.26	0.38	Alkane, Fusel	0.244	0.0661
Tridecane	2.05	0.18	Alkane, Fruity	0.175	0.0851
Undecane	0.88	2.16	Alkane	0.502	0.1211
Ketone					
Butane-2-3-Dione	16.34[b]	27.79[a]	Butter	2.620	0.0017
Pentan-2-one	1.28	1.05	Acetone	0.319	0.6466
Thiol					
2-Mercaptoethanol	902.02	832.45	Sulfurous	125.795	0.7007
Methanethiol	6.08	6.76	Cabbage	0.593	0.4272
Other					
2-Methylpropanoic Acid	1.30	1.16	Acidic, Rancid	0.631	0.8748
3-Methylfuran	322.21	1251.74	-	486.635	0.2358
3-Methyl-Octane	92.24	232.12	-	140.425	0.5258
Acetic Acid	704.63	616.50	Acidic, odorless	360.470	0.3365
Chloroform	2.99	2.54	Pleasant	0.457	0.3734
Dibromochloromethane	777.48	1357.15	-	339.505	0.2059
Dimethyl Sulfoxide	119.11	95.85	Fatty, oily	21.273	0.4616
Ethyl Chloride	401.37	418.36	Etheral	91.671	0.5133
Methyl Acetate	1922.04	2191.14	Fruity, Sweet	608.290	0.4550
Psi-Cumene	1.83	0.62	Aromatic	0.325	0.1194
Trimethylamine	4.09	3.16	Oily, Rancid	0.893	0.5092

[1]Sensory descriptor from AlphaMOS Software Library.
[2]SEM, Standard error of the mean.
[a-b]Mean values within a row lacking common superscripts differ ($p < 0.05$).

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CHAPTER III

Influence of vacuum packaging on pork loin chops

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Abstract:

Extending storage duration of fresh meat products while sustaining quality characteristics is necessary to meet the demand for animal protein for an increase in global population. Boneless pork loins (N = 63) were fabricated into 2.54-cm-thick chops and assigned to one of three vacuum treatments (VacA, VacB, VacC) or a fourth polyvinyl chloride overwrap (PVC) treatment to assess objective fresh color, cook loss, warner-bratzler shear force (WBSF), and lipid oxidation over a 15-day storage period. Pork chops (n = 1008) were evaluated at 5-day intervals (D 0, 5, 10, 15) throughout a 15-day storage period in a randomized complete block design. Pork chop surface color was lighter (L*; $p < 0.0001$) when stored in vacuum ($p < 0.0001$) compared to PVC packaged loin chops regardless of storage duration. Redness values were greater ($p < 0.0001$) for loin chops stored in PVC than all other vacuum packaging treatments throughout the entire 15-day display period. Relative values for chroma on PVC packaged loin chops were greater ($p < 0.0001$) throughout the simulated retail display period. Values for WBSF were greater ($p < 0.0040$) on day 5 of storage for pork chops using VacA compared to the two other vacuum treatments, and pork chops packaged in VacB had greater ($p < 0.0040$) WBSF values on day 15 than the other vacuum treatments. TBARS values in pork chops packaged using PVC were significantly greater ($p < 0.0001$) from day 10 through the completion of the storage period. Results indicate Vacuum packaging suspends the deterioration of fresh pork loin chops, whereas traditional overwrapping expedites the color and lipid decline during refrigerated storage.

Keywords: Instrumental color, overwrap, pork, shelf life, vacuum packaging

1. Introduction

Packaging of meat products is continuously evolving to meet both product quality and consumer satisfaction demands. At the retail level, consumer perception for meat quality is based primarily on surface color as an indicator of safe and wholesome meat [1]. Unfortunately, over storage time, surface colors of meat products may change, and packaging methods may alter the consumers indicators of freshness, making visual appraisal a less accurate predictor of quality. Consumer purchasing decisions are so heavily biased by surface color that products perceived as discolored will require discounting or discarding at retail regardless of product wholesomeness and quality [2]. Identifying the impact of packaging materials on consumer perception during time of purchase is essential in developing new packaging products, but overall understanding of the impact of packaging materials on quality characteristics and storage-life of meat products requires additional investigation.

Food losses within the meat, poultry, and fish industries account for almost $48 billion dollars annually [3]. Innovations in meat packaging may reduce loss at all levels throughout the industry including the retail level by extending storage and reducing throwaways that retail outlets incur. Furthermore, it has been concluded that factors leading to food waste, packaging and the atmosphere within packaging can alter the visual appraisal and perceived quality of meat products [4]. Efforts to reduce food losses and retail discarding for an increasing global population requires improvements in creative technologies such as packaging and storage conditions.

Global pork consumption has increased over the past two decades and is projected to continue increasing through 2030 [5-6]. With consumption of pork projected to increase, identifying methodologies for extending the storage duration of pork products without altering quality is

essential. Previous research concluded that vacuum packaging pork and reducing storage temperatures can extend storage duration of fresh pork products [7]. Throughout the literature it is well documented that vacuum packaging pork reduces the rate of lipid oxidation occurring and stabilizes surface color of fresh pork products [8-10]. Vacuum packaging pork products have also demonstrated the ability to improve tenderness when compared to products stored in an aerobic environment up to 14 days [11-12].

