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Effect of Wet Brewer's Grain Inclusion on the Growth Performance, Carcass Performance, and Meat Quality of Finishing Cattle

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53 Pages

The objective of this study was to determine the effects of Wet Brewer’s Grains (WBG) on the growth performance, carcass performance, and meat quality of finishing cattle. Twenty-four (n=24; 12 heifers, 12 steers) beef calves of Simmental-Angus genetics, heifers weighing approximately 303kg and steers weighing approximately 346kg, were utilized and finished at the Illinois State University (ISU) Farm. Animals were utilized in accordance with ISU’s Institutional Animal Care and Use Committee (IACUC) approval (Protocol # 014 – 2015). Calves were paired by sex, blocked by body weight (BW) within sex in a 2 x 2 factorial arrangement with three replications per treatment, and fed for 140d. Control diets were a conventional finishing-diet consisting primarily of corn silage and shelled corn. Experimental diets were modeled after the control diet with the inclusion of WBG on a thirty-percent dry matter (DM) basis. Diets were mixed on a per week basis with feed refusal collection prior to the offering of new diet batches (~5d periods) and feed was offered once daily. Calves were weighed every 28d with two-day average weights collected and used to calculate Average Daily Gain (ADG), Average Daily Feed Disappearance (ADFD), and Gain to Feed (G:F). Daily feed offered was increased in constant increments, adjusted from feed refusal, and cattle were visually appraised by an industry procurement agent for degree of finish. Following feeding, calves were transported 159km for slaughter and processing. Following harvest under USDA-FSIS inspection, whole primal ribs (IMPS #1103) were obtained and transported to the ISU Fresh Meat Lab for further fabrication. Boneless ribeye steaks (IMPS #1112) were fabricated from the ninth – eleventh ribs and utilized for further meat quality analyses. Statistical analysis was modeled in a two-way fixed ANOVA utilizing the MIXED procedure of SAS. No differences were observed in Total Gain (TG) and ADG between diets respectively ($P = 0.6919$). Calves fed WBG exhibited an increase in ADFD ($P < 0.0001$). Decreases in G:F were observed in calves fed WBG ($P = 0.0121$). No differences were observed in Hot Carcass Weight (HCW), Yield Grade (YG), or Quality Grade (QG) respectively ($P > 0.05$). No differences were observed in Warner-Bratzler Shear Force (WBSF), Package Purge (PP), or Cook Loss (CL) measurements respectively ($P > 0.05$). This data indicates WBG inclusion supports growth performance, carcass performance, and meat quality of finishing cattle similar to that of a conventional corn – corn silage finishing diet.

KEYWORDS: Wet Brewer’s Grain, Growth Performance, Carcass Performance, Meat Quality, Finishing Cattle

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CONTENTS

TABLES

CHAPTER I: GENERAL INTRODUCTION

The livestock industry is a dynamic industry that is constantly evolving, driven by growing populations and incomes, changing food preferences, and increased global trade in livestock products (Steinfeld et al., 2006). Advances in meat production, product variety, and increased meat consumption have driven increases in production efficiency for domestic use and foreign export. Livestock products supply one-third of global protein intake and is projected to nearly double from 252 million tons in 1999/2001 to 512 million tons by 2050 (Steinfeld, 2006). On average, American men consume 6.9 ounces of meat per day and women consume slightly less at 4.4 ounces per day (NAMI, 2016). These increased costs, production size, and rate of consumption push for the adoption of necessary changes to maintain a successful enterprise.

Corn is considered a traditional energy source in feedlot diets. However, as traditional energy sources are diverted to supply substrates for other production purposes (ethanol production), an increase in by-product utilization has been seen (Hersom et al., 2010). Since feedstuffs often encompass the largest portion of production costs, more emphasis has been placed on the cost effective use of alternative and supplemental feed sources (Hersom, 2006).

Over the past few decades, Dried Distillers Grains with Solubles (DDGS) has become one of the industry standards for alternative feeds. Specifically, DDGS is the residue remaining after the starch fraction of fermented corn is removed for alcohol production and distillation, during the ethanol production process (Hersom, 2006). Dried Distillers Grains with Solubles are viewed as an excellent source of protein, particularly by-pass protein which is roughly fifty-percent of its crude-protein content (Hersom, 2006). This nutritional value has driven DDGS as a leading feed supplement, because its ability to provide supplemental protein and combat possible protein deficiencies from the microbial supplied protein of the rumen (Aines et al., 1986).

Wet Brewer's Grains are the by-product of brewing for the production of beer and malt products (Hueze et al., 2015). More specifically, after the fermentation process and formation of wort for beer or malt, the fermented medium is filtered off resulting in a high-moisture residual (Mussato et al., 2006). Wet Brewer's Grains are a variable product both in physical composition and nutritional value (Hueze et al., 2015). The process of using Wet Brewer's Grains (WBG) is not a newly discovered trend, but increases in production, micro-brewery location, and availability have stimulated new interest in this product.

In the past decade, the Micro-brewing industry has increased (Cohen, 2016). According to the Brewers Association (BA), the trade association representing small and independent American craft brewers, the number of operating breweries in the U.S. in 1970 was roughly one-hundred and by 2015 breweries totaled 4,269, equating to the most in American history (Cohen, 2016). The revival of micro-brewery production has renewed an age-old relationship between brewers and livestock producers (Landry, 2002). The opportunity exists for producers to benefit from a brewing by-product that can be utilized in cattle feeding, all while creating a local industry partnership.

Meat quality can be an ambiguous term, including components of eating quality, shelf life, wholesomeness, nutritional composition, and convenience (Apple and Yancey, 2016). Hofmann (1986), as referenced by Otto (2004), defined meat quality as the sum of all meat quality characteristics. One of many important quality factors that is a determinant of consumer preference and choice is meat color. Meat purchasing decisions are influenced by color more than any other quality factor, because consumers use discoloration as an indicator of freshness and wholesomeness (Mancini and Hunt, 2005). Flavor, tenderness, and juiciness are quality characteristics grouped closely together by consumers; who in the market place are the ultimate decider of meat quality (Maltin et al., 2003). Some of these characteristics are determined during the muscle to meat conversion and postmortem events (Maltin et al., 2003). Pre-slaughter handling, slaughter methods, and carcass chilling rate having the greatest impacts on quality (Apple, 2010). Other contributing factors affecting these quality traits are: ratio of fat to lean, pH decline rate, Water Holding Capacity (WHC), flavor compounds present, and the synergistic action of enzymatic systems including calpains; μ-calpain specifically (Ouali et al., 2006). Flavor is the subjective characteristic perceived by consumers while consuming a meat product. Many descriptors exist to describe what exact flavor is experienced and complaints of blandness or off-flavors are a focus of concern (Ouali et al., 2006). The tenderizing process is enzymatic in nature and it is generally agreed that postmortem events are the main determinants of tenderness (Maltin et al., 2003). Juiciness, or the amount of moisture present, is a function of WHC. Water holding capacity is the ability of meat to retain naturally occurring or added moisture during the application of external forces and affects nearly every meat quality characteristic (Aberle et al., 2012).

Since consumer preference for high quality meat and the role inputs of production play in product quality is important, research on how feeding by-products and co-products effect this is critical. However research on WBG inclusion in beef cattle and evaluating the effect on meat quality and carcass characteristics is lacking. Thus further research is necessary. Linton (1973), observed that brewery by-products had no effect on carcass characteristics or meat quality, but further research was indicated as necessary. Homm et al. (2008) further supported this, concluding that feeding fifteen to forty-five percent WBG in feedlot diets supported animal performance and carcass characteristics similar or greater to traditional finishing diets. As echoed by Shand et al. (1998), few reports of beef trials of animals fed WBG have been published, which may give producers and feedlots opportunities to take advantage of these alternative feeds to provide quality product for the consumer.

The Illinois livestock industry is expected to experience significant growth, with total number of "Notices of Intent to Construct" filed by local producers, increasing 137% between 2010 to 2014 (DIS, 2015). Although cattle inventories are low compared to the past, record high beef prices will continue to drive prices and further incentivize producers to expand in livestock production (DIS, 2015). Illinois alone produced 279.1 million pounds in June of 2016, equating to 101% of production from the year prior (USDA-NASS, 2016). Since feedstuffs often encompass the largest portion of production costs, more emphasis will be placed on the cost effective use of alternative feed sources as expansion continues (Hersom, 2006). The revival of micro-brewery production has renewed an age-old relationship between brewers and livestock producers (Landry, 2002). This opportunity enables producers to benefit from WBG to be utilized in cattle feeding, all while creating a local partnership with micro-brewers. Moreover, much of the literature available on WBG focuses on product from large scale brewers and does not address increases from micro-breweries and possible product differences. As producers seek to utilize this local and economical alternative feed source, further research on the efficacy of WBG inclusion in necessary.

