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ARTICLE

Effects of Muscle and Finishing Diets Containing Distillers Grains with Low Moisture Levels on Fatty Acid Deposition in Two Novel Value-added Beef Cuts

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Abstract This study evaluated the effects of muscle and dietary treatments including CORN, dry distillers grains (DDGS), and modified distillers grains (MDGS) on fatty acid (FA) deposition in two novel value-added beef cuts (Petite Tender - *M. teres major* - TM, and Flat Iron – *M. infraspinatus* - INF). Crossbred steers were randomly assigned to one of three dietary treatments (CORN, 40% of DDGS with 8%–12% of moisture, and 40% of MDGS with 45%–55% of moisture - DM basis) and fed for 190 days. The TM muscle had higher concentrations of ω6 FAs and polyunsaturated fatty acids (PUFA) when compared to INF. Beef fed CORN showed greater C16:0 and lower C18:0 values when compared to beef fed distillers grains (DGS). Beef fed DDGS had higher concentrations of ω6 FAs when compared to MDGS. Different moisture levels only affected FAs containing 14, 16, and 17 carbons. Different muscles, diets, and moisture levels of DGS affected the deposition of FAs in the lean.

Keywords beef, distillers grains, fatty acids, *infraspinatus*, *teres major*

Introduction

The inclusion of Distillers Grains (DGS) in finishing diets has become a common practice in U.S. feedlots due to the exponential growth of the ethanol industry (Cleveland et al., 2017; de Mello et al., 2018; Ribeiro et al., 2018). In 2018, U.S. ethanol plants produced 16,061 million gallons of ethanol increasing the availability of byproducts suitable to be used as animal feed (RFA, 2018).

During the milling process, final levels of moisture in DGS are determined by the number of times that solids pass through the dryer. Wet DGS (WDGS) contain approximately 65% to 70% of moisture, modified DGS (MDGS) contain 50% to 55%,

and dry DGS [dry distillers grains (DDGS)] contain 10% to 12% moisture (Lardy, 2007; Nuttelman et al., 2011). When included in finishing diets, DGS usually impact overall beef quality by compromising lipid and color stability of beef (de Mello et al., 2018; Mello et al., 2012; Roeber et al., 2005). Previous studies showed that feeding WDGS increases the deposition of polyunsaturated fatty acids (PUFA) in the lean (de Mello et al., 2018; de Mello et al., 2012; Schoonmaker et al., 2010). These FAs are more susceptible to oxidation when compared to saturated fatty acids (SFAs) due to the weakness of double bonds. In addition, lipid peroxidation byproducts affect oxymyoglobin stability increasing the susceptibility of this pigment to oxidation (Papuc et al., 2017), which compromises meat color due to metmyoglobin formation.

FA composition of adipose tissue and muscle in meat animals is determined by a number of factors including breed, genotype, age, gender, but mostly animal diet and rumen microbial metabolism (Hwang and Joo, 2017; Liu et al., 2015; Vahmani et al., 2015; Wood et al., 2008). Regarding PUFA concentrations, ruminal microbes produce branched-and odd-chain FAs and precursors generating PUFA biohydrogenation products that are further absorbed at the duodenum and transferred to the muscle (Vahmani et al., 2015). When feeding DGS, some of its lipid content may be protected from rumen biohydrogenation (Vander Pol et al., 2009). This also increases the amounts of unsaturated fatty acids (FAs) reaching the duodenum, leading to higher absorption and deposition of these FAs in the lean. However, final concentrations of PUFA in muscle also depend on fiber types and the expression of desaturases in the tissue (Bartoň et al., 2006, Wood et al., 2008). Desaturases convert SFA into unsaturated in the lean and may also be regulated by lipid content of the feedstuff (Waters et al., 2009). In this study, we evaluated the dietary effects of the inclusion of low moisture distillers grains (DDGS and MDGS) in finishing diets as well as muscle effect on FA profile of two novel value-added cuts, the Petite Tender (*M. teres major*, TM); and Flat Iron (*M. infraspinatus*, INF). Both cuts were introduced in the north American market after an extensive muscle profiling investigation conducted to improve value of underutilized cuts (Jones et al., 2001). Although previous research conducted by our team investigated the effects of feeding DGSs on the FA profile of the INF (de Mello et al., 2018), research to determine the effects of feeding low versus dry moisture DGSs on FA profile of value-added cuts including the INF and TM was not yet reported.