Nevertheless, composition of vacuum packaging films constructed and used during meat packaging may alter the storage of meat products. Packaging films designed and formulated with reductions in oxygen transmission rate have improved the duration of storage time of fresh pork products [13]. Objective of the current study was to evaluate the influence of 3 different vacuum packaging films and the traditional PVC overwrap on the storage and quality attributes of fresh pork loin chops during a 15-day refrigerated storage period.

2. Materials and Methods

2.1 Sample Preparation

Whole boneless pork loins (Institutional Meat Purchasing Specification No. 413) were purchased from a commercial retailer and transported to the Lambert Powell Meat Laboratory at Auburn University (Auburn, AL, USA) and placed in refrigerated storage (2 °C ± 1.25 °C) (Model LEH0630, Larkin, Stone Mountain, GA, USA) for nine days in the absence of light. After storage, boneless pork loins (N = 63) were removed from packaging and fabricated using a BIRO bandsaw (Model 334, Biro Manufacturing Company, Marblehead, OH, USA) into 2.54-cm-thick chops (N = 1008 chops; n = 16 chops/loin). After fabrication, loins were divided into quarters (n = 4 chops/quarter) and quarters were assigned to one of four packaging treatments.

Packaged chops were individually identified, and randomly assigned to evaluation for instrumental fresh surface color, cook loss, lipid oxidation, and Warner-Bratzler shear force.

2.2 Packaging Treatments

Pork loin chops (n = 252/treatment) assigned to vacuum packaging were packaged individually using a Variovac Optimus system (OL0924, Variovac, Zarrentin am Schaalsee, Germany). Loin chops (n = 252/treatment) were randomly assigned to one of four treatments; one of three thermoforming vacuum packaging films, VacA, VacB, VacC, and sealed with a standardized non-forming film constructed with the following parameters: 75 μ nylon/EVOH/enhanced/poloefin plastomer coextrusion with an oxygen transmission rate of 0.10 cc/sq. m/24h and a vapor transmission rate of 4.0 g/sq. m/24h. PVC packaged chops were placed on a foam tray (1S**,** GENPAK, Charlotte, NC, USA) with an absorbance pad (DRI-LOC AC-50, Novipax, Oak Brook, IL), and hand wrapped with polyvinyl chloride film (O_2 transmission rate = 14,000 cc O_2/m/24 h/atm). Film composition and oxygen transmission rates of vacuum films are displayed below (Table 1).

2.3 Simulated Retail Display Conditions

After packaging, all cut and packaged pork loin chops (N = 1008) were placed in an LED lighted refrigerated, 3-tier display case (Model TOM-60DX-BN, Turbo Air Inc., Long Beach, CA, USA) to simulate fresh retail display conditions during a 15-day storage period. Data loggers (ThermoData WiFi Loggers, Thermoworks, American Fork, UT, USA) were used to monitor the temperatures inside the retail cases for the duration of the study. Packaged chops were rotated in the display case daily to simulate consumers moving products in a retail setting with analysis completed on days 0, 5, 10, and 15 of display.

2.4 Instrumental Color

Throughout the 15-day simulated retail display period, loin chops (n = 42/treatment) were assessed for instrumental color with a HunterLab MiniScan EZ colorimeter, Model 45/0 LAV (Hunter Associates Laboratory Inc., Reston, WV, USA) on days 0, 5, 10, and 15. Prior to instrumental color readings, the colorimeter was standardized using black and white tiles. Three readings were captured through the packaging film of each chop and an average of the readings were calculated. Pork chops were evaluated for surface color lightness (L*), redness (a*), and yellowness (b*). Hue angle (HA) and Chroma (CHMA) were calculated from the L*, a*, and b* values using the equations $\sqrt{a^{*2} + b^{*2}}$ and $\tan^{-1}(b^*/a^*)$, respectively. Hue angle represents the color shift from red to yellow, with a greater value indicating a greater shift, while chroma is indicative of a more vivid color and a greater value indicates a more vivid color. Red-to-brown (RTB) was calculated using the measured reflectance ratio of 630 nm:580 nm and is indicative of the color shift from red to brown. Relative myoglobin percentage values were calculated as deoxymyoglobin (%DMb = {2.375 × [1 – ({A473 – A700})]} × 100), metmyoglobin (%MMb = {[1.395 – ({A572 – A700}/{A525 – A700})]} × 100), and oxymyoglobin (%OMb = 100 – (%MMb + %DMb).

2.5 Cook Loss and Warner-Bratzler Shear Force

Loin chops were removed from packaging (n = 560; n = 140/treatment) and excess surface moisture was blotted dry with a paper towel. Chops were weighed on an analytical balance (PB3002-S, Mettler Toledo, Greifensee, Switzlerland) prior to cooking then cooked in a convection oven (Vulcan, Baltimore, MD, USA) preheated to 192.22 °C to an internal temperature of 70.0 °C. Cooked chops were removed from the oven, cooled to room temperature (22.2 °C), and re-weighed so cook loss could be calculated using the following equation:

$$\% \text{ Cook Loss} = ((\text{Raw Wt. (g)} - \text{Cooked Wt. (g)}) \div \text{Raw Wt. (g)}) \times 100$$

From each cooled chop, six 1.27 cm diameter cores were removed by a handheld corer parallel to the muscle fiber and sheared once perpendicular to the muscle fiber [14]. Objective tenderness was measured using a texture analyzer (Model Ta-XT Plus100C, Texture Technologies Corp., South Hamilton, MA, USA) equipped with a 50 kg load cell and a crosshead speed of 50 mm/min. Maximum peak force values for each core were averaged to calculate the average peak force (N) value of each sample.