However, much of the literature available on WBG focuses on product from large scale brewers and does not address increases from micro-breweries and possible product differences. As producers seek to utilize this local and economical alternative feed source, further research on the efficacy of WBG inclusion is necessary. The objective of this study was to determine the effects of Wet Brewer's Grains (WBG) on the growth performance, carcass performance, and meat quality of finishing cattle.

Thesis Organization

This thesis is an alternate format. It includes a general introduction, manuscript formatting according to the style of The Professional Animal Scientist (PAS), and a review of the literature.

CHAPTER II: EFFECT OF WET BREWER'S GRAIN INCLUSION ON THE GROWTH PERFORMANCE, CARCASS PERFORMANCE, AND MEAT QUALITY OF FINISHING CATTLE

ABSTRACT

The objective of this study was to determine the effects of Wet Brewer's Grains (WBG) on the growth performance, carcass performance, and meat quality of finishing cattle. Twenty-four (n=24; 12 heifers – 303kg, 12 steers – 346kg) calves of Simmental-Angus genetics were utilized. Calves were paired by sex, blocked by BW within sex in a 2 x 2 factorial arrangement with three replications per treatment, and fed for 140d. Control diets were a conventional corn silage – shelled corn finishing-diet. Experimental diets modeled the control diet with the inclusion of WBG on a thirty-percent DM basis. Cattle were visually appraised by an industry procurement agent for degree of finish. Finished cattle were transported 160km for slaughter under USDA-FSIS inspection. Primal ribs (IMPS #1103) were obtained and transported to ISU's Meat Lab. Ribeye steaks (IMPS #1112) were fabricated from the ninth – eleventh ribs for further meat quality analyses. Statistical analysis was modeled in a two-way fixed ANOVA utilizing the MIXED procedure of SAS. No differences were observed in total gain and ADG between diets respectively ($P = 0.6919$). Average daily feed disappearance (ADFD) increased in WBG calves ($P < 0.0001$). Decreases in G:F were observed in WBG calves ($P = 0.0121$). No differences were observed in HCW, YG, or QG respectively ($P > 0.05$). No differences were observed in Warner-Bratzler Shear Force, Package Purge, or Cook Loss measurements ($P > 0.05$). This data indicates WBG inclusion supports growth performance, carcass performance, and meat quality of finishing cattle similar to a conventional finishing diet.

Keywords: Wet Brewer's Grain; Growth performance, Carcass performance, Meat quality, Finishing cattle

INTRODUCTION

Feedstuffs often encompass the largest portion of production costs, emphasis has been placed on utilization of alternative feed sources (Hersom, 2006). Corn is considered a traditional energy source in feedlot diets. However, as traditional energy sources are diverted to supply substrates for other industries, emphasis has been placed on the utilization of alternative feed sources to further maintain a successful enterprise (Hersom et al., 2010).

Wet Brewer's Grains (WBG) are the by-product of brewing (Hueze et al., 2015). After mashing and formation of wort for beer or malt, the medium is filtered off resulting in a high-moisture residual (Mussato et al., 2006). Physical composition and nutritional value of WBG is highly variable (Hueze et al., 2015). The process of feeding WBG to cattle is not a newly discovered trend. Linton (1973), observed that brewery by-products had no effect on carcass characteristics or meat quality, but indicated further research was necessary. Increases in micro-brewing and product availability have stimulated new interest in this product.

In the past few decades micro-brewing has increased substantially (Cohen, 2016). According to the Brewers Association (BA) there were approximately 100 breweries in the U.S. in 1970, and by 2015 this increased to 4,269, the most in American history (Cohen, 2016). The revival of micro-brewery production has renewed an age-old relationship between brewers and livestock producers (Landry, 2002).

Although cattle inventories are low compared to the past, record-high beef prices will continue to drive prices and further incentivize producers to expand (DIS, 2015). This opportunity enables producers to benefit from WBG utilized in cattle feeding, all while creating a local partnership with the micro-brewing industry. Moreover, much of the literature available on WBG focuses on grains from large scale brewers and does not address micro-breweries and possible product differences. As producers seek to utilize this local and economical alternative feed source, further research on the efficacy of WBG inclusion is necessary. The objective of this study was to determine the effects of WBG sourced from a local craft brewery on the growth performance, carcass performance, and meat quality of finishing cattle.

MATERIALS AND METHODS

All animals were utilized in accordance with Illinois State University's Institutional Animal Care and Use Committee (IACUC) approval (Protocol # 014 – 2015).

Experimental Design

Twenty-four (n=24; 12 heifers, 12 steers) beef calves of Simmental-Angus genetics, heifers weighing approximately 303kg and steers weighing approximately 346kg, were utilized and finished at the Illinois State University (ISU) Farm. Calves were paired by sex and blocked by body weight (BW) within sex in a 2 x 2 factorial arrangement with three replications per treatment. Pen was the experimental unit in both the live and carcass phase, thus data collected was reported as pen averages. Following an acclimation period, cattle were implanted (Synovex® – H, Synovex® – S; Zoetis Services LLC, Parsippy, NJ, USA) and fed for 140d. Control diets were a conventional finishing-diet consisting of corn silage, shelled corn, DDGS, lime mineral, and a pelleted balancer. Experimental diets were modeled after the control diet consisting of; corn silage, shelled corn, DDGS, lime mineral, pelleted balancer, and inclusion of WBG on a thirty-percent dry matter (DM) basis.

Diet Mixing, Feeding, and Feed Refusal

Calculated analysis of trial diets are shown in Table 1. Diets were mixed on a weekly basis to coincide with availability of WBG from the brewery. Diet batches were mixed and stored indoors in three-walled open bunkers on concrete flooring. Calves were offered feed once daily. Feed refusal collection was performed prior to the offering of new diet batches in approximately five day periods.

Growth Performance

Calves were weighed every 28d with two-day average weights collected and used to calculate Average Daily Gain (ADG), Average Daily Feed Disappearance (ADFD), and Gain to Feed (G:F). Daily feed offered was increased in constant increments and adjusted from feed refusal calculations and measurements. At the end of the finishing period, cattle were visually appraised by an industry procurement agent for degree of finish. Upon determination of finish, cattle were transported 160km for slaughter and fabrication at a USDA-FSIS inspected packing facility.

Carcass Measurements

Following harvest under USDA-FSIS inspection, hot carcass weight (HCW) was obtained immediately. After 24h chilling period carcasses were measured for Ribeye area (REA), 12^{th} rib fat thickness (RIBF), and kidney-pelvic-heart (KPH) fat. Quality grade (QG) for each carcass were assigned by an in-plant USDA grader. Carcasses were then further fabricated into whole primals. Vacuum-packaged whole bone-in primal ribs (IMPS #1103), from the right side of each carcass, were obtained and transported 160 kilometers to Illinois State University's (ISU) Meat Lab for further fabrication and processing.

Fabrication and Meat Quality Analysis

Twenty-four (n = 24) whole primal ribs (IMPS #1103; NAMP, 2007) were deboned, trimmed, and sliced into boneless ribeye steaks (IMPS #1112: NAMP, 2007) from the ninth – eleventh ribs. Three ribeyes from each rib-roll were utilized for further meat quality analyses as follows:

One boneless ribeye steak was utilized for Warner-Bratzler Shear Force (WBSF; Tallgrass Solutions, Manhatten, KS, USA) analysis and Cook Loss (CL) measurements. Steaks were weighed raw and cooked to a common degree of doneness by the way of the following: samples were cooked to an internal temperature of 35ºC, turned and cooked to a final internal temperature of 71ºC, removed from heat and reweighed after a period of cooling. Cook Loss percentages were calculated by subtracting the weight following cooking from the raw weight and reported as a percentage of weight (water) lost from the raw steak, where CL% = {100 – [(cooked weight / raw weight) * 100]}. Six cores (13mm) from each steak were removed and sheared perpendicular to the cut surface. WBSF applied a crosshead speed of 225mm/minute. A WBSF value was determined as the peak force in kilograms required to completely shear through each core. The shear-force value was then averaged from the values of all six cores per sample.

