THE IMPACT OF POST-HARVEST INTERVENTIONS ON THE COLOR STABILITY, AND SUBSEQUENTLY, THE PALATABILITY, OF BEEF FROM CATTLE FED WET DISTILLERS GRAINS

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CHAPTER I

INTRODUCTION

Dried distillers grains plus solubles (DDGS) were being used in animal rations by the late 19th century but it was not until the mid 20th century that scientists began to research distillers grains (Clemens and Babcock, 2008; Firkins et al., 1985; Klopfenstein et al., 2008). In the last several years there has been a large increase in fuel ethanol production (Klopfenstein et al., 2008). This corn based fuel ethanol production has conversely led to an increase in processed by-products (Clemens and Babcock, 2008). Thus, the utilization of distillers grains (DG) in beef cattle diets has become more popular in recent years. With this increased usage, there has been a gradual increase in the amount of research being done. Early research was conducted to determine if inclusion of distillers grains would have a negative impact on average daily gain (ADG) and other animal performance traits. This research also evaluates the effects of feed types (i.e. corn vs. sorghum) and wet vs. dry distillers products. Beef cattle diets can affect the color and palatability of the beef products. As a result, more current research has been directed toward potential impact of distillers grains on carcass and meat quality. When evaluating meat quality, two major factors play critical roles in consumer decisions. Grobbel et al. (2008b) asserts that color is the major factor affecting the purchasing decisions of consumers. In addition, tenderness is the most important palatability factor to determine overall eating experience of the consumer (Grobbel et al., 2008b). Thus, it is important to continue research in the area of distillers grains in order to evaluate whether feeding these rations in the diet has a positive or negative effect on the end meat products. If color and palatability are negatively impacted by inclusion of distillers grains, there are several post-harvest interventions that can be used to combat these effects. Two popular interventions in recent years have been increasingly utilized: Modified Atmosphere Packaging (MAP) and enhancement injection solutions.

Modified atmosphere packaging is a packaging technique that has been used for several years because of its ability to maintain color over a longer period of time in the retail case than more traditional oxygen permeable overwrap packaging methods. High oxygen packaging can increase red color stability up to 14 d, compared to the 4-7 d generally offered by the traditional polyvinyl chloride (PVC) overwrap packaging methods (John et al., 2005).

Likewise, enhancement solutions can be used to reduce variation in tenderness that is common in beef products (Hoffman et al., 2008). Blends containing sodium and potassium salts, phosphates, and lactates can be used effectively to enhance the sensory attributes of beef without negatively impacting palatability factors (Hoffman et al., 2008). The area of injection enhancements is vast and widely researched because of the great variety of combinations possible. Regardless, enhancements have the distinct benefit of creating a more tender, juicy, and often flavorful product. In addition, enhancements can be effectively used to reduce variation that occur from use of distillers grains in cattle diets that were produced in different plants. Research in the area of distillers grains and enhancements is minimal and needs to be continued.

CHAPTER II

REVIEW OF LITERATURE

PRE-HARVEST AND POST-HARVEST EVALUATION OF CATTLE FED DISTILLERS GRAINS

Pre-Harvest: Use of Distillers Grains in Beef Cattle Diets

As discussed by Clemens and Babcock (2008), corn-based ethanol production results from one of two systems: wet milling or dry grinding. Distillers grains are a by-product of the dry grinding process, which is often preferred over wet milling (Clemens and Babcock, 2008). The dry milling industry is quite flexible in that they can use several types of grain in the fermentation process, such as corn, grain sorghum, wheat, barley, or any mixture of these (Stock et al., 2000). The product is first fermented then passed through a distillation column after which it is referred to as whole stillage (Stock et al., 2000). Afterwards, the coarser grain particles are removed and either sold as wet distillers grains (WDG) or dried and sold as dried distillers grains (DDG) and the remaining product is termed thin stillage (Stock et al., 2000). Larson et al. (1993) indicates thin stillage can be marketed with dried distillers grains as distillers dried grains with solubles (DDGS) or separately as condensed distillers solubles. Initially, two-thirds of the original corn and sorghum grain are composed of starch (Stock et al., 2000). After the fermentation process, only one-third of this starch remains, resulting in a concentration of the other nutrients found within the grains (Stock et al., 2000). Thus, these grains contain a high level of both fat and protein (Stock et al., 2000).

Early on Bidner et al. (1981) established that high energy diets, defined as such if the animals are fed within a feedlot setting for 70+ d, resulted in cattle with a better average daily gain (ADG) in comparison to primarily forage fed cattle. While there were no significant differences in dressing percentages between treatment groups, there was a difference in the amount of fat thickness (FT) and marbling between forage fed cattle and cattle on high energy corn diets (Bidner et al., 1981). The cattle on completely forage fed diets had less fat than the other treatment groups that included corn in the diet (Bidner et al., 1981). Cattle on the high energy diets had higher marbling scores than forage fed cattle (Bidner et al., 1981). However, this did not lead to any significant differences in yield or quality grades (Bidner et al., 1981). Significant differences were also found between lean color of steaks from forage fed cattle and high energy diet cattle as the forage fed cattle had darker lean then feedlot steers (Bidner et al., 1981). Bidner et al. (1981) established the concept that diets including grains can have a positive effect on carcass characteristics and meat quality.

Corn grains in comparison to sorghum grains

A variety of research has been conducted on the feed value of both sorghum and corn DG, dry and wet, in comparison with several other feedstuffs. Previous studies have well documented that corn grain is more digestible than sorghum grain (Rooney and Pflugfelder, 1986; Wester et al., 1992).

In contrast, Brandt et al. (1992) compared the effect of steam flaked sorghum grains to steam flaked corn (SFC) on feedlot performance of steers. Grain type had no affect on gain efficiency of the steers (Brandt et al., 1992). Likewise hot carcass weight (HCW), dressing percentage (DP), kidney pelvic heart fat (KPH), marbling, and percent of carcasses that graded Choice were not affected by treatment (Brandt et al., 1992). Brandt et al. (1992) found that loin muscle area (LMA) was larger in steers fed the SFC diet. The external fat cover of beef fed the SFC diet was more yellow than other treatments (Brandt et al., 1992). No treatment differences were discovered by sensory panels and Warner-Bratzler Shear Force (WBSF) analysis in juiciness, flavor, or tenderness (Brandt et al., 1992). Overall, findings in this study indicated that beef from steers fed sorghum grains is not inferior to beef fed SFC, as previous research had implied (Brandt et al., 1992).

A study conducted by Lodge et al. (2007) found that sorghum dried distillers grains plus solubles had a lower feed efficiency than dry rolled corn (DRC), sorghum wet distillers grains, and sorghum wet distillers grains plus solubles, but this had no negative impact on cattle performance data. No differences were seen in daily gain or dry matter intake (Lodge et al., 1997). Fat thickness, quality grade, yield grade, and liver abscess scores did not differ between carcasses from cattle fed corn and sorghum diets (Lodge et al., 1997).

Wet distillers grains in comparison to dry distillers grains

Several studies have been conducted to evaluate the feeding value of both wet and dry distillers. Larson et al. (1993) researched the effects of wet distillers by-products (corn distillers grains and thin stillage) at different inclusion levels (5.2%, 12.6%, and

40%). When drying costs increase, wet distillers grains provide more energy and are a cost efficient alternative to dried distillers products (Larson et al., 1993). However, these wet distillers products are subject to mold during transport due to their high water content, not to mention expensive transportation fees (Larson et al., 1993). Thus, the usefulness of wet distillers by-products is limited to areas located near the place of production (i.e. ethanol plant) where they can be used rapidly (Larson et al., 1993). The base of the diet in this study consisted of dry rolled corn (Larson et al., 1993). Yearling cattle became more efficient as percent of wet distillers by-products in the diet increased (Larson et al., 1993). Carcass characteristics such as FT, liver abscess scores, and quality grades were not affected by the level of wet distillers by-products. Larson et al. (1993) also analyzed the energy and protein content of the wet distillers by-products. Data suggested that when fed up to 40% of DM to finishing cattle, this wet distillers by-products contained 63% more net energy for gain/kg than corn (Larson et al., 1993). The findings that wet distillers grains plus solubles contain more energy per kilogram than the corn it replaced was also supported by Firkins et al. (1985).

Peter et al. (2000) studied the utilization of modified corn fiber (MCF) to dry corn gluten feed (DCGF) and corn based DDG in beef cattle. Heifers fed the DDG had 39% greater ADG than heifers fed MCF (Peter et al., 2000). Concluding data suggested that DDG was a much more effective energy and protein source in high grain diets than MCF (Peter et al., 2000).

Past finishing trials found that cattle fed wet and dry distillers grains gained faster and more efficiently than cattle fed a DRC diet. Furthermore, the cattle fed wet distillers grains were more efficient then cattle fed dried distillers grains plus solubles (Ham et al., 1994). These findings indicated that including a small amount of distillers grains, wet or dry, in an animal's finishing diet may be necessary to help maximize performance (Ham et al., 1994). This is, in part, due to it being more degradable than a diet higher in starch and also due to its reduction of subacute acidosis (Stock et al., 2000). A more degradable diet resulted in less overall acid production in the rumen which, in turn, decreased the occurrence and duration of subacute acidosis (Stock et al., 2000). Ham et al. (1994) also found moisture content of the corn byproducts may play a minor role in increasing performance by increasing particle size thus slowing the rate of passage through the digestive system. Distillers grains can be a cheap alternative to more expensive corn products with the added benefit of increasing performance in the feedlot (Ham et al., 1994). While DDG may not always be as effective as WDG, use of DDG still improves DRC diets and are more beneficial than other by-products such as MCF.

Inclusion of distillers in relation to performance and carcass characteristics

Leibovich et al. (2009) evaluated the effect of corn processing method with inclusion of sorghum wet distillers grains with solubles on carcass characteristics and performance of feedlot cattle. In contrast to findings by Ham et al. (1994), this study found that diets with 15% inclusion of sorghum wet distillers grain plus solubles had a lower overall ADG than diets with 0% inclusion of the same product (Leibovich et al., 2009). Leibovich et al. (2009) found no difference in ADG between animals fed SFC and DRC. While previous research has indicated that G:F has improved with inclusion of distillers (Ham et al., 1994; Larson et al., 1993), the current study found that G:F was reduced in both the DRC based diets and the diets which included sorghum wet distillers grains plus solubles (Leibovich et al., 2009). It is unclear as to exactly why the findings of these studies are so different. However, Vasconcelos and Galyean (2007) used sorghum wet distillers grains with solubles from the same source as Leibovich et al. (2009) with similar findings. Research also found no significant differences between corn processing method and inclusion of sorghum distillers grains, except for marbling percentages (Leibovich et al., 2009). Cattle fed a normal steam flaked diet had lower marbling scores than those from cattle fed the normal dry rolled diet and the steam flaked diet which included 15 % distillers products (Leibovich et al., 2009). Marbling scores of carcasses fed a DRC diet with 15% distillers were not different from any of the other treatments (Leibovich et al., 2009). Data from this study suggested that the response to 15% sorghum distillers included in the diet had no significant interaction with either the dry rolled or steam flaked corn of diet (Leibovich et al., 2009). Source of the diet ingredients may be a very important factor and have an influence on carcass characteristics.