Materials and Methods

Animals, diets, and sample collection

A total of twenty-four crossbred steers (n=24, 8 steers per treatment), under 30 months old, were randomly finished with corn-based diets with three inclusion levels of DGS, 0% DGS (CORN), 40% DM of DDGS, and 40% DM of MDGS (Table 1). Nutrient composition and digestibility for the three diets were previously reported by Garland et al. (2019) (CORN=CON, DDGS=DDGS, and MDGS=WDGS). Steers were fed 190 days prior to slaughter. After slaughter, shoulder clods (IMPS 114, USDA-AMS, 2014) were commercially acquired from a USDA inspected facility and transferred under refrigeration to the University of Nevada, Reno Meat Quality Laboratory. All animal care and management procedures were approved by the University of Nebraska—Lincoln Institutional Animal Care and Use Committee (Garland, 2018). After 7 days of aging, the *M. infraspinatus* (INF, IMPS 114D PSO1, USDA-AMS, 2014) and *M. teres major* (TM, IMPS 114F¸ USDA-AMS, 2014) were fabricated from the clods. Muscles were trimmed of subcutaneous fat and connective tissue and an aliquot weighing approximately 150 g was sampled for further analysis.

Sample preparation, and proximate and fatty acids profile analyses

Samples were pulverized with liquid nitrogen (−174°C) using a blender (Waring Commercial, model 51BL32, Torring,

Table 1. Composition (%DM) and fatty acids weight percentage of finishing diets[1)]

Ingredients (% DM)	CORN	DDGS	MDGS	Ingredients (% DM)	CORN	DDGS	MDGS
High moisture corn	39.25	20.5	20.5	C18:2 ω6	53.52	52.92	53.01
Dry rolled corn	39.25	20.5	20.5	C18:3 ω6	0.39	0.39	0.39
DDGS	-	40.0	-	C18:3 ω3	1.54	1.45	1.48
MDGS	-	-	40.0	C20:1 ω9	0.26	0.26	0.25
Corn silage	15.0	15.0	15.0	C20:2 ω6	0.03	0.03	0.04
Supplement	6.5[2)]	4.0[3)]	4.0[3)]	CLA 18:2c9t11	0.00	0.01	0.00
Fatty acids				C20:3 ω6	0.21	0.18	0.20
C4:0	0.08	0.02	0.02	C20:4 ω6	0.00	0.01	0.00
C5:0	0.01	0.01	0.01	C20:5 ω3	0.04	0.02	0.03
C12:0	0.02	0.02	0.03	C24:0	0.25	0.16	0.08
C14:0	0.07	0.07	0.07	C22:3 ω3	0.14	0.18	0.14
C15:0	0.01	0.02	0.01	C22:4 ω6	0.04	0.00	0.00
C15:1	0.00	0.02	0.00	C22:5 ω3	0.02	0.02	0.00
C16:0	12.15	13.36	13.38	C22:6 ω3	0.06	0.06	0.04
C16:1 ω7	0.12	0.13	0.13	SFA	14.56	15.75	15.72
C17:0	0.08	0.08	0.08	PUFA	55.99	55.30	55.35
C17:1 ω5	0.03	0.03	0.04	ω6	54.19	53.55	53.66
C18:0	1.89	2.01	2.03	ω3	1.80	1.74	1.69
C18:1t ω6	0.00	0.04	0.04	ω6:ω3	30.22	30.72	31.73
C18:1 ω9	27.27	26.23	26.37	Total	98.97	98.52	98.67
C18:1d11 ω7	0.74	0.76	0.77	Others	1.03	1.48	1.33
C18:2t ω6	0.00	0.03	0.03				

[1)] Weight percentage values are relative percentage of all peaks observed by gas chromatography.
[2)] Limestone, tallow, urea (1.285%), SoyPass®, salt, minerals, vitamins A, D, and E, Rumensin®90, and Tylan®40.
[3)] Fine ground corn, limestone, tallow, salt, minerals, vitamins A, D, and E, Rumensin®90, and Tylan®40.
DDGS, dried distillers grains plus solubles; MDGS, modified distillers grains plus solubles; SFA, saturated fatty acids; PUFA, polyunsaturated fatty acids.