One boneless ribeye steak was weighed, placed on a foam tray with an absorbent pad, overwrapped in oxygen-permeable polyvinylchloride film and placed in a deli-style retail display case (4.5 ºC). Color measurements (L*, a*, b*), utilizing a HunterLab Miniscan Spectrophotometer (Hunter Associates Laboratory, Inc., Reston, VA, USA), from the face of each steak were taken on d 0, 1, 4, and 7. Following the 7d display period, steaks were removed from packaging and reweighed to determine water loss as Package Purge (PP). Package purge was calculated as PP% = {100 – [(post weight / pre weight)*100]}.

One steak from each carcass was halved, each half was packaged in a 4-ounce WHIRL-PAK® bag, and frozen (-20 ºC) for 60d. Following storage, samples were analyzed for fat, moisture, and fatty acid profile. Analysis of fat and moisture percentage was performed per manufacturer's instructions using a CEM SMART Trac Moisture and Rapid Fat Analyzer System, (CEM Corp., Matthews, North Carolina, USA). Fatty acid analysis was determined using an adaptation of the methods outlined by Folch et al. (1957) and Morrison and Smith (1964). Adaptations of these methods were discussed by Wiegand et al. (2011). Percentages of individual fatty acids were used to calculate an Iodine Value (IV) for free fatty acids for each sample using the following equation: IV = (0.95 x C16:1) + (0.86 x C18:1n9) + (1.732 x C18:2n6) + (2.616 x C18:3n3) + (0.785 x C20:1) (AOCS, 1998).

Statistical Analysis

In this study pen was the experimental unit in both the live phase and carcass phase. Statistical analysis was modeled in a two-way fixed ANOVA utilizing the MIXED procedure of SAS to obtain LSMeans. Furthermore, LSMeans were separated using the PDIFF option. Model design included the main effects of diet and sex, as well as all possible interactions. Block was included as a random effect and significance was determined administering a level of $\alpha = 0.05$.

Growth performance variables consisted of ADG, G:F, F:G, Total gain (TG), and Average daily feed disappearance (ADFD). Carcass performance variables analyzed consisted of HCW, YG, DP, KPH, Ribeye Area (REA), Marbling score (MS), and 12^{th} Rib fat thickness (RIBF). Meat quality measurements analyzed consisted of Warner-Bratzler Shear Force (WSBF) measures, Package Purge (PP) measures, Cook Loss (CL) measures, and Fatty Acid Profile.

Retail display quality measurement analysis was conducted using the repeated measures in the MIXED procedure of SAS. The model included the main effects of diet, sex, day of retail display, and all possible interactions. Block was included as a random effect and significance was determined at a level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Growth Performance

Growth performance data is shown in Table 2. Total Gain (TG) and ADG were not different between dietary treatments ($P = 0.619$). Average Daily Feed Disappearance (ADFD) was affected by dietary treatments ($P < 0.0001$), where cattle fed WBG consumed more feed than cattle receiving the control diet; but no differences were observed between sex ($P = 0.2086$). However, the inclusion of WBG had no effect on G:F or F:G conversion rates ($P > 0.05$).

Homm et al. (2008) observed increased growth performance (ADG and final BW) in heifers offered thirty-percent WBG, however in our study ADG was not affected by treatment ($P > 0.05$). Furthermore, the inclusion of WBG had no effect on G:F or F:G conversion rates and is in agreement with Homm et al. (2008), who concluded no differences in G:F between dietary treatments. Growth performance in the current study is supported by Preston et al. (1973), who reported acceptable feedlot performance when either 25% or 50% of the total ration was derived from Dried Brewer's Grain (DBG) compared to a 95% corn ration. Findings by Crickenberger and Johnson (1982) further support the current study, by concluding that feeding a WBG – corn silage diet had no effect on ADG, DM intake, or final weight in wintering beef heifers. Additionally, Aguilera-Soto et al. (2007) found no differences, despite different fiber and lipid content in diets, from WBG fed growing lambs on rumen fermentation, digestion, and performance. Yang et al. (2000) also reported similar growth performance results on the influence of feeding WBG-silage to castrated dairy goats.

Previous studies have reported varying results following WBG inclusion and could possibly be a result of product variation utilized between individual studies. Thomas et al. (2010), reported a 13% varying range in DM percentages collected. Furthermore, Murdock et al. (1981) reported Total Digestible Nutrient (TDN) and net energy for lactation of dry matter of WBG as approximately sixteen-percent higher than those listed by the NRC. Cozzi and Polan (1994), accredited positive production responses of cows fed DBG to a more favorable balanced amino-acid profile in Rumen Undegradable Protein (RUP).

Carcass Performance and Meat Quality

Carcass performance and meat quality data is shown in Table 3. No differences were exhibited in carcass characteristics between dietary treatments for HCW, YG, REA, MS, and DP ($P > 0.05$). Steers exhibited the lowest 12th Rib fat thickness (1.693 cm) regardless of diet ($P = 0.0157$). Heifers exhibited the highest KPH percentages (3.92%) regardless of diet ($P = 0.0322$). No differences based on diet or sex were observed for Warner-Bratzler Shear Force, Package Purge (PP), or Cook Loss (CL) measurements ($P > 0.05$).

Carcass characteristics gathered in this current trial were similar to that of Linton (1973), who reported brewery byproducts had no effect on carcass characteristics or meat quality. This study was further supported by Homm et al. (2008), who reported no significant differences in DP and YG across dietary treatments at harvest. Preston et al. (1973) indicated a positive correlation between DP and amount of DBG offered, however in this study no relationship was observed. Heifers exhibiting higher levels of KPH could be further explained by Zinn et al. (1970), who reported heifers fattened more rapidly and accredited this to heifers maturing at an earlier age. Additionally, Homm et al. (2008) reported a negative linear relationship between REA as WBG increased in the diet, which is in contrast to the current study. Homm et al. (2008)

also concluded there was a tendency for heifers fed WBG to exhibit lower MS. In the present study no significant differences were found in diet or sex on MS. Although MS was not significantly different across dietary treatments (P = 0.1086), WBG fed cattle exhibited lower numerical MS values. This may be an issue when marketing on a quality grid basis. Control fed cattle graded within the top two-thirds of Choice (MS = 655.00) and WBG fed cattle graded slightly below in the bottom third of the Choice (MS = 585.00). If the goal is to produce product to meet or exceed Mid-Choice quality grade and its associated premium, producer discretion is necessary when incorporating WBG and maintaining production goals. However, all cattle in this study graded Choice and 87% graded Mid-Choice or greater.

Few reports of WBSF, PP, and CL of WBG fed beef have been published. Linton (1973) and Homm et al. (2008) primarily assessed the effects of WBG on carcass characteristics and meat quality. The current study showed no significant effects on WBSF, PP, and CL measurements of beef from animals fed WBG. Mills et al. (1992) slightly address these traits, who concluded that a trained sensory panel found no differences in hardness, juiciness, or other textural properties of beef steaks due to varying dietary forages. Shand et al. (1998), reported that eating quality and meat properties of beef fed WBG or wheat based Wet Distillers Grain (WDG) were not superior to meat from animals fed conventional feeds, but neither were there any negative effects on meat quality.

Fatty Acid Profile

Fatty acid analysis data is shown in Table 4. Heifers exhibited a 3.86% lower SFA content (P = 0.0292), 3.85% higher MUFA content (P = 0.0175), and a 3.62% increase in IV scores (P = 0.0106) regardless of diet. Waldman et al. (1968) support these findings, who observed heifers of Angus genetics displaying higher concentrations of unsaturated acids and lower concentrations of saturated acids compared to steers. In contrast, Marchello et al. (1970) observed no significant differences in fatty acids due to sex, utilizing chloroform-methanol extraction.

In the current study, higher MUFA concentrations and IV values shown in heifers could be attributed to increased levels of soft fat present. This is in agreement with Wood et al. (2003) who indicated as unsaturation of fats increases, fat firmness and melting point decreases. Additionally, Rickard (2011) further explains that IV is the measure of the degree of unsaturation of the fat profile, therefore a higher IV correlates to a softer fat profile. However, Smith et al. (2006) convey that there is no economic incentive for producers to produce beef higher in concentrations of certain fatty acids and in the present beef grading systems, carcass value is determined primarily by the abundance of total intramuscular fat and not by type alone.