Al-Suwaiegh et al. (2002) studied the energy content of wet distillers grains fermented from both sorghum and corn grains when used in finishing diets of yearling beef steers in comparison to DRC which was used as a control. This study found that HCW, FT, and yield grade (YG) were all higher in cattle fed wet distillers rate at an inclusion level of 30% than cattle fed the DRC (Al-Suwaiegh et al., 2002). There was no difference between treatments in DP, LMA and marbling score (Al-Suwaiegh et al., 2002). The effects on carcass characteristics were similar to those found in previous experiments by Larson et al. (1993), Ham et al. (1994), and Lodge et al. (1997).

Jenschke et al. (2008) evaluated sensory properties of beef finished on a wet distillers diet with treatments that consisted of varying levels and types of roughage.

Results indicated that the levels of alfalfa and corn stalks had a significant effect on tenderness and juiciness of the product (Jenschke et al., 2008). Low levels of alfalfa and corn stalks resulted in a more tender and juicier steak than treatment groups which included higher levels of these roughages; however they also had a higher prevalence of the bloody off flavor (Jenschke et al., 2008). This is important to note because even with inclusion of distillers, other factors in the diet such as roughage levels may have an influence on beef sensory properties.

Effect of distillers grains on meat quality

Background

As mentioned previously, color and palatability both play major roles in consumer purchasing decisions. Gray et al. (1996) asserts consumers will discriminate against meat cuts which lose a fresh appearance. Discolored meat products are often ground and marketed as a reduced value item (Gray et al., 1996). Liu et al. (1995) indicates that radicals produced during the process of lipid oxidation may either act directly to promote pigment oxidation or may indirectly damage pigment reducing systems; resulting in the known positive correlation between lipid oxidation and pigment oxidation. Discoloration is a result of oxidation of the protein myoglobin, producing metmyoglobin (Mancini and Hunt, 2005). Mancini and Hunt (2005) stated that myoglobin formation depends on multiple factors such as oxygen partial pressure, temperature, pH, meat's reducing activity, and microbial growth.

Lipid oxidation has been widely recognized as one of the primary contributing deterioration reactions responsible for loss of meat quality (Gray et al., 1996). This degradative process results in rancidity in raw meat or what has been dubbed as the warmed-over flavor in cooked meat products (Liu et al., 1995). Rancidity in meat begins to develop shortly after death and slowly increases in intensity until consumers find the product unacceptable (Gray et al., 1996). Phospholipids are major contributors to the oxidative off-flavors in animal muscles as the severity of oxidation often depends on the amount of unsaturated fatty acids present (Kanner, 1994). Lipid oxidation begins when a hydrogen atom is removed from an unsaturated fatty acid, which results in the formation of free radicals (Buege and Aust, 1978). Ultimately, the breakdown of polyunsaturated fatty acids produces malondialdehyde (Buege and Aust, 1978). Buege and Aust (1978) developed a procedure that uses thiobarbituric acid to react with the malondialdehyde, allowing absorbance to be read on a spectrophotometer at 535 nm to determine the level of lipid oxidation. In a study by Campo et al. (2006), the crossing point at which flavor perception of rancidity overpowered perception of beef flavor was 2.28 mg of maldonaldehyde per kg of lean muscle. Rancidity of the steaks in this study increased rapidly until either reaching a saturation point or the panelist could no longer perceive higher levels of oxidation (Campo et al., 2006). Thus, observing thiobarbituric acid reactive (TBAR) concentrations within a sample is an important way in determining the levels of lipid oxidation and, ultimately, consumer acceptability. Therefore, control of oxidation to prevent discoloration and development of off-flavors in meat products is imperative in order to sell what consumers consider a high quality product.

Many authors emphasize the importance of tenderness as a qualitative characteristic of meat (Destefanis et al., 2008). While objective methods allow for comparison of different treatments, they do not provide information on overall product acceptability; thus, consumer opinion via sensory methods is a key factor to establishing meat value (Destefanis et al., 2008). Warner-Bratzler Shear Force (WBSF) tests are a common way of objectively evaluating beef tenderness, but consumer panels need to be used to evaluate how meat contributes to an individual's personal satisfaction (Destefanis et al., 2008). Essentially, color, tenderness, and lipid oxidation all become important factors in evaluating the quality of beef products.

In relation to distillers grains

Research in more recent years has begun to focus on the response of meat quality to the increasing usage of distillers grains in finishing diets. Roeber et al. (2005) researched the effects of wet or dry distillers grains on beef quality traits and sensory properties in Holstein steers. Results indicated that including distillers grains in cattle finishing diets may have a negative impact on color stability during retail display (Roeber et al., 2005). Roeber et al. (2005) concluded, with WBSF data, that there was no difference in tenderness between treatments, but overall tenderness was below the consumer acceptability threshold as designated by Shackelford et al. (1991). Consumer panels also indicated that steaks from steers fed at 25% wet distillers grains received the highest numerical tenderness and juiciness scores while steaks from steers fed 50% wet distillers grains received the lowest numerical tenderness and juiciness scores (Roeber et al., 2005). Roeber et al. (2005) also reported that flavor ratings did not differ among treatments. These data may suggest that distillers grains can be fed up to a 25% inclusion rate without negatively impacting palatability characteristics (Roeber et al., 2005).

Gill et al. (2008) studied the impact of corn or sorghum distillers grains on beef color and sensory attributes. Steaks were placed under retail display and both objectively and subjectively evaluated for differences in color (Gill et al., 2008). While there were no differences in visual appearance, objective evaluation revealed that cattle fed DG in the diet (either sorghum or corn, 15% inclusion) yielded steaks which were brighter, but less red overall than steaks from cattle fed simply SFC (Gill et al., 2008). Thiobarbituric acid reactive concentrations also indicated that diet had no effect on lipid oxidation (Gill et al., 2008). Consumer panelists indicated that steaks from corn DG diets were preferred over steaks from sorghum DG diets because they were perceived as more tender (Gill et al., 2008). However, in the same study, WBSF analysis indicated no difference in tenderness between treatments (Gill et al., 2008).

Overall, distillers grains plus solubles have proven to be a good protein source and contain sufficient feeding values (Klopfenstein et al., 2008). Distillers grains have a higher feeding value than DRC, but feeding value in comparison to other ingredients depends on level of inclusion in the diet (Klopfenstein et al., 2008). The energy value of distillers by-products appears to be increased in the wet form (Stock et al., 2000). There does seem to be an interaction between level of distillers in the diet and type of grain processing used (Klopfenstein et al., 2008). It is also extremely important to note that the milling process varies from plant to plant, so by-products should only be evaluated on a plant by plant basis for accurate conclusions (Stock et al., 2000).

Post-harvest interventions: packaging methods in relation to color and palatability

With more research being done in the area of distillers grains and its effect on meat quality, color stability is also becoming a topic of interest. Globally, the most wide spread method of packaging is the use of an oxygen permeable polyvinyl chloride (PVC) film overwrapping a polystyrene tray (McMillin, 2008). The PVC method of packaging can be offered both in store and in case ready systems unlike other methods, which are generally only offered in a centralized location (McMillin, 2008). Modified Atmosphere Packaging (MAP) is a packaging technique that has been used for several years because of its ability to maintain color over a longer period of time in the retail case than more traditional oxygen permeable overwrap packaging methods. High oxygen (HiO_2) packaging can increase red color stability up to 14 d, compared to the 4-7 d generally offered by the traditional PVC overwrap packaging methods (John et al., 2005). Simply put, the purpose of MAP is to maintain the desired properties of meat for the desired period of storage and display (McMillin, 2008). Various levels and types of gases have been researched and experimented with in MAP systems. The most common gases used are oxygen, carbon dioxide, and nitrogen (Zakrys et al., 2009). Oxygen itself is primarily used to keep myoglobin in its oxygenated form while carbon dioxide is present to prevent growth of certain bacteria (Zakrys et al., 2008). There are benefits and drawbacks to each packaging method used (Table 2.1).

Grobbel et al. (2008b) researched the effects of various packaging atmospheres on beef tenderness, color stability, and internal cooked color by comparing different gas blends (HiO_2, vacuum packaged, and several ultra low oxygen (LO_2) plus CO blends). Warner Bratzler Shear Force data revealed HiO_2 MAP resulted in less tender steaks than the other treatment groups (Grobbel et al., 2008b). This may have been in part due to the fact that HiO_2 packages were held in dark storage for less time than LO_2 packages (Grobbel et al., 2008b). In this study, HiO_2 MAP product was slightly brighter, but they discolored more quickly and to a greater extent than the other treatments (Grobbel et al., 2008b). In addition, Grobbel et al. (2008b) found HiO_2 MAP products exhibit a premature browning effect. Essentially, HiO_2 steaks were less stable in color and either as tender or less tender than steaks from other packaging treatments (Grobbel et al., 2008b).

While HiO_2 atmospheres are popular because they promote a bright cherry red color (O'Grady et al., 2000), oxidative stability of lipids is often compromised leading to off flavors within the product (Estévez and Cava, 2004). Zakrys et al. (2008) also compared effects of various O_2 atmosphere levels within MAP packaging systems. Results of this particular study documented that an increasing oxygen level in MAP led to a decrease in color stability and an increase in lipid oxidation (Zakrys et al., 2008). As with Grobbel et al. (2008b), WBSF data demonstrated a positive correlation between tenderness and oxygen levels, meaning as oxygen level in MAP increased, tenderness of the steaks decreased (Zakrys et al., 2008). Trained sensory panelists seemed to find the $O_2$50 steaks the most acceptable of all the treatments (Zakrys et al., 2008). In another very similar follow up study to the previous experiment by Zakrys et al. (2009), a consumer panel found $O_2$40 samples to be the most acceptable overall, followed by $O_2$80 samples. Over time in the retail case, samples were identified as growing less juicy and less tender (Zakrys et al., 2009). Zakrys et al. (2008, 2009) speculated that consumers may choose the $O_2$80 product as second best despite its lack of juiciness and tenderness because they may already be accustomed to oxidized off flavors from products they purchase in the grocery store. These two studies give interesting insight into potential consumer preferences when it comes to purchasing MAP beef products.

O’Sullivan et al. (2003) evaluated the effect of different rations on retail packaged beef products. It is well known that diet has a significant impact on meat quality and composition which subsequently effects shelf life (O'Sullivan et al., 2003). In this particular study, beef quality differed depending on the packaging method used (overwrap or high oxygen MAP) (O'Sullivan et al., 2003). In overwrapped samples, significant differences in meat quality due to dietary treatments were observed, but in MAP samples there were significant differences (O'Sullivan et al., 2003). The forage diet presented the best color stability according to both objective and subjective analysis while the all concentrate diet presented the highest lipid oxidation values (O'Sullivan et al., 2003). These findings led O'Sullivan et al. (2003) to conclude that the all forage diet was of higher meat quality overall when compared to the all concentrate diet. This study clearly demonstrates that packaging methods can have an impact on meat quality, which may also interact with animal diets.