2.6 Lipid Oxidation

Lipid oxidation of samples was evaluated by 2-thiobarbituric acid reactive substances (TBARS). Chops (n = 280; n = 70/treatment) were removed from packaging and cut into an approximate 2 g sample duplicate representative of the entire chop. Samples were homogenized (Model PT 10-35, Brinkman Inst., Westbury, NY, USA) for 30 seconds with 8 mL of cold 50 mM phosphate buffer (pH 7.0) (Ward's Science, Rochester, NY, USA) and 2 mL of trichloroacetic acid (VWR Chemicals, Solon, OH, USA). After homogenizing, samples were filtered through Whatman No. 1 filter paper, and filtrate was separated into duplicate 2 mL aliquots. Aliquots were combined with 2 mL of 0.02 M 2-thiobarbituric acid reagent (MP Biomedicals, Solon, OH, USA) and cooked in a water bath (100 °C) for 20 min. Tubes were placed directly into an ice bath for 15 min. Absorbance was measured using a spectrophotometer (Model UV-1600PC, VWR International LLC, Randor, PA, USA) set at 533 nm. Absorbance readings were multiplied by 12.21 and values recorded as mg malondialdehyde (MDA)/kg of fresh meat as previously described [15].

2.7 Statistical Analysis

The current study was analyzed as a randomized complete block design. Data were analyzed using the GLIMMIX procedures of SAS (version 9.2; SAS Inst. Cary, NC, USA). Treatment and

day were fixed effects with loin as a blocking variable and replication as the random effect. Orthogonal contrasts were computed for comparing vacuum packaging treatments to the PVC treatment (VacA, VacB, and VacC vs PVC overwrapped). Least square means were computed for all variables and significant ($p \leq 0.05$) means were separated using pairwise *t*-tests (PDIFF option).

3. Results and Discussion

3.1 Instrumental Color

An interaction ($p < 0.0001$) of treatment × day occurred for objective measured lightness (L*) on packaged fresh pork chops (Table 2). Vacuum packaged chops were lighter ($p < 0.0001$) compared to PVC packaged chops from day 10 through 15 of the storage period. As expected, surface color of PVC packaged chops was darker ($p < 0.0001$) as storage time increased, while chops stored in vacuum were objectively lighter in storage. Chops packaged in treatment VacA were lighter ($p < 0.0002$) on day 15 of storage than all other chops regardless of packaging method. Orthogonal contrasts calculated for lightness confirmed packaging treatments of vacuum and PVC packaged chops differed ($p = 0.0074$) with vacuum packaging leading to lighter surface color in pork chops. It is plausible that the measured color changes for lightness among packaging treatments is attributed to the permeability of the packaging film to atmospheric gases, specifically oxygen. Changes in surface color lightness have been observed and documented throughout the literature for vacuum packaged meat. Current results agree with previous research regarding vacuum packaged meat can have greater L* values than meat packaged using materials with greater exposure to atmospheric gases [16-17]. It is plausible that the increased surface reflectance measured using objective color methods for vacuum packaged chops may be caused by pork muscle variation in pH as reported from previous research [8].

Nevertheless, mean pH values for pork loins used in this study were 5.71 and likely not the source of surface lightness variation. As expected, with surface color deterioration many factors have been well documented throughout the literature including age of raw material, packaging materials, storage temperature, duration of storage, and exposure to atmospheric gases.

An interaction ($p < 0.0001$) of packaging treatment × day was also recorded for redness (a*) values during the 15-day display period (Table 2). Loin chops packaged in PVC were redder ($p < 0.0001$) than chops in all vacuum treatments throughout the entire simulated storage period. Redness values of pork chops in only vacuum treatments (VacA, VacB, and VacC) decreased ($p < 0.0001$) by day 5, then remained similar ($p =$) through the conclusion of the 15-day period. Orthogonal contrasts calculated for redness confirm ($p < 0.0001$) packaging method PVC vs. VAC can influence surface redness of fresh pork chops, and the aerobic atmosphere of PVC packaging led to greater surface redness in pork chops throughout the current display period compared to vacuum packaged chops. Changes in a* values observed in the current study do not agree with previous literature for redness values of vacuum packaged ground beef that were not altered during a 10-day storage period [18]. However, a* values support the conclusions of previous literature, that reports redness of both vacuum packaged beef and pork will decrease after day zero, then do not differ over a similar storage period [19-20]. Differences in redness values in the current study between vacuum packaging and PVC may be attributed to the differences in oxygen content in the atmosphere within the package. It has been well documented in the literature that many factors can affect surface redness such as packaging, atmosphere, and myoglobin [12].

Unlike lightness and redness, there was not an interaction for packaging treatment × day ($p = 0.8118$) for objective yellowness values, however packaging treatment ($p < 0.0001$) and day of

display ($p < 0.0001$) differed (Figure 1 and Figure 2, respectively). Yellowness values significantly decreased ($p < 0.0001$) from day zero to five, then remained similar from day five through the completion of the display period regardless of treatment. A decrease in b* values of loin chops observed in the current study supports previous literature reporting b* values of beef and pork decreased from day zero values and remained lower throughout the respective display periods [21-22]. Loin chops packaged in overwrap had significantly greater ($p < 0.0001$) b* values than all other treatments (Figure 1). It is documented that pork products packaged in vacuum have lower b* values than products packaged in the presence of oxygen, and the results of the current study further show that while vacuum packaged chops had lower b* values compared to PVC, vacuum film did not have a significant impact ($p > 0.0001$) on b* values [19].