Retail Display Color

Retail display color data is shown in Table 5, 6, and 7. Heifers exhibited significantly higher L* values on d 1 and 7 regardless of diet ($P < 0.05$). A significant interaction of diet x sex was observed for L* scores on d 7, with control fed heifers displaying the highest L* value ($P = 0.0294$). This was the only interaction observed in the retail display analysis. No significant effect of diet or sex was observed for a* and b* values during the duration of retail display (d 0, 1, 4, 7) ($P > 0.05$). Although it is generally recognized that male cattle have much higher propensity to produce darker color values, a small number of authors have investigated the differences in color between steers and heifers (Murray, 1989). Jones et al. (1989) reported heifers showed a lower occurrence of darker meat than steers. In contrast, Murray (1989) reported heifers display slightly darker meat than that of steers, but considered this as an effect of carcass weight and more rapid cooling post-slaughter. However, Murray (1989) reported that carcass fatness was highly related to ultimate color and as carcass fatness increases the occurrence of dark meat decreases several-fold. This could possibly explain the occurrence of steers exhibiting lower color scores than heifers in this study, since steers also exhibited significantly lower 12th rib fat (1.693 cm versus 2.053 cm). Furthermore, Jeremiah et al. (1996) found no significant effect of gender on Hunter L* values.

IMPLICATIONS

These data indicate that the inclusion of Wet Brewer's Grain (WBG) on a thirty-percent DM basis support the growth performance, carcass performance, and meat quality of finishing cattle. As producers seek to utilize this local and economical alternative feed source, opportunity exists to decrease production costs without sacrificing production returns. Moreover, much of the preceding literature available focuses on WBG from large scale brewers and does not address possible differences of grains from micro-breweries. Further research on the effects of WBG inclusion on growth performance, carcass performance, and meat quality of finishing cattle is necessary.

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Table 1. Diet formulation*

Ingredient	Control Diet*	Experimental Diet*
Corn Silage	27.80	26.70
Shelled Corn	54.40	42.80
DDGS[a]	15.30	9.10
Limestone	0.18	0.12
WBG[b]	------	19.30
Beef Balancer[c]	2.30	2.00
Total	100.00	100.00

* Diet ingredients reported as percentage of total diet on as fed basis
[a] Dried Distillers Grains with Solubles
[b] Wet Brewer's Grain
[c] Beef Balancer .66 R700 – BIG GAIN WISCONSIN, LLC.

Table 2. Effect of wet brewer's grain inclusion on the growth performance of finishing cattle*

	Diet		Sex					
Trait	Control	WBG	Steer	Heifer	SEM	Diet	Sex	Diet x Sex
TG[a]	239.000	236.000	246.000	229.000	4.92620	0.6919	0.0866	0.9701
ADG[b]	1.672	1.651	1.723	1.600	0.03445	0.6919	0.0866	0.9701
ADFD[c]	27.000	31.000	29.000	29.000	0.07167	<.0001	0.2086	0.0473
G:F[d]	0.179	0.179	0.185	0.173	0.00361	0.9128	0.0864	0.9430
F:G[e]	5.615	5.597	5.402	5.810	0.11510	0.9202	0.0872	0.9269

* Values reported as LSMeans
[a] Total gain (for trial), kg
[b] Average daily gain, kg
[c] Average daily feed disappearance, kg
[d] Gain : Feed, kg
[e] Feed : Gain, kg

Table 3. Effect of wet brewer's grain inclusion on the carcass performance and meat quality of finishing cattle*

	Diet		Sex					
Trait	Control	WBG	Steer	Heifer	Pooled SEM	Diet	Sex	Diet x Sex
HCW[a]	394.000	392.000	403.000	382.000	6.91015	0.8698	0.0705	0.3649
YG[b]	3.773	3.371	3.477	3.667	0.13040	0.1171	0.3791	0.4775
REA[c]	97.508	94.373	94.301	97.581	1.91945	0.3192	0.2879	0.0851
MS[d]	655.000	585.000	626.000	614.000	22.12650	0.1086	0.7163	0.5835
DP%[e]	64.020	63.452	63.461	64.011	0.41030	0.4002	0.4131	0.1472
RIBF[f]	2.065	1.681	1.693	2.053	0.09225	0.0202	0.0157	0.5106
KPH[g]	3.500	3.500	3.000	3.900	0.20850	0.8902	0.0322	0.3421
WBSF[h]	2.384	2.788	2.527	2.646	0.09352	0.0553	0.4369	0.1028
PP[i]	2.892	3.093	2.933	3.052	0.22050	0.5588	0.7197	0.8057
CL[j]	27.399	28.416	28.822	26.993	1.82060	0.7194	0.5287	0.6656

* Values reported as LSMeans
[a] Hot carcass weight, kg
[b] Yield grade (calculated)
[c] Ribeye loin area, cm^2
[d] Marbling score
[e] Dressing percentage, %
[f] 12th rib fat thickness, cm
[g] Kidney pelvic heart fat, %
[h] Warner-Bratzler Shear force, kg/f
[i] Package purge, %
[j] Cook loss, %

Table 4. Effect of wet brewer's grain inclusion on fatty acid profile*

	Diet		Sex			Probability Value		
Trait	Control	WBG	Steer	Heifer	Pooled SEM	Diet	Sex	Diet x Sex
SFA[a]	47.4573	46.7474	49.0318	45.173	0.74885	0.5363	0.0292	0.3673
MUFA[b]	47.3959	46.8952	45.2230	49.068	0.5698	0.5784	0.0175	0.6102
PUFA[c]	5.0159	5.3813	5.1179	5.2793	0.3040	0.2794	0.5442	0.2639
IV[d]	49.4627	49.2811	47.5598	51.1841	0.82395	0.8227	0.0106	0.1188

* Fatty acids reported as percentage of the total fatty acids

[a] Saturated Fatty Acids

[b] Monounsaturated Fatty Acids

[c] Polyunsaturated Fatty Acids

[d] Iodine Value

Table 5. Effect of wet brewer's grain inclusion on L* values during retail display*

	Diet		Sex			Probability Value		
Day	Control	WBG	Steer	Heifer	Pooled SEM	Diet	Sex	Diet x Sex
0	37.8065	37.9402	36.5050	39.2417	1.1417	0.9223	0.0905	0.1235
1	38.9430	39.3112	37.6900	40.5642	0.96665	0.7424	0.0483	0.1286
4	37.8392	37.3642	35.7058	39.4975	0.9869	0.756	0.0728	0.0996
7	36.9850	36.1783	34.5608	38.6025	1.0788	0.5089	0.0332	0.0294

* Values reported as LSMeans of pen averages

Table 6. Effect of wet brewer's grain inclusion on a* values during retail display*

	Diet		Sex			Probability Value		
Day	Control	WBG	Steer	Heifer	Pooled SEM	Diet	Sex	Diet x Sex
0	28.1130	28.5612	27.8600	28.8142	0.5846	0.5865	0.254	0.7139
1	27.8863	28.7320	27.8317	28.7867	0.82095	0.5001	0.432	0.7171
4	26.1924	27.2584	26.4617	26.9892	0.48075	0.2134	0.4906	0.139
7	19.7108	18.5517	18.4050	19.8575	1.7762	0.6759	0.6036	0.4737

* Values reported as LSMeans of pen averages

Table 7. Effect of wet brewer's grain inclusion on b* values during retail display*

	Diet		Sex			Probability Value		
Day	Control	WBG	Steer	Heifer	Pooled SEM	Diet	Sex	Diet x Sex
0	22.4383	22.1125	21.3775	23.173	0.6025	0.7276	0.1256	0.6676
1	19.4258	19.6558	18.7033	20.3783	0.8426	0.8593	0.2545	0.4367
4	19.2142	20.0167	19.2392	19.9917	0.4129	0.263	0.2879	0.1478
7	16.3183	16.6275	15.8267	17.1192	0.6859	0.7708	0.2749	0.1797

* Values reported as LSMeans of pen averages

CHAPTER III: LITERATURE REVIEW

Introduction

The livestock industry is a dynamic industry that is constantly evolving, driven by growing populations and incomes, changing food preferences, and increased global trade in livestock products (Steinfeld et al., 2006). In livestock production, there are roughly six-hundred thousand operations specializing in beef cattle feeding, with 13.2 million head of slaughter cattle inventoried as of January 1st, 2016 (USDA-NASS, 2016). Nearly eighty-percent of cattle are fed in feedlots with capacities of one-thousand head or more (USDA-NASS, 2016). Advances in meat production, product variety, and increased meat consumption have driven increases in production efficiency for domestic use and foreign export. In 2013 alone, total beef production in the U.S. reached nearly twenty-six billion pounds of product; exporting 1.7 billion metric tons (MT) of beef (NAMI, 2016). Furthermore, companies associated in meat production, livestock supply, distribution, retail and auxiliary sectors employ 6.2 million individuals in the U.S. alone, totaling $200 billion in wages (NAMI, 2016). Livestock products supply one-third of global protein intake and is projected to nearly double from 252 million tons in 1999/2001 to 512 million tons by 2050 (Steinfeld, 2006). On average, American men consume 6.9 ounces of meat per day and women consume slightly less at 4.4 ounces per day (NAMI, 2016). These increased costs, production size, and rate of consumption push for the adoption of necessary changes to maintain a successful enterprise.