A study by Grobbel et al. (2008a) compared the effects of both various packaging techniques and injection enhancement on various beef cuts. Injection enhancement will be discussed in greater detail later. Enhanced steaks produced more off flavors, were darker in color, juicier, and had less perceptible connective tissue than nonenhanced steaks (Grobbel et al., 2008a). Also, HiO_2 packaged steaks were found to be less tender and have more off flavors than the LO_2 CO MAP products or vacuum packaged steaks (Grobbel et al., 2008a). Lastly, regardless of enhancement or not, steaks packaged in LO_2 CO environments did not discolor through 7 d of display whereas steaks in HiO_2 MAP environments did discolor (Grobbel et al., 2008a).

As can be seen, MAP techniques have been studied quite judiciously, especially in recent years. While low oxygen CO atmospheres may do a better job of maintaining color stability and a palatable product, consumers still associate negatively with the use of CO in packaging. Because of this, CO MAP is not used as widely, commercially.

While some of the drawbacks of high oxygen MAP techniques include a more accelerated development of lipid oxidation, and thus rancidity, or slightly tougher products or premature browning it does offer a distinct advantage of an extended shelf life and greater stability than traditional overwrap. Thus, modified atmosphere packaging may and can be a suitable option if attempting to extend the shelf life of beef products such as animals fed distillers grains that may potentially have a shorter shelf life to begin with.

Post-harvest interventions: enhancement injections in relation to color and palatability

A wide variety of enhancement solutions exist for use with beef products. Regardless of the numerous types of enhancements, it is important that processors choose ingredients in their solution which maximize both color stability and meet consumers palatability expectations (Lawrence et al., 2004). Types of enhancement injections include calcium chloride solutions, sodium phosphate solutions, and various lactate solutions. As with packaging techniques, each type has its benefits and drawbacks. In general, the meat industry has developed enhancements in order to create a more consistently tender and flavorful product (Knock et al., 2006a).

Calcium chloride has been researched significantly because of its ability to enhance tenderness; however, it has been found to have several drawbacks in relation to color, flavor, and purge loss (Lawrence et al., 2004). Because of these significant issues, researchers attempted to utilize calcium lactate solutions (Lawrence et al., 2004). One significant drawback exists - when using calcium in a solution, processors cannot also use phosphates to help water binding within the same solution because phosphates will chelate calcium in solution, thus inactivating the calcium (Lawrence et al., 2004). Thus, Lawrence et al. (2004) compared the effects of a phosphate and salt solution to a calcium lactate enhancement solution. Findings demonstrated that calcium lactate solutions provided better in initial color and color stability throughout retail display than the phosphate and salt solutions (Lawrence et al., 2004). However, the phosphate and salt solutions had higher sensory panel tenderness scores than the calcium lactate solutions and better water binding ability (Lawrence et al., 2004).

Sodium phosphate solutions are commonly used because of their ability to increase protein solubility and water binding ability of the product (Scanga et al., 2000). In a study by Scanga et al. (2000), a marination technique was utilized to compare the use of calcium chloride and sodium phosphate and to evaluate whether the inclusion of beef flavoring to both of these solutions would have a positive effect on beef palatability. In relation to nonenhanced steaks, marinated steaks improved palatability, specifically perceived tenderness, and even more so when beef flavoring was added to each solution (Scanga et al., 2000). Beef flavoring effectively reduced off flavors that are generally produced by these solutions, especially calcium chlorides (Scanga et al., 2000). Thus, negative off flavors can be effectively reduced by adding beef flavoring agents to enhancement solutions.

Vote et al. (2000) compared palatability of strip loins enhanced with a combination of sodium tripolyphosphate, sodium lactate, and sodium chloride and evaluated the effect on sensory characteristics. The combined solution ended up having beneficial effects on tenderness and juiciness of the strip loins (Vote et al., 2000). In addition, panelists preferred steaks with a 15% injection over the 12.5% treatment group and tended to give injected product higher cooked beef flavor ratings than paired, untreated control steaks (Vote et al., 2000). Such combinations of enhancements can be utilized in order to bring about a product which will be appealing to the consumer.

Baublits et al. (2005) examined the effect of different phosphate solutions and pump rates on the sensory properties of lower quality beef cuts. Three phosphate types were observed: sodium hexametaphosphate (SHMP), sodium tripolyphosphate (STPP), an tetrasodium pyrophosphate (TSPP) (Baublits et al., 2005). All phosphate types were rated juicer than control steaks and no off flavors were detected by the panel in any of the treatments (Baublits et al., 2005). Additionally, steaks with a higher pump rate were given higher tenderness scores than the other steaks and all phosphate enhanced steaks scored better on tenderness than non-enhanced steaks (Baublits et al., 2005). An additional follow up study by the same researchers using the same enhancements evaluated the effect on instrumental color (Baublits et al., 2006). Data indicated that TSPP was most effective in maintaining beef color through the display period, while STPP was second and SHMP was the last effective enhancement (Baublits et al., 2006). The TSPP enhancement distinguished itself from the others by being redder, more vivid, and containing higher oxymyoglobin levels than the other two treatments (Baublits et al., 2006). Thus, TSPP enhancement would provide a longer shelf life and an equally palatable product in comparison to the other sodium phosphate enhancements (Baublits et al., 2006).

Knock et al. (2006a) examined the effects of potassium lactate, sodium chloride, and sodium acetate on sensory properties of steaks when MAP packaged. All steaks had low WBSF values (< 25.5 Newtons) and tenderness and juiciness of all steaks decreased with days in MAP (Knock et al., 2006a). Concerning flavors, steaks injected with solutions containing lactate tended to have more intense brown roasted flavors and lactate plus high salt solutions demonstrated salty flavors (Knock et al., 2006a). Flavors of rancidity grew stronger with number of days in MAP, but more significantly for control and lactate plus high salt steaks (Knock et al., 2006a). According to sensory panels, all samples were tender and juicy (no treatment differences), but these qualities decreased with time (Knock et al., 2006a). In this study, potassium lactate injection enhancements seem to amplify a brown roasted flavor in the product which limits the development of rancidity flavors (Knock et al., 2006a). However, too much salt may increase rancidity flavors in beef products (Knock et al., 2006a). A similar study by Knock et al. (2006b) on rib steaks found that use of potassium lactate will help stabilize color and the addition of sodium acetate reduces glossiness of surface. The use of these two ingredients in an injection solution could create a more appealing looking product to the consumer and would last longer in the retail case (Knock et al., 2006b).

Enhancement solutions can be used to reduce variation in tenderness that is common in beef products (Hoffman et al., 2008). Blends containing sodium and potassium salts, phosphates, and lactates can be used effectively to enhance the sensory attributes of beef without negatively impacting palatability factors (Hoffman et al., 2008). Many of the target consumers actually prefer these enhancements (Hoffman et al., 2008). The area of injection enhancements is vast and widely researched because of the great variety of combinations possible. Regardless, enhancements have the distinct benefit of creating a more tender, juicy, and often flavorful product. In addition, enhancements can be effectively used to reduce variation that may occur from use of distillers grains in cattle diets that were produced in different plants. Therefore, research in the area of distillers grains and enhancements is minimal and needs to be continued.

Conclusions

Distillers grains are undoubtedly becoming increasingly utilized as a feed source in the beef industry because they are both cheap and available. Research on distillers grains is quite varied because it encompasses many different types of distillers grains and its interactions with several different types of feedstuffs in the diet. Research has only recently been directed towards the effects of wet and dry distillers grains on meat quality and end products. Results of distillers experiments tend to vary, but this may in part be due to the fact that nutritive quality of distillers grains often depends heavily on the plant it was made and processing method. Since distillers grains are simply a by-product, no concern is placed on product consistency or quality. Because variation in the feed may potentially affect variation in the beef product, controls such as packaging techniques and enhancement injections may be used to ensure a longer lasting and a more uniform product. Consumers make buying decisions based on color, thus MAP techniques can be used to maintain stability of color in retail case for a longer period of time. Likewise, once a consumer purchases product, palatability plays a major role in satisfaction and repurchasing decisions. If the beef industry wants to maintain its focus on the already difficult task of creating the most uniform product possible, more research needs to be done on the effects of distillers grains on color and palatability of beef products and subsequently, any post-harvest intervention methods that can be used to counteract negative effects.

CHAPTER III

THE IMPACT OF POST-HARVEST INTERVENTIONS ON THE COLOR STABILITY, AND SUBSEQUENTLY, THE PALATABILITY, OF BEEF FROM CATTLE FED WET DISTILLERS GRAINS

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ABSTRACT

Two hundred and forty heifers were fed at Oklahoma State University in Stillwater, OK, in one of two treatment groups: A dry rolled corn (CON) diet or a diet including 30% wet distillers grains plus solubles (WDGS). Chuck rolls (n = 60) and paired strip loins (n = 75 pairs; 38 CON, 37 WDGS) were collected from each treatment group and processed at 3 d and 14 d, respectively. After grinding, each chuck was separated into 8 polyvinyl chloride (PVC) film overwrapped packages and 8 high oxygen modified atmosphere packages (MAP), each containing approximately 0.45 kg of ground beef for color, sensory and Thiobarbituric Acid Reactive Substance (TBAR) analysis. After 14 d, one strip loin from each pair was injected with an enhancement solution. Steaks from each strip loin were fabricated and packaged, half PVC and half MAP, then evaluated for color, tenderness, and palatability. Color was evaluated subjectively using a trained color panel and objectively using a HunterLab Miniscan XE. An Instron Universal Testing Machine with a Warner-Bratzler head was used for evaluation of instrumental tenderness and a trained sensory panel was used to assess palatability along with TBAR analysis. Ground beef exhibited no significant differences in color between dietary treatments; however, sensory panelists did find MAP WDGS had less beefy flavor (P = 0.05) and more painty flavor (P = 0.01) intensities than the MAP CON ground beef. Cattle fed WDGS discolored more (P = 0.01) and had less bright steaks than cattle fed the CON when MAP and enhanced. Distillers fed, non-enhanced (NE) MAP steaks were redder and yellower than control steaks (P < 0.05) upon removal from simulated retail display. There were no other significant color differences between dietary treatments using any other combination of post-harvest interventions. In sensory panels, WDGS NE PVC products were juicier and more tender, initially, and contained less connective tissue (5.30 ± 0.07, 5.49 ± 0.05, and 5.86 ± 0.43, respectively) than the steaks from CON carcasses (5.06 ± 0.07, 5.37 ± 0.05, and 5.73 ± 0.43, respectively). While WDGS NE MAP steaks had showed more oxidation than CON NE MAP steaks upon removal from retail case, all TBAR values were well below the threshold of 2 mg malonaldehyde/kg. Essentially, MAP packaging, but not enhancing products, from cattle fed WDGS may be the best way to maintain a visually appealing appearance in the retail case, but at possible risk to product juiciness.