CT). Total fat was determined by ether extraction using the Soxhlet procedure (AOAC, 2005).

Fatty Acids Methyl Esters (FAME) of both muscles were obtained by following the methodologies of Folch et al. (1957), Morrison and Smith (1964), and Metcalfe et al. (1966). One gram of pulverized muscle tissue was homogenized with 5 mL of 2:1 chloroform:methanol (v/v) and extraction of total lipids was allowed to happen for 1 h at room temperature. The homogenate was filtered through a Whatman #2 filter paper and the final volume was brought to 10 mL in a screw cap glass tube. Further, 2 mL of a 0.74% KCl solution was added in the tube, which was vortexed for 5 s. Samples were centrifuged at 1,000×g for 5 min and following centrifugation, the aqueous phase (top layer) was aspirate off. Samples were then evaporated to dryness under a nitrogen atmosphere to avoid oxidation. Subsequently, 0.5 mL of a 0.5 M NaOH in methanol was added into the tube, which was vortexed and heated for 5 min at 100°C. For methylation, 0.5 mL of boron trifluoride in 14% methanol was homogenized with the sample and heated for 5 min at 100°C. One mL of a saturated salt solution to retain the polar material of the sample and one mL of hexane was homogenized with the sample. Finally, samples were centrifuged

at 1,000×g for 5 min to separate the hexane layer containing the FAME. The content of the layer was transferred to a GC vial, which was purged with nitrogen and analyzed by gas chromatography (Agilent Technologies, model 6890 series). FA profile was analyzed using a capillary column (Chrompack CP-Sil 88–0.25 mm×100 m). Oven temperature was programmed to raise from 140°C to 220°C at 2°C/min and held at 220°C for 20 min. Injector and detector temperature were maintained at 270°C and 300°C, respectively. The carrier gas was hydrogen at a flow rate of 30 mL/min. FAs were identified by comparison of retention times with known standards and expressed as a percentage of total FAME extracted.

Statistical analysis

Data were analyzed as a completely randomized design whereas dietary treatments and muscle were considered the fixed effects. Individual animals were used as experimental units and the experiment was arranged as a 3×2 factorial. The following model was used: $Y_{ijk}=\mu+\alpha_i+\beta_j+(\alpha\beta)_{ij}+\varepsilon_{ijk}$, where Y_{ijkl} was the final FA concentration, μ was the grand mean across the treatments included in the experiment, α_i was the effect of dietary treatment from the grand mean specific to the i levels (CORN, DDGS, and MDGS), β_j was the effect of muscle from the grand mean specific to j levels (INF and TM), $(\alpha\beta)_{ij}$ was the interaction between both effects, and ε_{ijk} was the error of the experiment. Data were analyzed using the GLIMMIX procedure of SAS® (9.4 package, SAS Institute, Inc., USA) and when comparisons were significantly different at $p\leq0.05$, LSMEANS and DIFF functions were used to separate the means.