Corn is considered a traditional energy source in feedlot diets. However, as traditional energy sources are diverted to supply substrates for other production purposes (ethanol production), an increase in by-product utilization has been seen (Hersom et al., 2010). A by-product is produced during industrial processing and has marginal value or is seen as waste. A by-product can be considered a co-product by acquiring value through application in another industry sector, for example beef cattle feeding. Since feedstuffs often encompass the largest portion of production costs, more emphasis has been placed on the cost effective use of these alternative and supplemental feed sources (Hersom, 2006).

Co-Product Use

Over the past few decades, Dried Distillers Grains with Solubles (DDGS) has become one of the industry standards for alternative feeds. Specifically, DDGS is the residue remaining after the starch fraction of fermented corn is removed for alcohol production and distillation, during the ethanol production process (Hersom, 2006). This process results in two products, Dried Distillers Solubles (DDS) or Dried Distillers Grains (DDG), which are blended together into an intermediate product labeled Dried Distillers Grains with Solubles (DDGS) (Hersom, 2006). Dried Distillers Grains with Solubles saw a large increase in production during the mid-2000s due to tripling crude oil prices, provisions from the Energy Policy Act of 2005, and already existing federal and state biofuel programs incentivizing the expansion (Westcott, 2007).

After its initial introduction, a market for DDGS was established in the cattle feeding sector and has grown in value. This has been accomplished through improved profitability and competitive pricing from subsidized production, and a better understanding of the nutritional composition of DDGS (Loy and Lundy, 2014). Dried Distillers Grains with Solubles are viewed as an excellent source of protein, particularly by-pass protein which is roughly fifty-percent of its crude-protein content (Hersom, 2006). By-pass protein or protein that escapes digestion in the rumen is vital in ruminant nutrition, due to its availability for absorption by the abomasum and small intestine for further productive functions (Aines et al., 1986). Furthermore, in comparison of available by-pass protein, DDGS are 230 to 260% higher than soybean meal (Aines et al., 1986). This nutritional value has driven DDGS as a leading feed supplement, because its ability to provide supplemental protein and combat possible protein deficiencies from the microbial supplied protein of the rumen (Aines et al., 1986).

Although DDGS are a valued feed supplement, considerations for use do exist in its nutritional composition, feeding, logistics, and storage. Dried Distillers Grains with Solubles are commonly low in Calcium (Ca) levels and relatively higher in Phosphorus (P) and Sulfur (S) (Tjardes and Wright, 2002). Mineral concentrations are important when formulating appropriate feed rations to prevent deficiencies and their associated symptoms (Tjarders and Wright, 2002). Also, proper manure management is key if excess mineral excretion is seen (Tjardes and Wright, 2002). Low levels of calcium can be offset through limestone supplementation in feed rations and suggested Ca:P ration is 1.2:1, but no greater than 7:1 (Tjardes and Wright, 2002). Studies have concluded that high levels of sulfur have led to Poloencephalomalacia, commonly termed "brainers", or the necrosis of the cerebral grey matter; as well as, inhibition of Copper (Cu) absorption and metabolism (Tjardes and Wright, 2002). Variation in overall composition has been speculated (Honeyman and Lammers, 2007). This variation could be due to different ethanol plants, drying techniques and equipment, grain quality, or the final mixing ratio; which makes sampling of each load delivered necessary (Honeyman and Lammers, 2007). Ultimately the utilization of DDGS is commonly dictated by the overall goals of production. However, other industry by-products do exist and knowledge of DDGS use may become beneficial when successfully utilizing similar products.

Wet Brewer's Grain

Wet Brewer's Grains are the by-product of brewing for the production of beer and malt products (Hueze et al., 2015). More specifically, after the mashing process and formation of wort for beer or malt, the medium is filtered off resulting in a high-moisture residual (Mussato et al., 2006). Wet Brewer's Grains commonly consist of but are not limited to; cereal grains of barley, wheat, rice, and corn (Hueze et al., 2015). Wet Brewer's Grains are a variable product both in physical composition and nutritional value (Hueze et al., 2015). This variation can be seen between breweries as well as the brew recipe used, whether it is a common recipe consistently brewed or a seasonal recipe brewed infrequently. The process of using Wet Brewer's Grains (WBG) is not a newly discovered trend, but increases in production, micro-brewery location, and availability have stimulated new interest in this product.

Physical Properties, Spoilage, and Storage

Physical characteristics of WBG vary, with the product marketed most commonly in wet form and in bulk composite loads (Thomas et al., 2010). This is primarily due to limited drying capabilities of breweries and daily batches being compiled into one composite batch for removal at the end of a production week. The varying physical composition of WBG becomes important to consider when assessing the feasibility of incorporation into a beef cattle operation. Studies conducted have conveyed general considerations concerning the physical properties such as: spoilage rates, transportation, and efficient utilization of WBG as a supplemental feedstuff.

The relationship between spoilage rate and utilization rate is a primary issue with WBG, due to loss in economic returns if utilization rates fall below that of the rate of spoilage. The high moisture content in WBG dramatically decreases the duration of time before spoilage (Mussato et al., 2006). High-moisture levels also increase susceptibility to weather conditions such as: spoilage from heat and freezing from low temperatures (Thomas et al., 2010).

Although the shelf-life of fresh WBG is finite, approximately five to seven days, studies have explored possible storage methods to increase longevity (Thomas et al., 2010). According to Thomas et al. (2010), blending WBG in a Total Mixed Ration (TMR) with other feedstuffs, is an adequate way to incorporate positive characteristics of other feeds and counter high moisture levels. Blending WBG with other feeds such as corn silage, hay, or soybean hulls results in a ration with increased dry matter and increases the shelf-life by a small number of days (Thomas et al., 2010). The authors also observed blending of WBG decreased the amount of gut-fill or distention produced through high levels of water intake (Thomas et al., 2010). Drying has been viewed as a possible preservation method, with the benefit of decreased product volume, thus decreasing transportation and storage costs (Santos, 2003). Drying of WBG is commonly accomplished with rotary-drum dryers, but is not cost effective and is energy-intensive, along with the possibility of air-pollution through burning/over-cooking grains (Mussatto et al., 2006). Furthermore, in a comprehensive review article published by Mussato et al. (2006), multiple alternative methods of drying have been studied such as oven-drying, freeze-drying, mechanical pressing, and superheated steam; but all have their own set of benefits and drawbacks. A third storage method which has shown possibly the most opportunity in preservation is the ensiling of WBG. Ensiling is the process of using high-moisture feedstuffs and fermenting the crop in a pit, tower, bunker, trench, or plastic silo bag (Jennings, 2013). Ensiling is a common practiced method of feedstuff storage in agricultural operations. The main goal of the process is fermentation, done by storing crops in an environment with minimal oxygen and lowering pH levels, through increased lactic acid content via microbial populations (Jennings, 2013). The fermentation process can be further achieved through incorporation of an inoculant (Muck, 2012). According to Wang and Nishino (2008) WBG can be successfully ensiled. The researchers found that WBG ensiled alone sustained *lactobacillu*s bacterial communities at 14d and 56d (Wang and Nishino, 2008). Additionally, WBG incorporated in a TMR prior to ensiling was shown to support microbial populations, active suppression of aerobic spoilage, and improved TMR stability at fourteen days and fifty-six days of storage (Wang and Nishino, 2008). Due to the high moisture and fermentable sugar content, WBG is a very unstable material and is liable to deteriorate rapidly due to microbial activity (Mussato et al., 2006). Opportunities do seem to exist in ensiling WBG when the ability to decrease moisture through TMR incorporation and stabilization of microbial populations through an anaerobic environment, as well as, incorporation of an inoculant.