INTRODUCTION

In the last several years, there has been a large increase in fuel ethanol production (Klopfenstein et al., 2008) which has conversely led to an increase in processed by-products (Clemens et al., 2008). As a result, the utilization of distillers grains (DG) in beef cattle diets has become more popular. Research has begun to focus on the response of meat quality to the increasing usage of DG in finishing diets.

When evaluating meat quality, two major factors play critical roles in consumer decisions: color and tenderness (Grobbel et al., 2008b). If color and palatability are negatively impacted by inclusion of DG, there are several post harvest interventions that can be used to combat these effects. Two popular interventions in recent years have been increasingly utilized: modified atmosphere packaging (MAP) and enhancement injection solutions.

Modified atmosphere packaging is a technique that has been used for several years because of its ability to maintain color over a longer period of time in the retail case than more traditional oxygen permeable packaging methods. Likewise, enhancement solutions can be used to reduce variation in tenderness that is common in beef products (Hoffman et al., 2008) while having the distinct benefit of creating a more tender, juicy, and often flavorful product. In addition, enhancement can be effectively used to reduce variation that may result from using DG in cattle diets that were produced in different plants.

The first objective of this experiment was to determine the impact of using post-harvest interventions on the color stability of beef products from cattle that have been fed DG. Secondly, this experiment sought to determine the impact of the post-harvest interventions on the palatability of beef steaks after they have been in retail display.

MATERIALS AND METHODS

Two hundred and forty heifers were fed at Oklahoma State University's Willard Sparks Beef Research Center in Stillwater, OK. The heifers were assigned to one of two treatment groups: dry rolled corn (CON), the control group; or 30 % wet distillers grains plus solubles (WDGS). Cattle were shipped to a commercial harvest facility for harvest and data collection. One hundred and twenty head were deemed suitable for harvest based on weight and visual inspection on January 20, 2009; the remaining were harvested on February 10, 2009.

Harvest and Data Collection

Heifers were harvested at a commercial processing facility in Dodge City, Ks. Data were collected by trained Oklahoma State University personnel. On the day of harvest, tag transfer was completed and hot carcass weights (HCW) were recorded. Liver scores were collected according to the Eli Lilly (Elanco) Liver Check System (√ = no abscesses, A- = 1 or 2 abscesses, A = 2 to 4 small active abscesses, A+ = 1 or more large active abscesses, A+ Adhesion = liver adhered to GI tract, A+ Open = open liver abscesses; other abnormalities recorded as Cirrhosis, Flukes, Telangiectasis or Contamination). After a 36 h chill, complete carcass data were collected: ribeye area (REA); marbling score at the 12^{th} and 13^{th} rib interface; kidney, pelvic, and heart (KPH) fat; fat thickness (FT); and lean and skeletal maturity. Quality and Yield grades (QG/YG) were calculated according to these data.

Strip loin and Chuck Collection

After data collection along the grade chain, cattle were railed out in the fabrication cooler to allow selection and tagging of strip loins and chucks. Approximately one half of the product collected was graded by the USDA grader as USDA Choice while the other half was graded as USDA Select. A total of 60 chuck rolls were collected from the right side, 30 from the CON diet and 30 from the WDGS diet. A total of 75 pairs of strip loins were selected and fabricated according to Institutional Meat Purchase Specifications (IMPS; USDA, 1996): 38 pairs of loins from the CON diet and 37 pairs from the WDGS diet. Product was vacuum packaged, boxed and immediately transported to the Oklahoma State University Robert M. Kerr Food and Agricultural Products Center (FAPC).

Sample Preparation, Ground Beef

Chuck rolls (n = 60) were processed and ground 3 d post harvest. Eight 0.23 kg samples of finely ground product were selected from each chuck. Four samples were placed in a styrofoam tray with a soaker pad and over-wrapped with a polyvinyl chloride (PVC) film. The other four samples were placed in plastic trays with a soaker pad and sealed in a high oxygen (HiO_2) modified atmosphere (approximately 70% O_2 and 30% CO_2). Modified atmosphere packaged products were placed in dark storage for 5 d at 4ºC before retail display, while all PVC products were immediately placed under retail lighting. A sample of ground product was collected from each chuck for fat analysis. Samples were powdered and analyzed via the Soxhlet extraction procedure.

Sample Preparation, Strip loins

After 14 d of aging at 4ºC one strip loin from each pair (n = 75 pairs; 38 CON, 37 WDGS) was injected with an enhancement solution (E). The other strip loin from the pair remained non-enhanced (NE). Strip loins were selected for injection by alternating left and right sides. Pump percentage was calibrated to be 10% of the initial strip loin weight. Enhanced strip loins from the first harvest were subsequently injected at an average of 12.05% of the initial weight. However, equipment was adjusted so E strip loins from the second harvest were injected to the target average of 10.02%. The enhancement solution consisted of Brifisol 750 (BK Guilini Corp., Simi Valley, CA), Cargill Hi-grade salt (Cargill, Inc., Minneapolis, MN), Vivox 4 Antioxidant (Vitiva, Markovci, Slovenia), Purasol HiPure P Plus (PURAC America, Lincolnshire, IL), Proliant B1301 Beef Stock (Proliant, Inc., Ankeny, IA), water, and ice. After injection, the E strip loins were allowed to equilibrate for 30 min before cutting steaks. Each strip loin (n = 150) was faced at the anterior end and nine 2.54 cm steaks were subsequently cut and packaged. The face steak was vacuum packaged and frozen in a blast freezer (-20ºC) for further pre-display thiobarbituric acid reactive (TBAR) substance analysis. The first two steaks were identified for Warner-Bratzler shear force (WBSF) analysis, the next two steaks were packaged for full retail display, the following two steaks were packaged for 3 d of retail display, the next steak was identified for MAP 1 d display. The final two steaks were cut in half and packaged alongside the four steaks identified for 3 d retail display and full retail display. These partial steaks were utilized in TBAR analysis. Half of these steaks (one from each category) was placed in a styrofoam tray with a soaker pad and over-wrapped with a PVC film. The other half of the steaks was placed in plastic trays on a soaker pad and sealed in a HiO_2 MAP package (approximately 70% O_2 and 30% CO_2). The MAP products were placed in dark storage for 5 d to simulate commercial transportation while the PVC products were immediately placed directly under retail lighting.

Simulated Retail Display

Products identified for retail display were placed in a coffin style display case which was maintained at an average temperature of 1.95 ± 1ºC, under continuous lighting conditions (Philips Delux Warm White Fluorescent lamps; Andover, MA). The surface of the meat was exposed to 807-1,614 lux for the entire period in retail display. Due to space restrictions, 28 packages of product which were color evaluated (approximately half CON diet and half WDGS diet) and ground beef reserved for sensory panels were placed in a separate room under the same retail lighting conditions and maintained at approximately 3.61 ± 1ºC.

Subjective Color Evaluation

A six person panel of trained Oklahoma State University personnel evaluated color subjectively every 12 h in retail display. Panelists were trained using Munsell color tiles (Gretagmacbeth, New Windsor, NY) and had to achieve a passing score before serving on the color panel. Panelists assigned scores to each package of ground beef for ground meat color using an 8-point scale (8 = light grayish-red pink or pale pink, 1 = very dark red or very grayish-pink) and for discoloration using a 7-point scale (7 = total discoloration [100%], 1 = no discoloration). Strip steaks were evaluated based on muscle color score, surface discoloration (% metmyoglobin), and overall acceptability. Muscle color was determined using an 8-point scale (8 = tan to brown, 1 = very bright red or pinkish red). Discoloration was depicted using a 7-point scale (7 = total discoloration [100%], 1 = no discoloration [0%]). Overall acceptability was evaluated based on an 8-point scale (8 = extremely desirable/acceptable, 1 = extremely undesirable/unacceptable). Since most retailers attempt to move steaks within 5 d, steaks were evaluated for 5 d then removed from the case. Product was then vacuum packaged and placed in the blast freezer for TBAR analysis, sensory analysis, or WBSF.

Objective Color Evaluation

Objective color was evaluated by measuring each steak using a HunterLab Miniscan XE spectrophotometer equipped with a 6 mm aperture (HunterLab Associates Inc., Reston, VA) following the procedures of the Commission Internationale de I'Eclairage (CIE, 1976) to determine color coordinate values for L* (brightness: 0 = black; 100 = white), a*(redness/greenness: positive values = red, negative values = green) and b* (yellowness/blueness: positive values = yellow, negative values = blue). Objective evaluation for PVC packaged steaks was taken upon time of initial retail display, 1 d in retail, 3 d in retail, and at 5 d in retail. Steaks which were MAP were evaluated immediately prior to packaging, before being placed in the retail case (referred to as 1 d), at 3 d retail display, and at 5 d retail display. At 1 d, 3 d, and 5 d MAP packages were sacrificed in order to obtain the readings. Three readings were obtained from each steak and were then averaged to get the final L*, a*, and b* values for each steak at each time of reading.

Warner-Bratzler Shear Force

From each strip, two steaks, one PVC packaged and one MAP, were designated for WBSF determination. After display, as described above, steaks were vacuum packaged and frozen until further analysis. Steaks were then allowed to temper at 4º C for 24 h prior to cooking. The steaks were cooked using an impingement oven (XLT Ovens, Model 3240TS2, BOFI, Wichita, KS) to an internal temperature of 70ºC. After cooking, steaks were allowed to cool for 24 h before determining shear force values.

After cooling, six cores from each steak were removed (1.27 cm in diameter) parallel to the muscle fiber orientation. Each core was sheared once using the Warner-Bratzler head on the Instron Universal Testing Machine (model 4502; Instron Corp., Canton, MA) at a cross head speed of 200 mm/min. Peak force (kg) of cores were recorded by an IBM PS2 (Model 55SX) using software provided by the Instron Corporation. Mean peak WBSF was then determined by averaging the six cores.

Sensory Evaluation

Steaks that remained in the retail case for 5 d were designated for sensory analysis and were randomly assigned a three digit number. Each session was randomized to include steaks from both diets and both E and NE groups. Steaks were tempered for 24 h prior to cooking then cooked as described above for WBSF. Immediately following cooking, steaks were cut into 1 cm x 1 cm x 2.54 cm pieces and placed into a cup with the corresponding three digit number. Cups were placed in individual warmers with heat pads in order to keep samples warm during the sensory session.

The sensory panel consisted of eight trained panelists (Cross et al., 1978) who were served the steaks under red lights. The panelists scored (AMSA, 1995) the steaks for initial and sustained juiciness (1 = extremely dry, 8 = extremely juicy), initial and overall tenderness (1 = extremely tough, 8 = extremely tender), and connective tissue amount (1 = abundant, 8 = none). Four flavor attributes were evaluated. These included beef flavor, painty/fishy, livery/metallic, and salty. The flavor intensity was scored on a 3-point scale (1= not detectable, 3 =strongly detectable). During sessions, panelists were randomly seated in individual booths in a temperature and light controlled room. Ten samples were served per session in a randomized order, which varied between panelists.