Results and Discussion

No interaction between fixed effects were observed for any FA (Table 2). Results related to muscle effects are shown in Table 3. As expected, INF had the highest fat content. Similar results were previously reported by Yeh et al. (2018) and the University of Nebraska, Lincoln (2018). This is possibly due to a higher number and larger size of adipocytes found in INF when compared to TM (Yang et al., 2006; Yeh et al., 2018). Although the highest concentration of the major monounsaturated FA (C18:1 ω9) was observed in INF, some monounsaturated FAs (C14:1t ω5, C18:1d11 ω7) and overall ω6 and PUFA concentrations were higher in TM. Lengyel et al. (2003) previously reported a significant muscle location effect on FAs when evaluating beef with different fat content. In their study, PUFA and ω6 FA levels were significantly higher in a leaner muscle (*M. semitendinosus*), when compared to either the *M. psoas major* or *M. longissimus thoracis et lumborum*. Although muscles evaluated by the authors were different, their results are in agreement with our study based on the total fat content of each muscle. The total fat content (neutral and phospholipids) of the muscle directly impacts the proportions of FAs. Since phospholipids are present in cell membranes, their proportion is usually constant when compared to neutral lipids, which increases as total fat increases (Wood et al., 2008). Phospholipids in beef have higher concentrations of PUFA and ω6 when compared to neutral lipids Warren et al. (2008). Total meat lipids are composed by polar lipids (mainly phospholipids) located in cell membranes and neutral lipids (mainly triacylglycerols) located in adipocytes. Higher concentrations of PUFA in phospholipids is due to its membrane function. Since phospholipids are membrane components, PUFA proportion is strictly controlled and consistent. Differently, PUFA in triacylglycerols may be diluted by *de novo* FA synthesis causing a decrease in its concentrations (De Smet et al., 2004). Additionally, although INF and TM are both located in the clod, they have different fiber composition. Kirchofer et al. (2002) showed that INF has more α and β-red fibers (approximately 75%), when compared to TM, which is ventrally attached to INF, and has approximately 68% of red fibers. In our study, higher deposition of PUFA and ω6 FAs was observed in a muscle that has higher percentage of white (fast) fibers, suggesting that

Table 2. P-values for fixed effects of dietary treatment and muscle effects

Fat % and fatty acid	Dietary treatment	Muscle	Dietary treatment×muscle	Fat % and fatty acid	Dietary treatment	Muscle	Dietary treatment×muscle
Fat%	0.0971	<0.0001	0.2711	C18:3 ω3	<0.0001	0.1592	0.4998
C8:0	0.0331	0.4203	0.2120	C20:0	0.1303	0.6489	0.4075
C10:0	0.2820	0.4636	0.6934	CLA 18:2c9t11	0.5352	0.7265	0.8650
C12:0	0.1641	0.5755	0.7388	C20:3 ω6	0.8001	0.0018	0.9618
C14:0	<0.0001	0.5032	0.2599	C20:4 ω6	0.0764	0.0002	0.7287
C14:1t ω5	0.4443	0.0456	0.8906	C22:4 ω6	0.2404	0.3254	0.8662
C14:1 ω5	<0.0001	0.8327	0.7381	C20:5 ω3	0.6077	0.4080	0.1886
C15:0	0.5572	0.7464	0.6932	C22:5 ω3	0.1837	0.6282	0.8063
C16:0	<0.0001	0.5365	0.2581	C22:6 ω3	0.4325	0.6537	0.6757
C16:1 ω7	<0.0001	0.1954	0.9095	Total trans	0.0190	0.1891	0.9613
C17:0	<0.0001	0.4236	0.9140	PUFA	0.0031	0.0048	0.7626
C17:1 ω5	0.0021	0.2852	0.4959	SFA	0.2343	0.7418	0.7130
C18:0	0.0010	0.9140	0.9076	ω6	0.0008	0.0049	0.8863
C18:1t[1)]	0.0111	0.2527	0.9183	ω3	0.6676	0.1932	0.2831
C18:1 ω9	0.2484	0.0118	0.7359	ω6:ω3	0.0162	0.2809	0.6844
C18:1d11 ω7	<0.0001	0.0108	0.3761	Total	0.8520	0.0049	0.9989
C18:2 ω6	<0.0001	0.0466	0.7945	Others	0.8520	0.0049	0.9989
C18:2t ω6	0.7615	0.3067	0.1824				

[1)] Includes transvaccenic ω7, elaidic ω9, and ricinelaidic ω9 isomers.
PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids.

deposition of these FAs is also associated with different types of fibers and their metabolism. This is in agreement with Hwang and Joo (2016), who observed higher PUFA deposition in the *M. Semimembranosus* (22% of red fibers) when compared to the *M. Psoas major* (46% of red fibers) (Joo et al., 2017). Therefore, although this study suggested a possible link between cell membrane and final FA content in beef, further lipidomics studies evaluating the effects of fiber types and concentrations of PUFA and ω6 in their membranes are necessary to understand if there is a cell membrane effect on total FA composition.