Logistical Implications

WBG is a highly perishable, high-moisture, and dense product; which incurs its own transportation issues (Ben-Hamed et al., 2011). The feasibility of WBG inclusion decreases when distance transported from the brewery increases (Ben-Hamed et al., 2011). The accepted maximum range for transporting WBG is approximately two-hundred miles (Thomas et al., 2010). If WBG can be purchased at minimal cost or 0% the price of corn and other traditional dry feeds, economic returns are optimized by the shorter distance of travel from brewery to the feedlot (Ben-Hamed et al., 2011). According to Ben-Hamed et al. (2011) factors that influence the efficacy of WBG are: costs of fuel, vehicle use, labor, and spoilage. If these operating costs are not properly managed, they essentially price-out the economic benefits of WBG versus traditional dry feeds (Ben-Hamed et al., 2001). Although animal performance can be maintained or even improved through proper inclusion rates of WBG versus conventional feeds, transportation in wet form is seen as one of the biggest impediments to its use (Ben-Hamed et al., 2011; Mussato et al., 2006).

Nutritional Properties

Currently, two main outlets for WBG are landfill dumping and feeding in the dairy industry. Research in feeding WBG to beef cattle is lacking (Landry, 2002), although multiple studies have concluded that its nutrient profile and complimentary traits to forage-based diets show opportunity as a supplemental feed (Mussato et al., 2006; Homm et al., 2008; Thomas et al., 2010; Shand et al., 1998). Since WBG is a variable product, deviation from standardized nutritional values could be expected and further research or sample analysis is necessary. Variation has been shown in values such as; Dry Matter percentage (DM, %), Crude Protein percentage (CP, %), and Crude Fiber Percentage (CF, %). The University of Florida, in cooperation with the Florida Cooperative Extension Service, published an article summarizing their findings on nutrient composition of WBG. The objective of the study was to determine the variation in nutritional values of locally available WBG. Nutrient values were compared between the National Research Council (NRC) standard, a study average, and a range of all values observed. The DM% listed value is 21.0%, where the determined range was 19.2% - 32.8%, and an average value of 26.0% (Thomas et al., 2010). The CP% listed value is 26%, where the determined range was 24.9% - 34.2%, with an average of 29.6% and the listed CF% is 15.3%, but the determined range was between 8.3% - 15.7%, with an average of 12% (Thomas et al., 2010). Minor variations from the NRC given standards were observed concerning micronutrients and traces minerals such as Potassium (K) and Sodium (Na), which reiterated the importance of proper mineral supplementation mentioned throughout the literature (Thomas et al., 2010; Mussato et al., 2006). When focusing on the nutritional profile of WBG, knowledge of fluctuation and variability becomes essential when formulating rations and assessing the efficacy of inclusion in beef cattle diets.

As previously mentioned, fluctuations in DM% can have adverse effects on feed efficiency from gut-fill or distention and palatability issues due to increased spoilage rates but has been shown to be offset through TMR incorporation (Thomas et al., 2010). Extreme variations in CP% and CF% could have more economic impacts by resulting in a less uniform product or individual animals not meeting optimal live performance or carcass characteristics. These concerns could be explained in possibly decreased amounts of by-pass protein and readily fermentable fiber for utilization in intestinal absorption and progression of biological functions (Aines et al., 1986). Granted these concerns are minimal, because WBG consists of roughly 35% rumen-degradable protein, indicating higher levels of by-pass protein present (Thomas et al., 2010). Furthermore, the energy value of WBG is 71 to 75%TDN with this energy being mainly derived from high fiber content and slight contribution from a 7 to 10% crude fat content (Thomas et al., 2010). This is further refuted by multiple studies, whose authors have concluded that feeding of WBG can maintain or enhance animal performance, economic return per head, and acceptable meat quality characteristics; if proper nutritional and feeding guidelines are followed (Mussato et al., 2006; Thomas et al., 2010; Ben-Hamed et al., 2011; Oltra et al.).

Feeding

Though research in feeding and supplementation of WBG in beef cattle operations is limited, suggested feeding guidelines and incorporation rates are available. Suggested feeding and supplementation rates are thirty to fifty pounds per animal per day for mature cattle and nine to twenty pounds per animal per day for young cattle (Thomas et al., 2010). In feedlot scenarios, studies have shown that feeding 15% to 45%WBG supported performance and carcass characteristics similar to or greater than cattle fed traditional finishing diets (Homm et al., 2008). Furthermore, dairy producers have seen that incorporating WBG with inexpensive forages is able to provide all amino acids needed for proper nutritional health (Mussato, 2013). Mussato (2013) also concluded that inclusion of WBG in cow diets increased milk production, contents of total solids, and decreased the content of overall fat in milk produced. Anheuser-Busch, a proponent of partnerships between brewers and animal producers, sold 1.76 million tons of spent grains to local dairy farms in 1999 (Landry, 2002). Coors Brewing Company has begun drying and pelleting some of its grain to ship internationally for swine and poultry feed (Landry, 2002).

Although research and industry practices support WBG inclusion, economic returns and feasibility have a direct influence on the use of alternative feeds. When vehicle costs and transportation distance from the brewery is within feasible range, feeding of WBG may provide an economical alternative and positively influence animal performance (Ben-Hamed et al., 2001).

Growth of the Micro-Brewing Industry

Although DDGS are commonly utilized in the cattle feeding industry, by-products from other industry sectors do exist and are gaining interest and availability. In the past decade, the Micro-brewing industry has increased (Cohen, 2016). According to the Brewers Association (BA), the trade association representing small and independent American craft brewers, the number of operating breweries in the U.S. in 1970 was roughly one-hundred and by 2015 breweries totaled 4,269, equating to the most in American history (Cohen, 2016). This growth in breweries represent a fundamental shift in the nature of brewing and product consumption (Schnell and Reese, 2003). In 2015, craft brewers produced 24.5 million barrels and saw a thirteen-percent increase in volume, representing twenty-one percent market share of the overall beer industry (Cohen, 2016). The growth in the micro-brewing industry is not a regionally isolated phenomenon, but a growth stretching from coast-to-coast; with over three-quarters of legal drinking age adults living within ten miles of a local brewery (Delventhal, 2015).

The revival of micro-brewery production has renewed an age-old relationship between brewers and livestock producers (Landry, 2002). The opportunity exists for producers to benefit from a brewing by-product that can be utilized in cattle feeding, all while creating a local industry partnership. The by-product is termed Wet Brewer's Grains (WBG); with annual production totaling approximately 400 million tons and is available to producers throughout the year at minimal cost (Landry, 2002). Wet Brewer's Grains may provide an economical alternative and positively influence animal performance (Ben-Hamed et al., 2001). Much of the literature available on WBG focuses on product from large scale brewers and does not address increases from micro-breweries and possible product differences may not be properly characterized. Product from microbrewers have more distinct compositional profiles and produce a diverse array of ales differing from those brewed by Budweiser, Coors, or Miller (Schnell and Reese, 2003). In recent years, the general public have become accustomed to a standardized list of product that renders large brewers indistinguishable from one another, and in response microbrewers have actively created new brews and locally-based economies that are not currently represented by available research (Schnell and Reese, 2003). As producers seek to utilize this economical alternative in cattle feeding, further research concerning the adoption of this within the industry in essential.

Meat Quality

Advancements in meat production, product variety, and increases in meat consumption have led to increases in production efficiency, as well as, increased amounts produced for domestic use and foreign export. In 2012 alone, total meat production in the U.S. reached more than ninety-three million pounds of product; exporting 1.7 billion metric tons (MT) of beef, 1.65 billion MT of pork, and 3.6 billion MT of poultry in 2014 (NAMI, 2016). The meat industry and all distribution linkages support many businesses and economies. All companies associated in meat production, livestock supply, distribution, retail and auxiliary sectors employ 6.2 million individuals in the U.S. alone, totaling $200 billion in wages (NAMI, 2016). Consumption of meat has transitioned from a position of social and economic prestige, to an accepted fact in the affluent lives of most Americans (Aberle et al., 2012; Bray, 1997). On average, American men consume 6.9 ounces of meat per day and women consume slightly less at 4.4 ounces per day (NAMI, 2016). Meat available for consumption has increased prominently, due to the increases in production quality via increased regulations, improved sanitation practices, and processing innovation. Initial fabrication of meat was done with the goal of preservation, through salting and packing into barrels for storage (Aberle et al., 2012). From the industrial revolution brought development of mechanical refrigeration and improved shelf-life and transportability of meat products (Aberle et al., 2012). The meat industry now has the capabilities to prolong shelf-life through multiple packaging and storage practices, such as, Modified Atmospheric Packages (MAP) and vacuum packaging (Aberle et al., 2012).