Distilled, deionized water and unsalted crackers were provided to each panelist to cleanse their palate between samples.

Sensory samples for ground beef were packed in replicate. Each ground beef sample was formed into 0.11 kg patties using a patty former, then cooked on the impingement oven as described above. Each patty was cut into eight equal sized wedges and served to the panelists. Ground beef product was evaluated for three flavor profiles: beef flavor, painty/fishy flavor, and livery/metallic flavor. Panelists were trained to evaluate flavors according to AMSA training methods (AMSA, 1995). Eleven samples of ground beef were served per session. A maximum of four sessions a day were conducted for all sensory panels, two in the morning and two in the afternoon. Any two consecutive panels were separated by a 10 to 15 min break.

Thiobarbituric Acid Reactive Substance (TBAR)

Upon removal from the retail case, steaks identified for TBAR analysis were vacuum packaged and frozen in a blast freezer at -20ºC. Products were either designated as pre-display (collected when steaks were fabricated), 1 d (MAP only), 3 d, or 5 d samples. Product was allowed to temper for 24 h prior to TBAR analysis. Lipid peroxidation was determined by a modified method of Buege and Aust (1978). First, a 10 g sample was selected from the product and placed in a waring blender to be homogenized with 30 ml of deionized water. The sample was then transferred to a disposable tube and centrifuged for 10 min at 3000 rpm and 2ºC. Two mL of the supernatant was extracted and placed in a disposable glass tube along with 4 ml of thiobarbituric acid/trichloroacetic acid (TBA/TCA) and 100 µl of butylated hydroxyanisol (BHA). This mixture was then vortexed, incubated in a boiling water bath for 10 min to develop color, then cooled for 15 min in a cold water bath. After cooling, the samples were vortexed for another 10 min at 3000 rpm at 23ºC. The absorbance of the supernatant was determined at 531 nm against standards which were developed each day.

Statistical Analysis

Data for steaks were analyzed using the mixed procedure of SAS as a completely randomized split plot design with carcass as the experimental unit (EU) and strip loin as the split plot. The analysis of variance (ANOVA) model for carcass data included treatment as the fixed effect and carcass identification number as the random effect.

Likewise, the analysis of variance model for WBSF, sensory, TBAR, and MAP packaged color attributes included treatment as the fixed effect, and strip identification number as random effect. Diet, enhancement and packaging method were treatment variables. The analysis of variance model for PVC samples for subjective and objective color attributes were analyzed using time as a repeated measure, sample as the subject, and treatment as the fixed effect. The ANOVA model for ground beef was set up in the same manner as the steaks for analysis of sensory, TBAR, and subjective color attributes. All ground beef was tested in replicate; thus the replicates were averaged together before analysis through SAS. For ground beef, diet and packaging method were treatment variables. Interactions were observed in all models. When the model was significant (α=0.05), least square means were computed and statistically separated using the pair-wise t-test (PDIFF option of SAS).

RESULTS AND DISCUSSION

Carcass Data

The effects of dietary treatment on carcass characteristics can be seen in Table 3.1. Carcasses from cattle fed the WDGS diet tended (P = 0.09) to have a higher HCW than cattle fed the CON diet. Al-Suwaiegh et al. (2002) found that HCW, FT, and YG were all higher in cattle fed wet distillers grain at the inclusion level of 30% than cattle fed dry rolled corn, but there were no differences between treatments in dressing percentage (DP), loin muscle area (LMA) and marbling score. In this study, carcasses from cattle fed the CON diet exhibited a tendency (P = 0.07) to have higher marbling scores than cattle fed the WDGS diet. In a study by Leibovich et al. (2009), cattle fed a normal steam flaked diet had lower marbling scores than those from cattle fed the normal dry rolled diet and the steam flaked diet which included 15% distillers products; marbling scores of carcasses fed a dry rolled corn diet with 15% distillers were not different from any of the other treatments. No differences were found in adjusted fat thickness, ribeye area, or yield grade in the current study (Table 3.1).

Color Evaluation

Upon removal of steaks from the case at 120 h, only 13% of the steaks were deemed moderately undesirable or less. At this time, the packaging by enhancement interactions for muscle color and overall acceptability were not different (Table 3.2). When observing package by enhancement interactions, in the enhanced MAP steaks cattle fed the WDGS diet discolored more (P = 0.01) than cattle fed the CON diet (Table 3.2).

According to subjective analysis, when looking only at packaging method (Table 3.3), muscle color of MAP steaks were significantly darker red ($P < 0.0001$) than PVC steaks and PVC steaks were more discolored than MAP steaks ($P = 0.03$) at 120 h. No significant differences were discovered in overall acceptability between packaging methods. Results of enhancement demonstrated that muscle color of E steaks was darker ($P < 0.0001$) than NE steaks. As shown in Table 3.3, panelists indicated that NE steaks were more discolored ($P < 0.0001$) than E steaks at the time of removal from the retail case. Concerning overall acceptability, E products were more desirable (P = 0.02) than NE products (Table 3.3) at 120 h. There were no differences in muscle color, discoloration, or overall acceptability between dietary treatments (Table 3.3). Gill et al. (2008) conducted a study in which results yielded no differences in visual appearance, but objective evaluation revealed that cattle fed DG in the diet either sorghum or corn, 15% inclusion) yielded steaks which were brighter, but less red overall than steaks from cattle fed simply steam flaked corn (SFC).

Ground beef was on average 81.29% lean. The leanest sample was 8.92% fat while the fattest sample was 29.68% fat. This large range in fat percentage may be due to several factors. While surface fat was trimmed on the chuck to fit IMPS within the plant, there was no attempt to standardize or control fat percentage of the end ground product. Also, there was no way to control the amount of intramuscular fat within the chucks of each animal. For these reasons, fat percentage within the ground beef samples varied widely. There were no differences in percent lean of CON product and WDGS product (data not shown in tabular form). Upon removal from the case at 120 h, only 11% of ground beef products exhibited greater than small discoloration (20-39%). Dietary treatment × packaging interactions revealed that there were no differences in ground meat color or discoloration of ground beef (Table 3.2). Likewise, no differences were found in ground meat color or discoloration when comparing dietary treatments, only. However, PVC ground beef did exhibit darker color ($P < 0.0001$) and more discoloration ($P < 0.01$) than MAP ground beef when removed from the case (Table 3.3).

Instrumental analysis of strip steak color at 120 h revealed no significant dietary treatment by enhancement interactions (Table 3.4) for L*, a*, and b* values of PVC steaks. There were also no significant differences in PVC steaks when observed by dietary treatment group (Table 3.5). Non-enhanced PVC steaks were brighter ($P < 0.0001$) and more yellow ($P < 0.0001$) than enhanced PVC steaks but there were no significant differences in a* value (Table 3.5). Objective color data on MAP steaks revealed that there were no significant interactive effects on 1 d or 3 d L* and a* values. However, analysis of MAP steaks revealed enhancement had a significant effect d 5 on L* values; MAP E CON steaks were significantly brighter than MAP E WDGS steaks (Table 3.4). Likewise, on 5 d, MAP NE WDGS steaks had higher a* values (were more red) than MAP NE CON steaks ($P = 0.01$). Significant diet × enhancement effects did occur in b* values on 1 d, 3 d, and 5 d NE MAP steaks (Table 3.4). On these d, in the NE MAP product, WDGS steaks were significantly more yellow than CON steaks. Differences could be seen in L* and b* values on all 3 d of readings when observing the enhanced treatment group and the dietary treatment group. Tables 3.5 and 3.6 show instrumental mean color data by treatment groups. Non-enhanced MAP steaks and WDGS MAP steaks were significantly brighter on all 3 d of readings than E and CON steaks, respectively. At 3 d and 5 d, NE MAP steaks were redder than E steaks and

WDGS MAP steaks were redder than CON MAP steaks (*P* < 0.05). Mean hunter values also indicated that, on all 3 d, WDGS MAP steaks were more yellow (*P* < 0.05) than control MAP steaks. Non-enhanced steaks were also more yellow (*P* < 0.05) than enhanced steaks for all 3 d of instrumental analysis. A study by Gill et al. (2008) found that steaks from cattle fed distillers grains in the diet were brighter, but less red then steaks from cattle fed a normal SFC diet. There were no significant differences in L*, a*, or b* values between CON PVC and WDGS PVC steaks throughout the entire period in the retail case. The use of MAP may have been the reason that steaks were significantly redder, unlike in the study by Gill et al. (2008).

Tenderness and Sensory Evaluation - Strip Steaks

Warner-Bratzler shear force values for packaging by enhancement interactions are presented in Table 3.7. The packaging × enhancement interaction indicated no differences in product from the CON and WDGS diets. However, WBSF values did indicate MAP products were significantly (*P* < 0.0001) tougher than PVC products and NE steaks were significantly (*P* < 0.0001) tougher than E steaks (Table 3.8). Gill et al. (2008) also found no differences in instrumental tenderness when comparing a SFC diet to a diet containing 15% DG.

Sensory panel findings indicated that there were some significant differences between dietary treatments in packaging × enhancement interactions for juiciness and tenderness. Table 3.9 presents findings for packaging × enhancement interactions of juiciness characteristics. Distillers products were ranked higher for initial juiciness than CON diet within the NE PVC products (*P* = 0.03). Products derived from the CON diet carcasses had a higher sustained juiciness than other treatments in the NE MAP grouping

(P = 0.04). Findings of tenderness characteristics for packaging x enhancement interactions are presented in Table 3.10. Distillers steaks were rated as significantly more tender upon first impression and overall tenderness when they were NE and PVC overwrapped (P < 0.0001). Distillers products contained less connective tissue than the CON when NE and PVC packaged (Table 3.10). Results indicated that there were no significant interactions in flavor intensities (Table 3.11).

When evaluating data by treatment group, E products were ranked as significantly juicier and more tender than NE products (Table 3.12 and Table 3.13). Likewise, PVC products were significantly juicier than MAP products, but no differences in tenderness characteristics were found. Flavor intensity data are outlined in Table 3.14. Non-enhanced products were ranked significantly higher on beef flavor intensity, painty/fishy flavors, and livery/metallic flavors than E products. Enhanced products were significantly more salty than NE products (P < 0.0001). No differences in any of the flavors were found between packaging method or between WDGS and CON diets by sensory panelists. In consumer panels in a study by Roeber et al. (2005), steaks from steers fed at 25% wet distillers grains received the highest numerical tenderness and juiciness steaks from steers fed 50% wet distillers grains received the lowest numerical tenderness and juiciness scores. This may indicate that a 25% inclusion rate is the threshold. Roeber et al. (2005) also reported that flavor ratings did not differ among treatments.