Dietary treatment effects are shown in Table 4. Overall, feeding DDGS and MDGS increased levels of C18:0, PUFA, and all ω6 FAs when compared to the CORN diet. In previous research, Mello et al. (2012) showed greater amounts of PUFA and ω6 FAs in INF from steers fed 30% of WDGS (DM) when compared to INF from steers fed corn. Similar results were also presented by Domenech-Pérez et al. (2017), and Ribeiro et al. (2018) who observed similar effects of feeding DGS on FA profile of beef. In addition, the increase of C18:0 in the lean, was also observed by de Mello et al. (2012) who evaluated the effects of diets containing 40% of MDGS (lower levels of moisture when compared to WDGS) in comparison with a corn only based diet. In their research, authors observed greater concentrations of C18:0, PUFA, and all ω6 FAs in the *M. longissimus thoracis* from beef fed MDGS when compared to steers fed corn. In this study, beef from steers fed CORN had higher concentrations of some saturated and monounsaturated FAs such as C14:0, C16:0, C16:1 ω7, and C18:1d11 ω7. Except for C14:0, similar results were observed by Mello et al. (2012), de Mello et al. (2012), and de Mello et al. (2018)

Table 3. Weight percentage of fatty acids of flat iron (INF) and petite tender (TM) from beef steers[1)]

Fat% and fatty acid	Muscle		SEM	Fat% and fatty acid	Muscle		SEM
	INF	TM			INF	TM	
Fat%	8.31[a]	5.56[b]	0.5921	C18:3 ω3	0.34	0.37	0.0164
C8:0	0.02	0.03	0.0090	C20:0	0.09	0.10	0.0115
C10:0	0.08	0.10	0.0167	CLA 18:2c9t11	0.33	0.32	0.0312
C12:0	0.10	0.12	0.0214	C20:3 ω6	0.20[b]	0.29[a]	0.0274
C14:0	3.01	2.92	0.0903	C20:4 ω6	0.51[b]	0.75[a]	0.0605
C14:1t ω5	0.08[b]	0.13[a]	0.0226	C22:4 ω6	0.03	0.05	0.0304
C14:1 ω5	0.66	0.65	0.0611	C20:5 ω3	0.12	0.16	0.0394
C15:0	0.56	0.57	0.0298	C22:5 ω3	0.13	0.14	0.0193
C16:0	24.53	24.33	0.2246	C22:6 ω3	0.02	0.02	0.0052
C16:1 ω7	2.80	2.59	0.1176	Total trans	4.23	4.71	0.2580
C17:0	1.47	1.43	0.0419	PUFA	5.71[b]	6.73[a]	0.3422
C17:1 ω5	1.01	0.95	0.0370	SFA	43.64	43.42	0.4637
C18:0	13.74	13.80	0.3934	ω6	4.77[b]	5.71[a]	0.3160
C18:1t[2)]	3.68	4.09	0.2538	ω3	0.61	0.70	0.0516
C18:1 ω9	36.38[a]	34.28[b]	0.7978	ω6:ω3	8.16	8.91	0.4855
C18:1d11 ω7	1.58[b]	1.74[a]	0.0618	Total	95.55[a]	94.59[b]	0.3233
C18:2 ω6	3.90[b]	4.45[a]	0.2652	Others	4.45[b]	5.41[a]	0.3233
C18:2t ω6	0.13	0.17	0.0267				

[1)] Weight percentage values are relative percentage of all peaks observed by gas chromatography.
[2)] Includes transvaccenic ω7, elaidic ω9, and ricinelaidic ω9 isomers.
[a,b] Means having different superscripts within row are significantly different.
TM, *teres major*.

when comparing the effects of diets containing corn versus either WDGS or MDGS.