Higher quality standards and meat quality research ensures a wholesome and safe product for the consumer. Meat quality can be an ambiguous term, including components of eating quality, shelf life, wholesomeness, nutritional composition, and convenience (Apple and Yancey, 2016). Hofmann (1986), as referenced by Otto (2004), defined meat quality as the sum of all meat quality characteristics.

Meat Color

One of many important quality factors that is a determinant of consumer preference and choice is meat color. Meat purchasing decisions are influenced by color more than any other quality factor, because consumers use discoloration as an indicator of freshness and wholesomeness (Mancini and Hunt, 2005). Smith et al. (2000), as referenced by Mancini and Hunt (2005), states that inference of freshness based on color results in nearly fifteen-percent of retail beef discounts, equating to roughly one billion dollars in revenue lost annually.

Meat color is influenced by the protein Myoglobin and what molecular state is present. Although myoglobin is the protein that is heavily focused and accredited for meat color, two accompanying heme-proteins, Hemoglobin and Cytochrome C may also play a role in color characteristics of beef, pork, lamb, and poultry (Mancini and Hunt, 2005). Myoglobin is a water-soluble protein molecule, containing eight α-helices linked by short non-helical sections, formed off of a centralized Iron (Fe^{2+}) atom (Mancini and Hunt, 2005). This molecule contains a ligand-binding site, four bound pyrrole nitrogen atoms, and another binding site; creating a varying hydrophobic heme-pocket influenced by a distal histidine-64 (Mancini and Hunt, 2005). The varying valence of Iron (Fe^{2+}) and the ligand presence allows for four chemical forms of myoglobin; Deoxymyoglobin, Oxymyoglobin, Metmyoglobin, and Carboxymyoglobin (Mancini and Hunt, 2005).

Deoxymyoglobin forms when no ligand is presently bound and the central heme iron is ferrous (Fe^{2+}) (Mancini and Hunt, 2005). Deoxymyoglobin is characterized by purplish-red or purplish-pink color, due to low oxygen tension (Mancini and Hunt, 2005). Oxymyoglobin is characterized by a bright cherry-red color and while there is no alteration in the valence of the heme iron (Fe^{2+}), the previously empty ligand-binding site is occupied by a diatomic oxygen

(Mancini and Hunt, 2005). Metmyoglobin is characterized by a brownish pale color caused from over-exposure to oxygen and the heme iron becoming ferric (Fe^{3+}) (Mancini and Hunt, 2005). Furthermore, Metmyoglobin formation is not only dependent on oxygen levels, but temperature, pH, reduced activity of the NADH pool, and microbial growth in some cases (Mancini and Hunt, 2005). Carboxymyoglobin is characterized by a bright-red that is relatively very stable, but there are many questions that have not yet been answered on the actuality and biochemistry behind carboxymyoglobin (Mancini and Hunt, 2005).

Meat color is subjective through consumer perception, but is also seen as objective through the use of colorimetry and its associated numerical values (Mancini and Hunt, 2005; AMSA, 2012). Use of a colorimeter allows for quantitative values to be observed and create an objective scale of measurability for experimentation and compared to consumer preference trends. L*, a*, and b* are three values measured, which establish a three-dimensional color space (AMSA, 2012). L* represents lightness of a meat product (0 – 100), a* values corresponds to the green (negative a*) – red (positive a*) color spectrum of meat, and b* corresponds to the blue (negative b*) – yellow (positive b*) color spectrum (AMSA, 2012). Although we can interpret meat color through numerical values and utilize this for research, it is still the consumer who ultimately decides in the marketplace (Maltin et al., 2003). Carpenter et al. (2001) concluded that packaging can alter dramatically how consumers see two similar products packaged differently. Panelists reviewed two products in two different packages with nearly identical L*, a*, b* values, but visually assessed the two drastically different (Carpenter et al., 2001). Product in a Vacuum Skin Package (VSP) was described as purple or brown by only fifteen-percent of the panelists and a product in a Modified Atmospheric Package (MAP) was described as either purple or brown by forty-percent of panelists (Carpenter, 2001). These results help show insight on the variability of consumer preference and perception of color while making purchasing decisions.

Flavor

Flavor, tenderness, and juiciness are quality characteristics grouped closely together by consumers; who in the market place are the ultimate decider of meat quality (Maltin et al., 2003). Some of these characteristics are determined during the muscle to meat conversion and postmortem events (Maltin et al., 2003). The conversion occurs in three steps: pre-rigor step, rigor step, and tenderizing step (Ouali et al., 2006). Animals are slaughtered and carcasses hung in refrigerated temperatures for ten to twenty-one days dependent on packer practice and preference, allowing the conversion to take place (Ouali et al., 2006). Pre-slaughter handling, slaughter methods, and carcass chilling rate having the greatest impacts (Apple, 2010). Other contributing factors affecting these quality traits are: ratio of Fat to Lean, pH decline rate, Water Holding Capacity (WHC), flavor compounds present, and the synergistic action of enzymatic systems including calpains; μ-calpain specifically (Ouali et al., 2006).

Flavor is the subjective characteristic perceived by consumers while consuming a meat product. Many descriptors exist to describe what exact flavor is experienced and complaints of blandness or off-flavors are a focus of concern (Ouali et al., 2006). Ouali et al. (2006) state that the major contributors to flavor are lipid peroxidation together with amino acids, as well as, the generation of peptides by proteolysis. Additionally, the oxidation process is initiated as a free-radical autocatalytic chain mechanism in which pro-oxidants, especially oxygen and related radicals, will continually generate more free radicals ensuring the oxidative chain continues (Ouali et al., 2006).

Furthermore, flavor in red meat is held synonymous with fat: subcutaneous, intermuscular, and intramuscular fat. When nutrient intake is adequate fat is deposited under the skin as subcutaneous fat and between muscle groups as intermuscular fat, otherwise known as seam fat (Aberle et al., 2012). Intramuscular fat, the last to be deposited, are deposits between the fibers and muscle bundles themselves, otherwise known as marbling (Aberle et al., 2012). The type of fatty acids present is important as well. Fatty acid composition effects the firmness or softness of fat in subcutaneous, intermuscular, and intramuscular fat (Wood et al., 2003). The effect of fatty acids on meat flavor is due to the products of lipid oxidation during cooking and their involvement with the products of the Maillard reaction (Wood et al., 2003). The combination of these products form other volatiles which contribute to odor and flavor (Wood et al., 2003). Additionally, unsaturated fatty acids are particularly important and have been seen to determine species' specific flavors (Wood et al., 2003). An experiment by Rodbotten et al. (2004) developed a sensory map of meat from different species, consisting of select characteristics such as: odor, flavor, color, texture, and juiciness. The sensory profile was designed to exclude species specific traits and include general traits exclusively (Rodbotten et al., 2004). The authors concluded that flavors differed among species, but only differed in intensities (Rodbotten et al., 2004). This could be expected since meat from various species are comprised of the same elements, but of varying degrees and compositions.

Tenderness

A major factor in determining consumer satisfaction with meat products after purchase is tenderness (Maltin et al., 2003; Melody et al., 2004). The tenderizing process is enzymatic in nature and it is generally agreed that postmortem events are the main determinants of tenderness (Maltin et al., 2003). Research suggests a role of calpains, mainly calcium dependent peptidases μ-calpain or calpain 1, which are active participants in the degradation of myofibrillar proteins (such as titin, nebulin, desmin, and troponin-T) (Huff-Lonergan et al., 1996; Melody et al., 2004; Ouali et al., 2006; Aberle et al., 2012). Ouali and Talmant (1990) suggest that there are four isoforms being expressed at different levels within fast-twitch and slow-twitch muscle respectively, possibly explaining why different levels of tenderness from different muscle groups of the carcass are experienced. Huff-Lonergan et al. (1996) reported μ-calpain as the major agent for many of the proteolytic changes that occur as meat is aged. Not only is tenderness determined by enzymatic pathways and reactions, fat plays a role as well. Grunert et al. (2004) concluded that degrees of marbling contributes to tenderness, even though some consumers perceive it as a detractor. This negative viewpoint towards fat could be linked to increased health awareness and authorities recommending a reduction in dietary fat (Wood and Enser, 1997). Since intramuscular fat is consumed with the meat and external fat is often discarded, consequently degrees of marbling has an impact on the overall composition of meat cuts (Mills et al., 1992).