Sensory Evaluation - Ground Beef

Sensory panelists ranked WDGS MAP ground beef as having less beefy and more painty flavor intensities than CON MAP products (Table 3.15). Zakrys et al. (2009)

found that oxidation flavors increased in high oxygen packed samples. Consumer panelists found products packed under 50% O_2 to be the most acceptable, followed by samples packed under 80% O_2 (Zakrys et al., 2009). Zakrys et al. (2009) suggested that this may be due to adaptation to or familiarity with oxidized flavors by panelists. No interactions were found among livery flavors in the current study. Ground beef in MAP exhibited a significantly greater beef flavor and less painty flavor than PVC ground beef ($P < 0.0001$). Ground beef from the CON chucks exhibited a more livery flavor than ground beef from WDGS chucks (Table 3.15).

Thiobarbituric Acid Reactive Substance Analysis

Dietary treatments did not have an effect on lipid oxidation as indicated by TBAR concentrations when strips were packaged with PVC overwrap (Table 3.16). On 5 d of retail display of MAP steaks, NE product from the WDGS diet cattle were more oxidized than the product from the CON group. All NE products oxidized significantly faster than E products ($P < 0.05$) with the exception of PVC steaks removed on 3 d of retail display. Ground beef products showed no differences in TBAR concentrations for either MAP or PVC packaged items (Table 3.16). In the previously mentioned study by Gill et al. (2008), TBAR concentrations also indicated that diet (SFC vs. 15% DG) had no effect on lipid oxidation. Campo et al. (2006) reported a TBAR value of 2.28 mg/kg as the limiting threshold for consumer acceptability of oxidation in beef. At a TBAR value of 2.28, the perception of rancidity overpowers the perception of beef flavor (Campo et al., 2006). All TBAR values in this study were well below this threshold.

CONCLUSION

Based on the results of this study, feeding distillers grains will not have an effect on carcass characteristics. Results indicated that MAP packaging, but not enhancing, products from cattle fed WDGS may be the best way to maintain a visually appealing appearance in the retail case, but at a possible risk to product juiciness. If enhanced and MAP packaged, the distillers product does not seem to maintain visual appearance in the retail case like the control product. Non-enhanced WDGS steaks which had been PVC packaged were initially and overall more tender than CON steaks and contained less connective tissue. The lower degree of connective tissue in the WDGS steaks contributed to the overall greater tenderness in comparison to CON steaks. Visual appearance of ground beef seemed to be positively impacted by using the MAP method of packaging, but the product tasted more oxidized and less beefy to panelists.

Results by treatment group revealed that enhancement showed the greatest significant differences. Enhanced products had darker, less bright, and less yellow colors in the retail case, but discolored slower resulting in greater overall acceptability, visually, than the non-enhanced products. Sensory and tenderness findings indicated that enhanced steaks are more tender instrumentally and according to trained panelists. Enhanced products were also juicier, less beef, painty, and livery flavored but more salty than non-enhanced products. Analysis of lipid oxidation via TBAR concentration indicated that from pre-display to 5 d retail display, enhanced products were less oxidized than non-enhanced products. Concerning packaging, MAP steaks were darker colored, but less discolored than PVC steaks. Sensory panelists indicated that MAP steaks were both less juicy and less tender than PVC steaks. While it is clear that enhancement has a significant effect on color and palatability, further research is needed to pin point the best combination of post-harvest interventions to preserve color and palatability in beef from cattle fed WDGS.

Table 2.1. Major packaging types and characteristics for fresh retail meat as described by McMillen (2008).

Package	Air-permeable overwrap	Air-permeable overwrap in master pack	Vacuum skin packaging (VSP)	Low O_2 with CO_2 and N_2	Peelable VSP or low O_2 with CO_2: N_2	Low O_2 with CO	High O_2
System description	Air-permeable film overwrap of product on tray; product displayed in package	Barrier bag with single or multiple trays of product in air-permeable packaging; trays removed for retail display	Flexible film shrunk around product on a rigid base web; product displayed in package	Thermoformed or preformed trays with lidding film; may be a master pack for product in air-permeable packages	VSP or barrier tray with 2 layer lidding film; outer barrier film peeled from inner permeable film before product display	VSP; may be thermoformed or preformed tray with lidding film; product displayed in package	Thermoformed or preformed tray with lidding film; product displayed in package
Gases in headspace	Atmosphere air	Usually CO_2 and/or N_2 in master pack	No gas headspace	CO_2 and/or N_2	No headspace with VSP; CO_2 and/or N_2	CO_2 and/or N_2; no headspace with VSP	O_2 and CO_2; often 80% O_2:20% CO_2
O_2 scavengers	none	Recommended	Sometimes	Recommended	Recommended	Recommended	None
Meat color in storage	Red	Purple	Purple	Purple	Purple	Red	Red
Meat color for display	Red	Red	Purple	Purple; red after removal from master pack	Red	Red	Red
Whole muscle shelf life, d at 4 °C	5–7	10–14	60–90	30–60	30–45	35	12–16
Minced or ground shelf life, d at 4 °C	2–3	7–10	45–60	20–40	20–30	28	10–12
Display life, d	2–7	2–7	30–60	15–40	2–7	28–35	7–16
Drip loss, %	8–10	3–5	2–5	1–5	0–7	1–7	0–5
Advantages	Consumers familiar with packaging; high product visibility; lowest cost; multiple sizes on same equipment	Storage life extended before display	Long storage life before display; high product visibility	Long storage life before display	Long storage life before display; high product visibility with VSP	Long red color stability and no lipid oxidation; high product visibility with VSP	Moderate red color stability
Disadvantages	Short display life; leaky package if bottom sealed rather than tube sealed at ends	Double packaging costs; short display life; reblooming after air exposure may be inconsistent	Display with purple color	Purple display color in MAP scavengers increase costs; bloom may be inconsistent on exposure to air after removal from MAP increased cost with master pack	Film peeling at retail store; may be mottling or inconsistent bloomed color after air exposure; short display life; increased package and scavenger costs	Negative image by consumers; concern red products may be spoiled in other factors; scavengers increase costs; cooked meat color may be pink	Lipid oxidation; may be bone darkening or decreased tenderness; headspace required; may be premature browning of cooked meat

Table 3.1. Least squares means ± SEM for carcass data[1].

Treatment[2]	Hot carcass wt., kg	Adj. fat thickness,cm.	Ribeye area, sq. cm	Marbling Score[3]	Yield Grade
Control	322.38 ± 2.96	1.50 ± 0.05	32.92 ± 0.48	428.16 ± 7.40	2.44 ±0.11
30% WDGS	329.44 ± 2.93	1.57 ± 0.05	32.36 ± 0.48	409.31 ± 7.40	2.63 ± 0.11
P > F[4]	0.09	0.36	0.42	0.07	0.22

[1] n = 240

[2] Treatment: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles

[3] Marbling: 100 = practically devoid^{00}, 200 = traces^{00}, 300 = slight^{00}, 400 = small^{00}, 500 = modest^{00}, 600 = moderate^{00}

[4] $\alpha = 0.05$

Table 3.2. Least squares means ± SEM for subjective color evaluation at 120 h for strip steaks (n = 296) and ground beef (n = 240) by post–harvest interventions stratified by dietary treatments.

Product	Post-Harvest Interventions[1]	Treatment[2]	Color[3]	*P* > F[4]	Discoloration[5]	*P* > F[4]	Overall Acceptability[6]	*P* > F[4]
Strip Steaks	Enhanced MAP	Control	5.35 ± 0.07	0.07	1.16 ± 0.03	0.01	4.68 ± 0.10	0.65
		30% WDGS	5.52 ± 0.07		1.28 ± 0.03		4.43 ± 0.09	
	Enhanced PVC	Control	4.77 ± 0.07	0.72	1.17 ± 0.03	0.65	4.73 ± 0.06	0.64
		30% WDGS	4.80 ± 0.07		1.16 ± 0.03		4.77 ± 0.06	
	Non-enhanced MAP	Control	4.62 ± 0.18	0.63	1.85 ± 0.12	0.18	4.44 ± 0.20	0.37
		30% WDGS	4.53 ± 0.09		1.67 ± 0.06		4.64 ± 0.10	
	Non-enhanced PVC	Control	3.96 ± 0.10	0.92	1.99 ± 0.11	0.40	4.39 ± 0.13	0.97
		30% WDGS	3.97 ± 0.10		2.11 ± 0.11		4.38 ± 0.13	
Ground Beef	MAP	Control	3.95 ± 0.10	0.52	2.07 ± 0.11	0.30		
		30% WDGS	4.04 ± 0.10		1.92 ± 0.11			
	PVC	Control	3.74 ± 0.06	0.21	2.16 ± 0.21	0.12		
		30% WDGS	3.62 ± 0.06		2.62 ± 0.21			

[1]Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatment: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3] Steak muscle color: 1 = very bright red or pinkish red, 8 = tan to brown; Ground meat color: 1 = very dark red or very grayish-pink, 8 = light grayish-red or pale pink.
[4] $\alpha = 0.05$.
[5]Discoloration: 1 = None (0%), 7 = Total Discoloration (100%).
[6]Overall Acceptability: 1 = extremely undesirable/unacceptable, 8 = Extremely desirable/acceptable.

Table 3.3. Least squares means ± SEM for subjective color evaluation at 120 h for strip steaks (n = 296) and ground beef (n = 240) by overall treatment and post-harvest intervention groups.

Product	Treatments[1]		Color[2]	P > F[3]	Discoloration[4]	P > F[3]	Overall Acceptability[5]	P > F[3]
Strip Steaks	Post-Harvest Handling	Enhanced	5.11 ± 0.05	<0.0001	1.20 ± 0.04	<0.0001	4.65 ± 0.06	0.02
		Non-enhanced	4.25 ± 0.05		1.88 ± 0.04		4.49 ± 0.06	
	Packaging	MAP	4.99 ± 0.06	<0.0001	1.46 ± 0.05	0.03	4.58 ± 0.06	0.88
		PVC	4.38 ± 0.06		1.61 ± 0.05		4.57 ±0.06	
	Diet	Control	4.68 ± 0.07	0.93	1.49 ± 0.05	0.23	4.55 ± 0.07	0.69
		30% WDGS	4.69 ± 0.06		1.57 ± 0.04		4.58 ± 0.06	
Ground Beef	MAP vs PVC	MAP	3.99 ± 0.06	<0.0001	1.99 ± 0.12	0.01		
		PVC	3.67 ± 0.07		2.39 ± 0.12			
	Control vs 30% WDGS	Control	3.84 ± 0.07	0.93	2.11 ± 0.13	0.40		
		30% WDGS	3.83 ± 0.07		2.27 ± 0.13			

[1] Treatments/Interventions: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Steak muscle color: 1 = very bright red or pinkish red, 8 = tan to brown; Ground meat color: 1 = very dark red or very grayish-pink, 8 = light grayish-red or pale pink.
[3] $\alpha = 0.05$.
[4]Discoloration: 1 = None (0%), 7 = Total Discoloration (100%).
[5]Overall Acceptability: 1 = extremely undesirable/unacceptable, 8 = Extremely desirable/acceptable.