An interactive effect of treatment × day occurred for the calculated spectral values of hue angle ($p < 0.0001$), chroma ($p < 0.0001$), and red-to-brown ($p < 0.0001$). Throughout the storage period, pork loin chops packaged in PVC were redder ($p < 0.0001$) as calculated HA were closer to the true red axis than chops packaged using vacuum (Table 3). With greater HA, it was expected chop surface vividness (CHMA) would be greater ($p < 0.0001$) in PVC overwrapped loin chops than chops packaged using vacuum (Table 3). Greater hue angle values observed in the current study for vacuum packaged pork chops differ from the results of previous research that concluded no difference in hue angle values of pork steaks regardless of packaging method [23]. Results of the current study for decreasing chroma values differ from that of previous research, where chroma values in vacuum packaged ground beef remained unchanged during storage [18]. Red to brown values were greater ($p < 0.0001$) on PVC packaged chops at day 0 of the storage period, but packaging did not alter values at the conclusion of storage period on day 15 (Table 3). Orthogonal contrasts calculated for HA, CHMA, and RTB spectral values

confirmed that differences observed in surface color variation was a result of the packaging treatment ($p \leq 0.0001$). Vacuum packaging of pork chops led to greater ($p < 0.0001$) hue angle values, and a duller ($p < 0.0001$) surface color compared to those packaged in PVC, and PVC packaging led to greater ($p < 0.0001$) values of RTB. Results of the current study for relative spectral values suggest that vacuum packaging loin chops may have limited surface color redness and vividness during storage. However, additional research is necessary to identify the mechanism of color changes in pork when using vacuum packaging. Limitations throughout the documented literature are focused more on meat proteins such as beef steaks and grinds with a greater reaction among oxygen and myoglobin.

A treatment × day interaction occurred for calculated myoglobin values of deoxymyoglobin ($p < 0.0001$), oxymyoglobin ($p < 0.0001$) and metmyoglobin ($p < 0.0001$). Deoxymyoglobin values in PVC packaged chops were the least ($p < 0.0001$) on day 0 of storage, and greatest for VacC on day 10 (Table 4). As expected, surface color in PVC chops became darker as storage time and the surface color deterioration likely caused the calculated values for deoxy myoglobin to increase. Greater relative concentrations of deoxymyoglobin for vacuum packaged pork chops in the current study supports the previous literature that vacuum packaged pork deoxymyoglobin values will increase more than pork packaged in the presence of oxygen giving rise to a more purple, dingy, surface color [19]. Additionally, it is well documented in the literature that complete oxidation of myoglobin can occur in PVC packaged meat by day 7 of storage, supporting the increase in relative deoxymyoglobin values of PVC loin chops at day 10 in the current study [24]. Calculated relative values of oxymyoglobin were greatest ($p < 0.0001$) on day 0 for PVC packaged chops (Table 4). Surface color changes during storage are well documented throughout the literature and current results suggest packaging method was a factor that

influenced the recorded changes in pork loin chops. As expected, metmyoglobin values were greatest ($p < 0.0001$) for PVC chops on day 5 and the least ($p = 0.0002$) for VacC packaged chops indicating that myoglobin had oxidized more in chops packaged aerobically as compared to those packaged anaerobically. Barrier properties of packaging films can reduce partial pressures within the package and limit the exposure of the meat surface to oxygen. Noted in the current study, VacC film had the least oxygen transmission rate and PVC had the greatest. Orthogonal contrasts indicate that packaging treatments of vacuum and PVC differed ($p < 0.0001$) for calculated relative forms of myoglobin, with PVC packaged chops having greater ($p < 0.0001$) values of oxymyoglobin and metmyoglobin while vacuum packaged chops had greater ($p < 0.0001$) values of deoxymyoglobin than PVC. It is well documented in the literature that metmyoglobin values of beef steaks packaged in PVC are greater after 10 days of storage supporting the results of the current study [25]. Contrary to current results, previous literature reports increase in MET values of vacuum packaged beef patties can occur when stored in refrigerated conditions [16]. It is plausible that the decrease in MET values observed after day five is the result of myoglobin succumbing to oxidation.

3.2 Cook Loss and Warner-Bratzler shear force

A treatment × day interaction ($p \leq 0.0040$) occurred for percent cook loss of pork loin chops. Cook loss values were greater ($p < 0.0001$) for pork chops packaged in VacA from day 0 through day 10 of the storage period, and cooking loss was the least ($p < 0.0001$) for chops packaged in PVC on day 10 (Table 5). Differences in cooking loss are likely attributed to the protective nature of the vacuum packaging film reducing evaporative moisture loss during storage. Therefore, cooking loss for vacuum packaged pork chops were likely caused by moisture retention and losses when heating. Orthogonal contrasts indicate packaging method can influence

moisture losses during storage whereby causing greater losses during cooking in chops packaged in vacuum compared to PVC. It has been extensively investigated and reported throughout the literature over the course of time that cooking losses will alter objective tenderness and sensory evaluation of cooked meats. Regardless, additional research is needed to evaluate the mechanism of packaging influences on both subjective and objective measures of tenderness and cookery.