Although FA composition of dietary treatments was very similar (Table 1), Díaz-Royón et al. (2012) reported that DDGS have higher concentrations of C16:0 and C18:0 when compared to corn. During digestion, SFAs largely escape the rumen without being degraded or metabolized and have little effect on the rumen environment (Havlin et al., 2015). The predominant SFA in corn and DGS-based diets is the C16:0 followed by C18:0 (Díaz-Royón et al., 2012). Overall, the deposition of both FAs in the lean significantly differ. From 13% to 16% of C16:0 found in corn and DGS, respectively (Díaz-Royón et al., 2012), concentrations of this FA in the lean usually reach up to 25% (Table 3). For C18:0, meat from cattle fed corn and DGS diets, contain approximately 1.8% to 2.2% of this FA. However, values in the lean may vary from 12% to 15% in the lean (ninefold). Higher values of C18:0 in beef are due to the conversion of C18:2, the predominant FA in corn-based diets (around 57%). Ward et al. (1964) reported that 93% of C18:2 is converted to C18:0. Proportionally, there is a smaller deposition of C16:0 when compared to C18:0 the lean. This could be associated to the high digestibility of C16:0 (Doreau and Ferlay, 1994). Lock et al. (2006) showed that intestinal absorption of C16:0 is usually higher when compared to C18:0. Therefore, final deposition of C16:0 and C18:0 may not depend only on amounts reaching the duodenum but also on additional factors related to hydrolysis of unsaturated FAs that may be converted to SFA (Jenkins et al., 2008), ruminal microbial activity, total amount availability, transit from the gut to the bloodstream, and how the deposition of this FA in the

Table 4. Weight percentage of fatty acids[1)] of beef (INF and TM) from steers fed CORN, DDGS, and MDGS

Fat% and fatty acid	Dietary treatment			SEM	Fat% and fatty acid	Dietary treatment			SEM
	CORN	DDGS	MDGS			CORN	DDGS	MDGS	
Fat%	6.56	6.39	7.86	0.5128	C18:3 ω3	0.32^{b}	0.36^{ab}	0.39^{a}	0.0214
C8:0	0.02^{b}	0.05^{a}	0.01^{b}	0.0110	C20:0	0.08	0.12	0.09	0.0141
C10:0	0.08	0.11	0.07	0.0204	CLA 18:2c9t11	0.36	0.31	0.30	0.0368
C12:0	0.10	0.15	0.08	0.0262	C20:3 ω6	0.26	0.25	0.23	0.0237
C14:0	3.42^{a}	2.98^{b}	2.51^{c}	0.1106	C20:4 ω6	0.69^{a}	0.67^{ab}	0.52^{b}	0.0524
C14:1t ω5	0.09	0.13	0.11	0.0196	C22:4 ω6	0.07	0.03	0.03	0.0181
C14:1 ω5	0.88^{a}	0.63^{b}	0.45^{c}	0.0611	C20:5 ω3	0.13	0.11	0.18	0.0483
C15:0	0.59	0.54	0.58	0.0365	C22:5 ω3	0.17	0.13	0.11	0.0236
C16:0	25.77^{a}	24.69^{b}	22.82^{c}	0.2750	C22:6 ω3	0.02	0.02	0.01	0.0063
C16:1 ω7	3.40^{a}	2.59^{b}	2.11^{c}	0.1440	Total trans	3.85^{b}	4.40^{ab}	5.16^{a}	0.3160
C17:0	1.47^{b}	1.24^{c}	1.65^{a}	0.0513	PUFA	5.43^{b}	6.95^{a}	6.29^{a}	0.2963
C17:1 ω5	1.10^{a}	0.86^{b}	0.97^{ab}	0.0453	SFA	43.79	44.06	42.74	0.5679
C18:0	12.23^{b}	14.16^{a}	14.91^{a}	0.4818	ω6	4.42^{b}	6.01^{a}	5.29^{a}	0.2736
C18:1t[2)]	3.24^{b}	3.80^{ab}	4.62^{a}	0.3109	ω3	0.64	0.62	0.70	0.0633
C18:1 ω9	35.38	34.48	36.14	0.6909	ω6:ω3	7.39^{b}	9.90^{a}	8.32^{ab}	0.5946
C18:1d11 ω7	1.89^{a}	1.48^{b}	1.61^{b}	0.0535	Total	95.19	94.97	95.05	0.2799
C18:2 ω6	3.25^{b}	4.91^{a}	4.37^{a}	0.2297	Others	4.80	5.02	4.95	0.2799
C18:2t ω6	0.16	0.16	0.13	0.0327					

[1)] Weight percentage values are relative percentage of all peaks observed by gas chromatography.
[2)] Includes transvaccenic ω7, elaidic ω9, and ricinelaidic ω9 isomers.
[a,b] Means having different superscripts within row are significantly different.
DDGS, dried distillers grains plus solubles; MDGS, modified distillers grains plus solubles.

lean occurs.