Table 3.4. Least squares means ± SEM for objective color evaluation at 120 h of strip steaks (n = 296) by post-harvest interventions stratified by dietary treatments.

Post-Harvest Interventions[1]	Treatment[2]	L* [3]	*P* > F[4]	a* [5]	*P* > F[4]	b* [6]	*P* > F[4]
Enhanced MAP	Control	38.12 ± 0.34	0.04	21.21 ± 0.22	0.30	15.78 ± 0.16	0.41
	30 % WDGS	37.15 ± 0.33		21.53 ± 0.21		15.60 ± 0.16	
Enhanced PVC	Control	33.59 ± 0.42	0.35	20.47 ± 0.26	0.16	17.20 ± 0.25	0.43
	30 % WDGS	33.04 ± 0.42		21.01 ± 0.26		17.48 ± 0.25	
Non-enhanced MAP	Control	41.80 ± 0.57	0.14	21.09 ± 0.55	0.01	17.13 ± 0.28	0.01
	30 % WDGS	42.74 ± 0.28		22.73 ± 0.26		17.96 ± 0.14	
Non-enhanced PVC	Control	38.50 ± 0.45	0.61	21.51 ± 0.42	0.40	18.62 ± 0.32	0.33
	30 % WDGS	38.17 ± 0.45		21.00 ± 0.42		18.18 ± 0.32	

[1]Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatment: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3]Mean Hunter Values for color of steaks where L* = brightness (0 = black, 100 = white).
[4] $\alpha = 0.05$.
[5]Mean Hunter Values for color of steaks where a* = redness (positive values = red, negative values = green).
[6]Mean Hunter Values for color of steaks where b* = yellowness (positive values = yellow, negative values = blue).

Table 3.5. Least squares means ± SEM for objective color evaluation at d 1, d 3, and d 5 of PVC packaged strip steaks (n = 148) by treatment groups.

Time	Treatments[1]		L*[2]	*P* > F[3]	a*[4]	*P* > F[3]	b*[5]	*P* > F[3]
D 1	Post-Harvest Handling	Enhanced	34.46 ± 0.29	< 0.0001	22.67 ± 0.20	< 0.0001	18.49 ± 0.22	< 0.0001
		Non-enhanced	39.40 ± 0.29		24.13 ± 0.20		19.77 ± 0.22	
	Diet	Control	37.07 ± 0.41	0.61	23.23 ± 0.24	0.32	19.05 ± 0.26	0.69
		30 % WDGS	36.78 ± 0.41		23.57 ± 0.24		19.20 ± 0.26	
D 3	Post-Harvest Handling	Enhanced	33.81 ± 0.29	< 0.0001	21.68 ± 0.18	< 0.0001	17.34 ± 0.20	< 0.0001
		Non-enhanced	39.20 ± 0.29		23.16 ± 0.18		18.40 ± 0.20	
	Diet	Control	36.55 ± 0.43	0.95	22.24 ± 0.20	0.19	18.60 ± 0.21	0.37
		30 % WDGS	36.55 ± 0.43		22.62 ± 0.20		18.86 ± 0.21	
D 5	Post-Harvest Handling	Enhanced	33.31 ± 0.31	< 0.0001	20.74 ± 0.25	0.07	17.34 ± 0.20	< 0.0001
		Non-enhanced	38.33± 0.31		21.25 ± 0.25		18.40 ± 0.20	
	Diet	Control	35.04 ± 0.42	0.47	20.98 ± 0.29	0.98	17.91 ± 0.23	0.81
		30 % WDGS	35.60 ± 0.42		21.00 ± 0.29		17.83 ± 0.23	

[1]Treatments: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles, PVC = polyvinyl chloride overwrap.
[2]Mean Hunter Values for color of steaks where L* = brightness (0 = black, 100 = white).
[3] $\alpha = 0.05$.
[4]Mean Hunter Values for color of steaks where a* = redness (positive values = red, negative values = green).
[5]Mean Hunter Values for color of steaks where b* = yellowness (positive values = yellow, negative values = blue).

Table 3.6. Least squares means ± SEM for objective color evaluation at d 1, d 3, and d 5 of MAP packaged strip steaks (n = 148) by treatment groups.

Time	Treatments[1]		L*[2]	*P* > F[3]	a*[4]	*P* > F[3]	b*[5]	*P* > F[3]
D 1	Post-Harvest Handling	Enhanced	38.66 ± 0.25	< 0.0001	22.39 ± 0.17	0.09	17.09 ± 0.10	< 0.0001
		Non-enhanced	43.93 ± 0.25		22.70 ± 0.17		18.69 ± 0.10	
	Diet	Control	39.86 ± 0.50	0.001	22.24 ± 0.23	0.08	17.42 ± 0.18	0.001
		30 % WDGS	41.86 ± 0.32		22.67 ± 0.16		18.07 ± 0.11	
D 3	Post-Harvest Handling	Enhanced	39.43 ± 0.23	< 0.0001	21.45 ± 0.17	< 0.0001	16.57 ± 0.11	< 0.0001
		Non-enhanced	43.22 ± 0.23		22.48 ± 0.17		18.14 ± 0.10	
	Diet	Control	40.45 ± 0.26	0.01	21.42 ± 0.16	0.01	16.86 ± 0.18	0.01
		30 % WDGS	40.46 ± 0.42		22.18 ± 0.16		17.55 ± 0.11	
D 5	Post-Harvest Handling	Enhanced	37.62 ± 0.25	< 0.0001	21.38 ± 0.21	< 0.0001	15.69 ± 0.12	< 0.0001
		Non-enhanced	42.56 ± 0.25		22.42 ± 0.21		17.80 ± 0.12	
	Diet	Control	39.15 ± 0.45	0.01	21.14 ± 0.26	0.0001	16.16 ± 0.20	0.01
		30 % WDGS	40.57 ± 0.45		22.29 ± 0.20		17.04 ± 0.14	

[1]Treatments: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles, MAP = modified atmosphere packaging.
[2]Mean Hunter Values for color of steaks where L* = brightness (0 = black, 100 = white).
[3] $\alpha = 0.05$.
[4]Mean Hunter Values for color of steaks where a* = redness (positive values = red, negative values = green).
[5]Mean Hunter Values for color of steaks where b* = yellowness (positive values = yellow, negative values = blue).

Table 3.7. Least squares means ± SEM for Warner-Bratzler Shear (WBS) force of strip steaks (n = 291) by post-harvest interventions stratified by dietary treatments.

Post-Harvest Interventions[1]	Treatment[2]	WBS (kg)	P > F[3]
Enhanced MAP	Control	2.36 ± 0.06	0.59
	30 % WDGS	2.32 ± 0.06	
Enhanced PVC	Control	2.09 ± 0.05	0.88
	30 % WDGS	2.07 ± 0.05	
Non-enhanced MAP	Control	3.73 ± 0.14	0.23
	30 % WDGS	3.49 ± 0.14	
Non-enhanced PVC	Control	3.03 ± 0.09	0.87
	30 % WDGS	3.01 ± 0.09	

[1]Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatment: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3] $\alpha = 0.05$.

Table 3.8. Least squares means ± SEM for Warner-Bratzler Shear (WBS) Force for strip steaks (n = 291) by overall treatment and post-harvest intervention groups.

Treatments[1]		WBS (kg)	$P > F$[2]
Post-Harvest Handling	Enhanced	2.21 ± 0.05	<0.0001
	Non-enhanced	3.32 ± 0.05	
Packaging	MAP	2.98 ± 0.07	<0.0001
	PVC	2.55 ± 0.07	
Diet	Control	2.81 ± 0.07	0.34
	30 % WDGS	2.72 ± 0.07	

[1]Treatments/Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap, Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[2] $\alpha = 0.05$.

Table 3.9. Least squares means ± SEM for sensory juiciness ratings of strip steaks (n =296) by post-harvest interventions stratified by dietary treatments.

Post-Harvest Interventions[1]	Treatment[2]	Initial Juiciness[3]	*P* > F[4]	Sustained Juiciness[3]	*P* > F[4]
Enhanced MAP	Control	5.39 ± 0.07	0.24	5.17 ± 0.08	0.17
	30 % WDGS	5.51 ± 0.07		5.32 ± 0.08	
Enhanced PVC	Control	5.83 ± 0.05	0.17	5.63 ± 0.05	0.75
	30 % WDGS	5.93 ± 0.05		5.65 ± 0.05	
Non-enhanced MAP	Control	4.77 ± 0.08	0.10	4.51 ± 0.09	0.04
	30 % WDGS	4.58 ± 0.08		4.26 ± 0.09	
Non-enhanced PVC	Control	5.06 ± 0.07	0.03	4.74 ± 0.08	0.12
	30 % WDGS	5.30 ± 0.07		4.91 ± 0.07	

[1]Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatment: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3]Juiciness: 1= extremely dry, 8 = extremely juicy.
[4] $\alpha = 0.05$.

Table 3.10. Least squares means ± SEM for sensory tenderness ratings of strip steaks (n = 296) by post-harvest interventions stratified by dietary treatments.

Post-Harvest Interventions[1]	Treatment[2]	First Impression Tenderness[3]	*P* > F[4]	Overall Tenderness[3]	*P* > F[4]	Connective Tissue[5]	*P* > F[4]
Enhanced MAP	Control	6.07 ± 0.07	0.40	6.17 ± 0.07	0.43	6.28 ± 0.07	0.50
	30 % WDGS	6.15 ± 0.07		6.25 ± 0.07		6.34 ± 0.07	
Enhanced PVC	Control	6.29 ± 0.05	0.70	6.36 ± 0.05	0.58	6.41 ± 0.05	0.49
	30 % WDGS	6.32 ± 0.05		6.40 ± 0.05		6.46 ± 0.05	
Non-enhanced MAP	Control	5.46 ± 0.08	0.31	5.59 ± 0.07	0.54	5.82 ± 0.07	0.50
	30 % WDGS	5.57 ± 0.08		5.65 ± 0.07		5.89 ± 0.07	
Non-enhanced PVC	Control	5.37 ± 0.05	<0.0001	5.45 ± 0.05	<0.0001	5.73 ± 0.43	0.001
	30 % WDGS	5.49 ± 0.05		5.58 ± 0.05		5.86 ± 0.43	

[1]Intervention: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatments: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3]Tenderness: 1= extremely tough, 8 = extremely tender.
[4] $\alpha = 0.05$.
[5]Connective Tissue: 1 = abundant, 8 = none.

Table 3.11. Least squares means ± SEM for sensory flavor intensities of strip steaks (n = 296) by post-harvest interventions stratified by dietary treatments.