There was a treatment × day interaction ($p = 0.0343$) on Warner-Bratzler shear force (WBSF) of pork loin chops (Table 5). Objective tenderness values were greatest ($p = 0.0010$) for VacA packaged chops on day 0 compared to all other packaging treatments, and least ($p = 0.0074$) on day 10 for chops packaged in PVC. Orthogonal contrasts calculated for WBSF confirm that packaging treatments of vacuum and PVC differed ($p \leq 0.0207$) and may have caused an increase in objective tenderness through moisture losses that occurred during storage within vacuum. Results of the current study support previous literature reporting that vacuum packaged pork chops had greater WBSF values than pork packaged in the presence of greater oxygen concentrations [11-12]. Differences in WBSF values in the current study do not agree with results of previous literature reporting pork packaged aerobically had greater WBSF values than pork packaged in vacuum [26]. Objective tenderness values in meat can be impacted by factors such as packaging as reported in the current study, but other factors have also been well documented to alter tenderness such as protein linking, cookery method, degree of doneness, and oxidation which were not analyzed in this study. Nevertheless, additional research is necessary to illustrate the influence packaging imparts on objective tenderness measurements of pork chops following refrigerated storage.

3.3 Lipid Oxidation

There was a treatment × day interaction ($p < 0.0001$) for lipid oxidation evaluated using 2-thiobarbituric acid reactive substances (TBARS) throughout the simulated storage period (Table 6). Lipid oxidation values were similar ($p = 0.7409$) among all treatments on day 0. Values then increased in PVC packaged chops on day 10 and were greatest ($p < 0.0001$) in PVC packaged chops on day 15 compared to all other treatments. Orthogonal contrasts calculated were significant ($p < 0.0001$) and indicate that vacuum packaging can hinder lipid oxidation during storage compared to PVC. As expected, lipid oxidation in oxygen permeable films increased, however all TBARS values for loin chops in all vacuum packaged treatments were below the detectable threshold by consumers of 0.5mg malonaldehyde. It has been reported that TBARS values greater than 0.5 mg MDA/kg are linked to the creation of off-flavors during consumer sensory evaluation, and TBARS values of loin chops packaged in PVC exceeded this threshold at day 10 [8]. Greater TBAR values of PVC packaged chops in the current study on Day 15 support the results of previous literature reporting PVC packaged pork fillets had greater TBARS values compared to vacuum packaged samples [8]. Changes in TBARS values for chops packaged in vacuum agree with previous literature which concluded TBARS values did not change, but TBARS did and can increase for pork packaged when presence of oxygen is greater [9,19]. In the current study, loin chops packaged in PVC had TBARS values great enough to reflect potential off-flavors from day 10 through the completion of the display period, while chops packaged in vacuum did not meet the 0.5 level at any point during storage. It is plausible that the storage period needed to be increased to reflect a greater increase of lipid oxidation when using vacuum packaging.

4. Conclusions

Current study results indicate that oxygen permeability of packaging film does improve objective surface color values, especially regarding redness on fresh pork chops. Further, calculated myoglobin values indicate that PVC packaging pork chops leads to greater oxidation of the myoglobin proteins than vacuum packaging regardless of the vacuum film used in the current study. Vacuum packaging increased cook loss percentages in the current study compared to PVC. However, the anaerobic nature of vacuum packaging can hinder lipid oxidation during storage. Further, vacuum packaging of pork loin chops did not greatly impact objective tenderness in the storage period currently investigated. It is apparent through this investigation that additional research is needed to fully understand the surface color changes that occur when storing pork retail cuts and subjective flavor attributes under vacuum conditions.

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TABLES & FIGURES

Table 1. Specifications for packaging films during fresh storage analysis of pork loin chops.

Treatment[1]	Composition	OTR[2]	VPR[3]
VacA	150 µ polyethylene/EVOH/polyethylene coextrusion	0.6 cc/sq. m/24 h	3.2 g/sq. m/24 h
VacB	175 µ polyethylene/EVOH/polyethylene coextrusion	0.5 cc/sq. m/24 h	2.8 g/sq.m /24 h
VacC	200 µ polyethylene/EVOH/polyethylene coextrusion	0.4 cc/sq. m/24 h	2.4 g/sq.m/24 h
PVC	Polyvinyl chloride	14,000 cc O_2/m/24 h/atm	-

[1]Packaging treatment defined as (VacA, VacB, VacC, PVC).
[2]OTR: Oxygen transmission rates.
[3]VPR: Vapor transmission rates.

Table 2. Interactive effect of packaging × storage day on surface color values of pork loin chops.