Feeding DGS usually leads to the modification of beef FA profile since some FAs may be protected from biohydrogenation (Klopfenstein et al., 2008) and because its lipid content has greater digestibility when compared to corn (Lodge et al., 1997). Wood et al. (1963) reported that around 33% to 50% of C18:2 is converted to C18:1t. Greater amounts of PUFA and ω6 FAs observed in beef fed DGS when compared to CORN-fed are due to higher levels of C18:1t, C18:1, and C18:2 FAs that usually reach the duodenum when DGS is fed (Vander Pol et al., 2009; Xu et al., 2014). Increased values of those FAs in the lean are due to the high digestibility of fat content in DGS when compared to CORN. Overall, DGS has 85%–95% of total digestible nutrients (TDN). During milling, starch is removed and the energy obtained is primarily from fiber fat whereas in corn, the starch may depress fiber digestion (Stewart et al., 2017). Differences in amounts of FAs containing 14, 16, and 17 carbons led by different moisture levels of DGS may be associated to the final concentration of FAs in the diets. The drying process of WDGS after milling can concentrate some SFA and modify the digestibility of fats, which may affect FAs reaching the duodenum after digestion. Possibly, this also led to greater concentrations of total trans FAs in beef fed MDGS, which were also reported by de Mello et al. (2012) in comparison to corn only fed beef. Regarding CLAs, enzymatic activity seems to play an important role in FA transformation. Desaturases introduce double bonds in FAs creating unsaturation of FAs, recycling or generating new PUFA (Lee et al., 2016). For example, Δ^{9}-desaturase transforms C18:2 into CLA 18:2c9t11.

However, in our study, no dietary effects were observed on CLA concentrations.

When comparing DDGS versus MDGS, different moisture levels of DGS affected only FAs containing 14, 16, and 17 carbons. Beef from steers fed DDGS had higher concentrations of SFAs including C14:0 and C16:0 and monounsaturated C14:1 ω5 and C16:1 ω7 FAs when compared to MDGS, whereas MDGS-fed beef had greater values of C17:0 when compared to DDGS-fed beef. In addition, feeding MDGS led to higher values of total trans FAs when compared to CORN whereas ω6:ω3 was higher in DDGS-fed beef than CORN-fed beef. To our knowledge this is the first research that evaluated isolated effects of moisture levels of DGS in finishing diets on FA deposition in the lean.

Conclusion

Different muscles from the same beef primal have different FA profiles. Leaner cuts containing more white fibers have higher proportions of PUFA and ω6 FAs when compared to fatter cuts containing more red fibers. Feeding DGS increases PUFA and ω6 FAs of beef, whereas different moisture levels of DGS may affect final concentrations of SFA in the lean, mainly FAs containing 14, 16, and 17 carbons. Different FA profiles of both muscles and effects on profiles caused by dietary treatments may differently affect shelf life and flavor since lipid oxidation plays an important role in color stability and flavor development when beef is packaged in oxygen permeable films and subsequently cooked. Extension of shelf-life and improvement of lipid stability of beef cuts containing higher levels of PUFA can be achieved by using modified atmosphere and antioxidants.

Conflicts of Interest

The authors declare no potential conflicts of interest.

Author Contributions

Conceptualization: Nörnberg JL, Calkins CR, de Mello A. Data curation: Giotto FM, Fruet APB. Formal analysis: Fruet APB, de Mello A. Methodology: de Mello A, Calkins CR. Software: de Mello A. Validation: Nörnberg JL, Calkins CR, de Mello A. Investigation: de Mello A. Writing - original draft: Giotto FM, de Mello A. Writing - review & editing: Giotto FM, Fruet APB, Nörnberg JL, Calkins CR, de Mello A.

Ethics Approval

Samples used in this experiment were obtained commercially directly from a USDA inspected facility. Therefore, no ethics approval was required.

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