Post-Harvest Interventions[1]	Treatment[2]	Beef Flavor[3]	*P* > F[4]	Painty/ Fishy Flavor[3]	*P* > F[4]	Livery/ Metallic Flavor[3]	*P* > F[4]	Salty Flavor[3]	*P* > F[4]
Enhanced MAP	Control	1.66 ± 0.04	0.91	1.07 ± 0.03	0.40	1.06 ± 0.02	0.80	2.25 ± 0.07	0.31
	30 % WDGS	1.66 ± 0.04		1.11 ± 0.03		1.07 ± 0.02		2.35 ± 0.07	
Enhanced PVC	Control	1.53 ± 0.03	0.62	1.03 ± 0.01	0.07	1.09 ± 0.02	0.48	2.48 ± 0.04	0.60
	30 % WDGS	1.51 ± 0.03		1.06 ± 0.01		1.06 ± 0.02		2.52 ± 0.04	
Non-enhanced MAP	Control	2.19 ± 0.03	0.44	1.17 ± 0.03	0.88	1.15 ± 0.02	0.43	1.02 ± 0.02	0.25
	30 % WDGS	2.15 ± 0.03		1.18 ± 0.03		1.18 ± 0.02		1.00 ± 0.02	
Non-enhanced PVC	Control	2.43 ± 0.03	0.63	1.16 ± 0.02	0.63	1.18 ± 0.02	1.00	1.00 ± 0.01	0.51
	30 % WDGS	2.42 ± 0.03		1.17 ± 0.02		1.18 ± 0.02		1.01 ± 0.01	

[1]Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatment: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3]Flavor Intensity: 1 = not detectable, 3 = strongly detectable.
[4] $\alpha = 0.05$.

Table 3.12. Least squares means ± SEM for sensory juiciness ratings for strip steaks (n = 296) categorized by overall treatment and post-harvest intervention groups.

Treatments[1]		Initial Juiciness[2]	*P* > F[3]	Sustained Juiciness[2]	*P* > F[3]
Post-Harvest Handling	Enhanced	5.67± 0.04	<0.0001	5.45 ± 0.04	<0.0001
	Non-enhanced	4.93 ± 0.04		4.61 ± 0.04	
Packaging	MAP	5.06 ± 0.05	<0.0001	4.82 ± 0.05	<0.0001
	PVC	5.53 ± 0.05		5.24 ± 0.05	
Diet	Control	5.26 ± 0.05	0.34	5.17 ± 0.08	0.70
	30 % WDGS	5.33 ± 0.05		5.32 ± 0.08	

[1]Treatments/Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride. overwrap, Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[2]Juiciness: 1= extremely dry, 8 = extremely juicy.
[3] $\alpha = 0.05$.

Table 3.13. Least squares means ± SEM for sensory tenderness ratings for strip steaks (n = 296) categorized by overall treatment and post-harvest intervention groups.

Treatments[1]		First Impression Tenderness[2]	*P* > F[3]	Overall Tenderness[2]	*P* > F[3]	Connective Tissue Amount[4]	*P* > F[3]
Post-Harvest Handling	Enhanced	6.21 ± 0.04	<0.0001	6.30 ± 0.04	<0.0001	6.38 ± 0.03	<0.0001
	Non-enhanced	5.47 ± 0.04		5.57 ± 0.04		5.82 ±0.03	
Packaging	MAP	5.82 ± 0.05	0.45	5.92 ± 0.05	0.63	6.09 ± 0.04	0.64
	PVC	5.87 ± 0.05		5.95 ± 0.05		6.11 ± 0.04	
Diet	Control	5.80 ± 0.05	0.18	5.89 ± 0.05	0.24	6.06 ± 0.04	0.11
	30 % WDGS	5.88 ± 0.05		5.97 ± 0.05		6.14 ± 0.04	

[1]Treatments/Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap, Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[2]Tenderness: 1= extremely tough, 8 = extremely tender.
[3] $\alpha = 0.05$.
[4]Connective Tissue: 1 = abundant, 8 = none.

Table 3.14. Least squares means ± SEM for sensory flavor intensities for strip steaks (n =296) categorized by overall treatment and post-harvest intervention groups.

Treatments[1]		Beef Flavor[2]	*P* > F[3]	Painty/ Fishy Flavor[2]	*P* > F[3]	Livery/ Metallic Flavor[2]	*P* > F[3]	Salty Flavor[2]	*P* > F[3]
Post-Harvest Handling	Enhanced	1.59 ± 0.02	<0.0001	1.07 ± 0.01	<0.0001	1.07 ± 0.01	<0.0001	2.40 ± 0.02	<0.0001
	Non-enhanced	2.30 ± 0.02		1.17 ± 0.01		1.17 ± 0.01		1.01 ± 0.02	
Packaging	MAP	1.91 ± 0.04	0.92	1.13 ± 0.01	0.16	1.11 ± 0.01	0.45	1.66 ± 0.06	0.28
	PVC	1.97 ± 0.04		1.11 ± 0.01		1.13 ± 0.01		1.75 ± 0.06	
Diet	Control	1.95 ± 0.04	0.82	1.11 ± 0.01	0.15	1.12 ± 0.01	0.82	1.69 ± 0.06	0.66
	30 % WDGS	1.94 ± 0.04		1.13 ± 0.01		1.12 ± 0.01		1.73 ± 0.06	

[1]Treatments/Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap, Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.

[2]Flavor Intensity: 1 = not detectable, 3 = strongly detectable.

[3] $\alpha = 0.05$.

Table 3.15. Least squares means ± SEM for ground beef (n = 239) sensory flavor intensities categorized by treatment group and by packaging method stratified by dietary treatments.

Treatments[1]		Beef Flavor[2]	*P* > F[3]	Painty/Fishy Flavor[2]	*P* > F[3]	Livery/ Metallic Flavor[2]	*P* > F[3]
Packaging	MAP	2.27 ± 0.03	<0.0001	1.51 ± 0.04	<0.0001	1.22 ± 0.02	0.09
	PVC	1.88 ± 0.03		1.91 ± 0.04		1.19 ± 0.02	
Diet	Control	2.08 ± 0.04	0.59	1.71 ± 0.04	0.90	1.88 ± 0.02	0.04
	30 % WDGS	2.05 ± 0.04		1.72 ± 0.04		1.22 ± 0.02	
Diet x Packaging Interaction							
MAP	Control	2.33 ± 0.04	0.05	1.43 ± 0.04	0.01	1.20 ± 0.02	0.10
	30 % WDGS	2.22 ± 0.04		1.59 ± 0.04		1.25 ± 0.02	
PVC	Control	1.83 ± 0.04	0.45	1.99 ± 0.05	0.06	1.17 ± 0.02	0.19
	30 % WDGS	1.88 ± 0.04		1.84 ± 0.05		1.21 ± 0.02	

[1]Packaging methods: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap; Treatments: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[2]Flavor Intensity: 1 = not detectable, 3 = strongly detectable.
[3] $\alpha = 0.05$.

Table 3.16. Least squares means ± SEM of thiobarbituric acid reactive substances (TBAR; mg of malonaldehyde/kg of beef) measured pre-display, 1 d, 3 d, and 5 d.

Product	Post-Harvest Interventions[1]	Treatment[2]	Pre-Display Strips[3]	MAP			PVC	
				1 d[4]	3 d[5]	5 d[6]	3 d[7]	5 d[8]
Strip Steaks	Enhanced	Control	0.1904 ± 0.0004	0.1915 ± 0.002	0.2025 ± 0.005	0.1973 ± 0.008	0.1999 ± 0.001	0.1916 ± 0.001
		30% WDGS	0.1913 ± 0.0006	0.1939 ± 0.003	0.1948 ± 0.008	0.2215 ± 0.014	0.2003 ± 0.002	0.1918 ± 0.002
		P > F[9]	0.26	0.53	0.44	0.14	0.89	0.94
	Non-enhanced	Control	0.1956 ± 0.0009	0.2085 ± 0.003	0.2413 ± 0.011	0.2244 ± 0.004	0.2018 ± 0.001	0.2604 ± 0.003
		30% WDGS	0.1974 ± 0.0016	0.2065 ± 0.005	0.2601 ± 0.019	0.2475 ± 0.006	0.2023 ± 0.002	0.2143 ± 0.004
		P > F[9]	0.31	0.74	0.40	0.02	0.85	0.12
Ground Beef	---	Control	---	---	---	0.2071 ± 0.003	---	0.2001 ±0.002
		30% WDGS	---	---	---	0.2114 ± 0.004	---	0.1994 ± 0.003
		P > F[9]	---	---	---	0.39	---	0.84

[1]Interventions: MAP = modified atmosphere packaging, PVC = polyvinyl chloride overwrap.
[2]Treatments: Control = dry rolled corn diet, WDGS = wet distillers grains plus solubles.
[3]n = 148.
[4]n = 142.
[5]n = 145.
[6]n = 148 (strip steaks); n = 120 (ground beef).
[7]n = 144.
[8]n = 148 (strip steaks); n = 118 (ground beef).
[9] $\alpha = 0.05$.

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VITA

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Master of Science

Thesis: THE IMPACT OF POST-HARVEST INTERVENTIONS ON THE COLOR STABILITY, AND SUBSEQUENTLY, THE PALATABILITY, OF BEEF FROM CATTLE FED WET DISTILLERS GRAINS

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Major Field: Animal Science

Scope and Method of Study: Due to more frequent use of distillers grains (DG) in fed cattle diets, further research on its effect on beef products has been required. The objective of the study was to determine the impact of using post-harvest interventions on the color stability of beef products from cattle fed wet distillers grains and whether these interventions affected palatability after retail 1 d, 3 d, and 5 d retail display. Heifers (n = 240) were assigned to one of two diets: a control diet of dry rolled corn (CON) or a diet including 30% wet distillers grains plus solubles (WDGS). After carcass data collection, chuck rolls (n = 60) and paired strip loins (n = 75 pairs) were collected. Chuck rolls were ground, packed using either polyvinyl chloride (PVC) overwrap or modified atmosphere packaging (MAP) and identified for simulated retail display, sensory panel analysis, and thiobarbituric acid reactive substance analysis (TBAR). One strip loin from each pair was injected with an enhancement solution and all strips were sliced into 2.54 cm steaks. Steaks were packed using either PVC or MAP and subsequently identified for 1 d, 3 d, or 5 d simulated retail display, sensory panel, Warner- Bratzler Shear Force (WBSF) analysis, or TBAR analysis.

Findings and Conclusions: Based on the results of this study, feeding distillers grains will not have an effect on carcass characteristics. Results indicated that MAP packaging, but not enhancing, products from cattle fed 30% WDGS may be the best way to maintain a visually appealing appearance in the retail case, but at a possible risk to product juiciness. If enhanced and MAP packaged, the distillers product does not seem to maintain visual appearance in the retail case like the control product. Non-enhanced WDGS steaks which had been PVC packaged were initially and overall more tender then CON steaks and contained less connective tissue. Visual appearance of ground beef seemed to be positively impacted by using the MAP method of packaging, but the product tasted more oxidized and less beefy to panelists. While it is clear that enhancement has a significant effect on color and palatability, further research is needed to pin point the best combination of post-harvest interventions to preserve color and palatability in beef from cattle fed WDGS.

ADVISER'S APPROVAL: Deb VanOverbeke