	Packaging Treatment[1]					P-value			
Day	VacA	VacB	VacC	PVC	SEM[2]	Contrast[3]	Treatment	Day	Treatment × Day
L*									
0	57.44^{def}	56.72^{ef}	57.35^{def}	57.46^{def}	0.494	0.0074	0.0543	< 0.0001	< 0.0001
5	58.02^{bcde}	57.43^{def}	57.60^{cdef}	57.88^{cde}					
10	58.71^{abcd}	58.37^{abcd}	58.19^{bcd}	56.41^{f}					
15	59.62^{a}	58.91^{abc}	59.30^{ab}	56.38^{f}					
a*									
0	3.96^{d}	4.03^{d}	3.87^{de}	8.72^{a}	0.190	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	3.13^{f}	3.42^{ef}	3.28^{f}	7.03^{b}					
10	2.93^{fg}	2.94^{fg}	2.91^{fg}	4.60^{c}					
15	2.62^{g}	2.94^{fg}	3.02^{fg}	4.68^{c}					

[1]Packaging Treatment: VacA (150 µ polyethylene/EVOH/polyethylene coextrusion), VacB (175 µ polyethylene/EVOH/polyethylene coextrusion), VacC (200 µ polyethylene/EVOH/polyethylene coextrusion), and PVC (polyvinyl chloride overwrap).
[2]SEM*, Standard error of the mean of the interaction of treatment × day.
[3]Orthogonal Contrast VAC (VacA + VacB + VacC) vs. PVC.
[a-g]Mean values lacking common superscripts within a color measurement differ significantly ($p < 0.05$).

Table 3. Interactive effect of packaging x storage day on calculated spectral values of pork loin chops.

	Packaging Treatment[1]					P-value			
Day	VacA	VacB	VacC	PVC	SEM[2]	Contrast[3]	Treatment	Day	Treatment x Day
HA[4]									
0	71.94^{de}	71.29^{e}	72.20^{de}	58.60^{g}	0.843	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	75.03^{bc}	73.47^{cd}	74.01^{bcd}	63.00^{f}					
10	76.12^{ab}	75.96^{ab}	75.93^{ab}	71.12^{e}					
15	77.59^{a}	76.05^{ab}	75.51^{abc}	71.01^{e}					
CHMA[5]									
0	12.86^{d}	12.70^{d}	12.79^{d}	16.76^{a}	0.135	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	12.23^{e}	12.13^{e}	12.07^{e}	15.46^{b}					
10	12.29^{e}	12.25^{e}	12.15^{e}	14.46^{c}					
15	12.27^{e}	12.31^{e}	12.29^{e}	14.56^{c}					
RTB[6]									
0	1.88^{d}	1.92^{cd}	1.91^{d}	2.41^{a}	0.029	0.0001	0.0009	< 0.0001	< 0.0001
5	1.93^{bcd}	2.00^{b}	2.00^{b}	1.89^{d}					
10	1.90^{d}	1.95^{bcd}	1.99^{bc}	1.92^{cd}					
15	1.87^{d}	1.93^{bcd}	1.90^{d}	1.89^{d}					

[1]Packaging Treatments: VacA (150 µ polyethylene/EVOH/polyethylene coextrusion), VacB (175 µ polyethylene/EVOH/polyethylene coextrusion), VacC (200 µ polyethylene/EVOH/polyethylene coextrusion), and PVC (polyvinyl chloride overwrap).
[2]SEM*, Standard error of the mean of the interaction of treatment × day.
[3]Orthogonal Contrast VAC (VacA +VacB + VacC) vs. PVC.
[4]HA: Hue angle represents the change from true red (greater value indicates a greater shift from red to yellow).
[5]CHMA: Chroma, measure of total color (larger number indicates a more vivid color)
[6]RTB: Red-to-brown, calculated as 630 nm reflectance / 580 nm reflectance representing a change in surface color from red to brown (larger value indicates a redder color).
[a-g]Means lacking a common superscript within a spectral value differ significantly ($p < 0.05$).

Table 4. Interactive effect of packaging × storage day on myoglobin values of pork loin chops.

	Packaging Treatment[1]						P-value		
Day	VacA	VacB	VacC	PVC	SEM[2]	Contrast[3]	Treatment	Day	Treatment x Day
DEO[4]									
0	27.24^{e}	27.64^{de}	28.63^{d}	6.23^{h}	0.429	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	33.14^{ab}	32.74^{abc}	32.71^{bc}	7.28^{g}					
10	32.97^{abc}	33.17^{ab}	33.91^{a}	22.19^{f}					
15	32.03^{bc}	31.90^{c}	32.05^{bc}	22.35^{f}					
OXY[5]									
0	57.81^{e}	56.51^{ef}	57.21^{e}	78.08^{a}	0.688	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	56.21^{ef}	61.35^{cd}	64.37^{b}	64.99^{b}					
10	55.25^{fg}	56.76^{ef}	58.00^{e}	53.98^{g}					
15	57.16^{e}	60.69^{d}	63.11^{bc}	60.70^{d}					
MET[6]									
0	14.95^{cd}	15.75^{cd}	14.17^{d}	15.69^{cd}	0.780	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	10.65^{e}	5.92^{hi}	2.93^{j}	27.73^{a}					
10	11.79^{e}	10.07^{ef}	8.09^{fg}	23.83^{b}					
15	10.82^{e}	7.41^{gh}	4.84^{ij}	16.96^{c}					

[1]Packaging Treatments: VacA (150 µ polyethylene/EVOH/polyethylene coextrusion), VacB (175 µ polyethylene/EVOH/polyethylene coextrusion), VacC (200 µ polyethylene/EVOH/polyethylene coextrusion), and PVC (polyvinyl chloride overwrap).
[2]SEM*, Standard error of the mean of the interaction of treatment × day.
[3]Orthogonal Contrast VAC (VacA + VacB + VacC) vs. PVC.
[4]DEO, relative values of deoxymyoglobin using spectral values.
[5]OXY, relative values of oxymyoglobin using spectral values.
[6]MET, relative values of metmyoglobin using spectral values.
[a-j] Means within a myoglobin state lacking a common superscript differ significantly ($p < 0.05$).