Tenderness can also be enhanced through mechanical tenderization such as: blade-tenderization, pre-massaging, moisture enhancement, and post-injection tumbling (Pietrasik and Shand, 2005). Pietrasik and Shand (2005) investigated the validity of post-fabrication processes through improved cooking yield, expressible moisture (EM), and textural characteristics (Warner-Bratzler Shear, Kramer Shear). The authors utilized round roasts, retail cuts from one area of an ovine carcass seen to have lower tenderness values (Pietrasik and Shand, 2005). Pietrasik and Shand (2005) concluded that blade tenderization and brine injection, significantly lowered shear force (SF) values, resulting in higher tenderness values. Blade tenderization increased tenderness through physically cleaving large muscle fibers into smaller fibers prior to cooking, whereas brine injection increased tenderness through increased water holding capacity and moisture retention (Petrasik and Shand, 2005). Furthermore, post-mortem electril stimulation has received considerable attention due to enhanced meat quality characteristics primarily tenderness and flavor (Unruh et al., 1986). Unruh et al. (1986) reported that rapid rigor onset as a result of Low Voltage Electrical Stimulation (LVES) and moderate chilling rate can result in improved tenderness, but possible decreased Water Holding Capacity (WHC) resulting in lighter-colored beef.

Water Holding Capacity

Juiciness, or the amount of moisture present, is a function of Water Holding Capacity (WHC). Water holding capacity is the ability of meat to retain naturally occurring or added moisture during the application of external forces and affects nearly every meat quality characteristic (Aberle et al., 2012). Lean muscle tissue is comprised of approximately 75% water, 20% protein, 5% lipids, while 1% is allocated to both carbohydrates, vitamins, and minerals (Aberle et al., 2012). Depending on the properties and treatment of meat after slaughter, water content may be gained or lost and is important economically since it is sold by weight (Offer et al., 1989). Water in meat is found in three forms: Bound, Immobilized, and Free (Aberle et al., 2012). Bound water is linked to charged molecules like protein and non-aqueous constituents, whereas immobilized water is held within the muscle, but is not bound to proteins, and is most affected by the muscle to meat conversion and the rigor process (Huff-Lonergan and Lonergan, 2005). Free water moves within the tissue unimpeded and weak surface forces hold this fraction of water in meat (Huff-Lonergan and Lonergan, 2005). Immobilized water is the primary water source affected by purge during the muscle to meat conversion (Huff-Lonergan and Lonergan, 2005). Knowledge of this has created a goal for packers to conserve as much of this water as possible. One factor that can enhance the retention capabilities of immobilized water is by manipulation of the myofibrillar protein net charge (Huff-Lonergan and Lonergan, 2005). Myofibrillar proteins form myofibrils or muscle strands and myofibrils form the structure of the muscle cell and its components (Huff-Lonergan and Lonergan, 2005). Net charge of myofibrillar proteins is important, because if the muscle proteins reach their isoelectric point (pI = 5.4), myfibrillar proteins essentially have a net charge of zero and pack tightly together decreasing available space, resulting in repulsion of structures in the myofibril and decreased water retention within the myofibrillar lattice spacing (Huff-Lonergan and Lonergan, 2005; Aberle et al., 2012). Product with high purge results in an unattractive appearance (pale or lacking in color) and therefore has lower consumer acceptance and loss in sales (Otto et al., 2004). Furthermore, decreased water holding capacity limits the yield in further processing (Otto et al., 2004). This process can be counteracted by guiding pH decline, rapid pH decline during the muscle to meat conversion process causes denaturation and water binding ability of many proteins (Aberle et al., 2012). Not only does pH alter water holding capacity of muscle, changes steric space effect water holding ability also. Myofibrils make up a large portion of the muscle cell, accounting for 85% of the volume within muscle, and believed to hold more than 80% of the water present through capillary forces (Aberle et al., 2012). Millman et al. (1981, 1983), as quoted by Huff-Lonergan and Lonergan (2005), reported that in living muscle, sarcomeres remain isovolumetric, meaning the amount of water within the filament structure does not change only the location. However, as muscle enters the rigor process, crossbridges form between the thick and thin filaments (Offer and Trinick, 1983). The resulting structure has decreased sarcomere filament spacing and forces sarcoplasmic fluid from between the myofilaments to the extramyofibrillar space (Offer and Trinick, 1983). Hoinkel et al. (1986) reported that purge, or expelled sarcoplasmic fluid, can increase linearly to the decrease in length of sarcomeres. In addition, decreased length in sarcomeres can influence shrinkage and lead to the expulsion of water from the myofibrillar structure; ultimately reducing overall water holding capacity (Bendall and Swatland, 1988).

Effects of Co-Product Use on Meat Quality

Since consumer preference for high quality meat and the role inputs of production play in product quality is important, research on how feeding by-products and co-products effect this is critical. Many studies have been conducted assessing the effects of by-product incorporation in feeding protocols on meat quality. In swine feeding, studies have reported that feeding as much as thirty-percent of DDGS will not only impact fat quality and composition, but also reduce carcass performance and meat quality characteristics (Apple, 2010; Rickard et al., 2012). Poor carcass characteristics and fat quality is detrimental and a concern for packers both in further processing and products not potentially meeting export criteria (Carr et al., 2005). However, losses in quality from feeding high levels of DDGS can possibly be recovered by removal of DDGS during the late period of finishing diets (Apple, 2010). Additionally, incorporation of ractopamine hydrochloride can further negate the effects of DDGS through improved growth performance and increased carcass weights (Wiegand et al., 2011; Rickard et al., 2012).

Furthermore, studies have shown the efficacy of supplemental feeding of by-products, in beef cattle production, from ethanol production. Segers et al. (2014) concluded that feeding co-product blends to early-weaned calves produced carcasses similar to those fed a traditional corn-diet. Furthermore, the authors indicate that the inherent variation in nutrient profiles of co-product feedstuffs constitutes further research (Segers et al., 2014). Contrary to swine feeding, feeding DDGS at a thirty-percent dry matter basis in beef cattle has resulted in no detrimental effects on performance, carcass characteristics, and sensory attributes (Leupp et al., 2009). This data was further supported by Koger et al. (2010), who concluded that distillers grains, wet or dry, has little to no effect on meat quality, retail display of ground beef, or fatty acid profile of longissimus muscle (LM). Although, it has been mentioned that feeding high levels of DDGS may negatively affect steak color and steers may need to be marketed early if excess fattening is observed (Koger et al., 2010; Leupp et al., 2009).

Since research on WBG inclusion in beef cattle, effect on meat quality, and carcass characteristics is lacking, further research is necessary. Linton (1973), as referenced by Shand et al. (1998), observed that brewery by-products had no effect on carcass characteristics or meat quality, but further research was indicated as necessary. Steers fed either conventional barley-based, Wet Distillers Grains (WDG), or WBG based rations during backgrounding and finishing had similar meat quality and eating properties (Shand et al., 1998). While there has been no indication that animals fed brewery by-products are superior to conventional or barley based diets, neither are there negative effects observed from these products, primarily eating quality (Shand et al., 1998). Homm et al. (2008) further supported this, concluding that feeding fifteen to forty-five percent WBG in feedlot diets supported animal performance and carcass characteristics similar or greater to traditional finishing diets. Additionally, feedlot performance and carcass quality was found to be very acceptable when either twenty-five percent or fifty-percent of the total ration was derived from brewers grains, in their dried form, compared to a ninety-five percent corn ration (Preston et al., 1973). As echoed by Shand et al. (1998), few reports of beef trials of animals fed WBG have been published, which may give producers and feedlots opportunities to take advantage of these alternative feeds to provide quality product for the consumer.

The Illinois livestock industry is expected to experience significant growth, with total number of "Notices of Intent to Construct" filed by local producers, increasing 137% between 2010 to 2014 (DIS, 2015). Although cattle inventories are low compared to the past, record high beef prices will continue to drive prices and further incentivize producers to expand in livestock production (DIS, 2015). Illinois alone produced 279.1 million pounds in June of 2016, equating to 101% of production from the year prior (USDA-NASS, 2016). Since feedstuffs often encompass the largest portion of production costs, more emphasis will be placed on the cost effective use of alternative feed sources as expansion continues (Hersom, 2006). The revival of micro-brewery production has renewed an age-old relationship between brewers and livestock producers (Landry, 2002). This opportunity enables producers to benefit from WBG to be utilized in cattle feeding, all while creating a local partnership with micro-brewers. Moreover, much of the literature available on WBG focuses on product from large scale brewers and does not address increases from micro-breweries and possible product differences. As producers seek to utilize this local and economical alternative feed source, further research on the efficacy of WBG inclusion is necessary.

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