Table 5. Interactive effect of packaging x storage day on cook loss percentage and objective tenderness values of pork loin chops

	Packaging Treatment[1]						P-value		
Day	VacA	VacB	VacC	PVC	SEM[2]	Contrast[3]	Treatment	Day	Treatment x day
CL%[4]									
0	33.83^{a}	29.86^{abc}	26.89^{cdef}	25.18^{ef}	1.453	< 0.0001	<0.0001	0.0103	0.0040
5	33.82^{a}	31.99^{ab}	25.60^{def}	24.97^{efg}					
10	33.77^{a}	28.52^{bcde}	27.17^{cdef}	21.10^{g}					
15	26.07^{cdef}	24.03^{fg}	29.46^{bcd}	24.55^{efg}					
WBSF[5]									
0	27.95^{a}	20.76^{bcd}	19.56^{d}	20.44^{cd}	1.526	0.0207	< 0.0001	0.0933	0.0343
5	24.45^{abc}	19.55^{d}	17.69^{d}	20.71^{bcd}					
10	24.62^{abc}	19.13^{d}	21.06^{bcd}	18.73^{d}					
15	24.83^{ab}	19.77^{d}	26.73^{a}	20.64^{bcd}					

[1]Packaging Treatments: VacA (150 µ polyethylene/EVOH/polyethylene coextrusion), VacB (175 µ polyethylene/EVOH/polyethylene coextrusion), VacC (200 µ polyethylene/EVOH/polyethylene coextrusion), and PVC (polyvinyl chloride overwrap.

[2]SEM*, Standard error of the mean of the interaction of treatment × day.

[3]Orthogonal Contrast VAC (VacA + VacB + VacC) vs. PVC.

[4]CL%: Percent cook loss.

[5]WBSF: Warner-Bratzler Shear Force, evaluated in Newtons (N).

[a-d] Means lacking a common superscript differ significantly ($p < 0.05$).

Table 6. Interactive effect of packaging × storage day on TBARS values of pork loin chops.

	Packaging Treatment[1]						P-value		
Day	VacA	VacB	VacC	PVC	SEM[2]	Contrast[3]	Treatment	Day	Treatment x Day
0	0.34^{cde}	0.36^{cd}	0.31^{e}	0.33^{de}	0.016	< 0.0001	< 0.0001	< 0.0001	< 0.0001
5	0.33^{de}	0.34^{cde}	0.33^{de}	0.37^{cd}					
10	0.35^{cde}	0.37^{cd}	0.33^{de}	0.55^{b}					
15	0.38^{c}	0.33^{de}	0.33^{cde}	0.71^{a}					

TBARS: 2-thiobarbituric acid reactive substances, reported as mg/kg of malonaldehyde in fresh tissue, a larger value indicates greater oxidation.

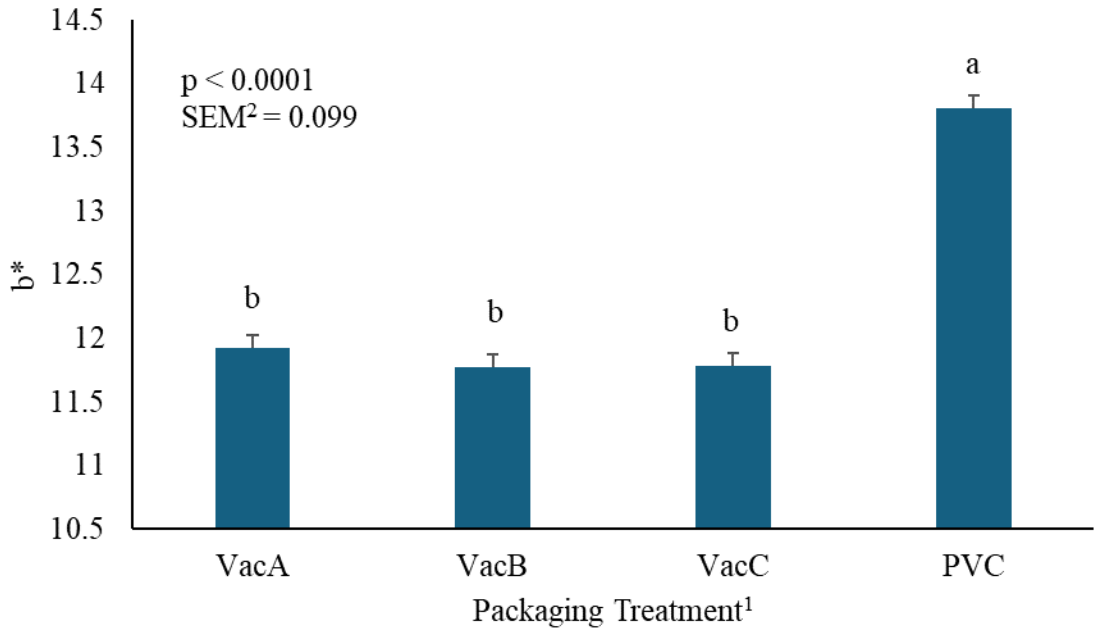
[1]Packaging Treatments: VacA (150 µ polyethylene/EVOH/polyethylene coextrusion), VacB (175 µ polyethylene/EVOH/polyethylene coextrusion), VacC (200 µ polyethylene/EVOH/polyethylene coextrusion), and PVC (polyvinyl chloride overwrap).

[2]SEM*, Standard error of the mean of the interaction of treatment × day.

[3]Orthogonal Contrast VAC (VacA + VacB + VacC) vs. PVC.

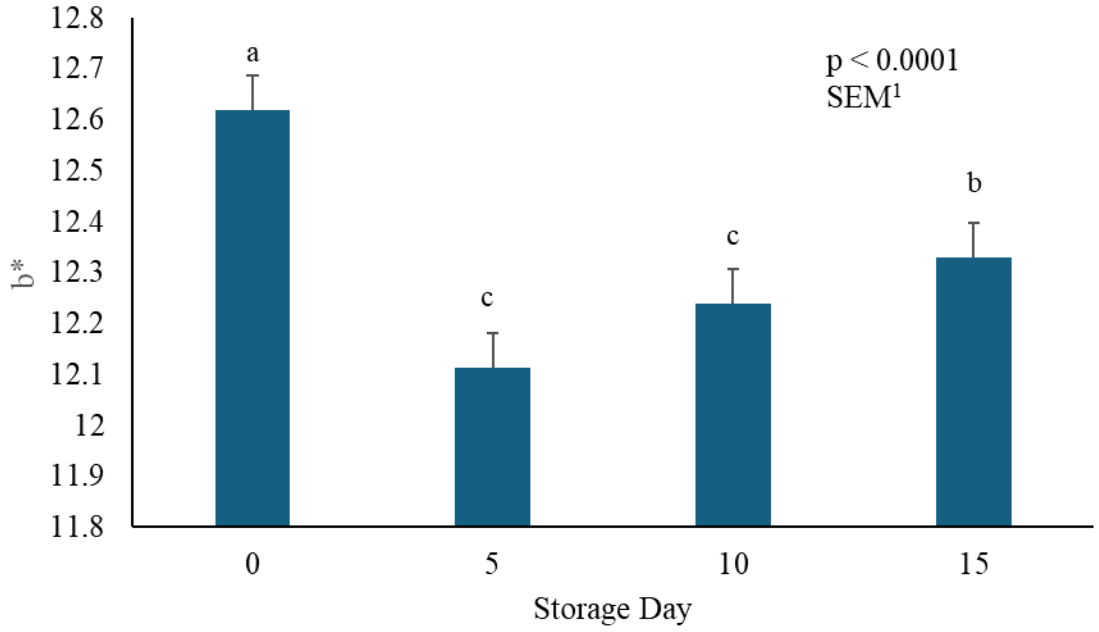
[a-d] Means lacking a common superscript differ significantly ($p < 0.05$).

Figure 1. Main effect of packaging treatment on yellowness values of fresh pork chops. Bars lacking common letters differ ($p < 0.05$).



[1]Packaging Treatment: VacA (150 µ polyethylene/EVOH/polyethylene coextrusion), VacB (175 µ polyethylene/EVOH/polyethylene coextrusion), VacC (200 µ polyethylene/EVOH/polyethylene coextrusion), and PVC (polyvinyl chloride overwrap).
[2]SEM, Standard error of the mean of treatment main effect.
[a-b]Bars lacking common superscripts differ significantly ($p < 0.05$).

Figure 2. Main effect of day on yellowness values of fresh pork chops. Bars lacking common letters differ ($p < 0.05$).



[1]SEM, Standard error of the mean for main effect of day.
[a-c]Bars lacking common superscripts differ significantly ($p < 0.05$).

APPENDICES

APPENDIX A

ELECTRONIC NOSE ANALYSIS (E-Nose)

General notes: Prepare Alpha MOS Software by generating a new test and designating an ID to each sample slot on the Heracles Neo e-nose.

For sample preparation:

To minimize the influence of volatiles naturally present in the laboratory, all preparation steps were completed under a laboratory ventilation hood.

1. Weigh out 2.00g of sample and place into a 20mL e-nose vial.
2. Seal vials individually with aluminum caps containing PTFE/silicon septum to establish an airtight seal.

For analysis:

1. Place all vials into the holding tray according to the established slot ID on the Heracles Neo e-nose.
2. Begin analysis and gather results once analysis has been completed.

APPENDIX B

ELECTRONIC TONGUE ANALYSIS (E-Tongue)

General notes: Prepare Alpha MOS Software by generating a new test and designating an ID to each sample slot, including cleaning steps between samples.

For sample preparation:

1. Weigh 20.00g of each sample/treatment and set aside.
2. Combine 20.00g samples with 100ml of distilled water and homogenize.
3. Place homogenate into centrifuge tube, and centrifuge at a rate of 1500 rpm for 15 minutes.
4. Pour centrifuged homogenate into a 500ml μm PES filter.
5. Filter samples with a vacuum to remove any excess solids
6. After filtering, place samples into e-tongue beakers for analysis.

For analysis:

1. Place samples into autosampler for analysis.
2. Prior to analysis submerge each sensor in deionized water for 30 minutes.
3. Analysis is repeated six times throughout acquisition for each sample.
4. Between samples, the sensors are cleaned by submerging in beakers of deionized water for 10 seconds to prevent contamination between samples.