Tropical Animal Health and Production (2021) 53: 162
https://doi.org/10.1007/s11250-021-02615-4

REGULAR ARTICLES

Lipid rich diet from sunflower seeds can alter the proportion of fatty acids on hybrid Beefalo × Nellore cattle

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Received: 27 July 2020 / Accepted: 8 February 2021 / Published online: 15 February 2021

Abstract

We evaluated the lipid level effects in the diet on performance, carcass, and meat characteristics of forty-eight steers and heifers, F1 Beefalo (*Bostaurus taurus* × *Bison bison* hybrid) × Nellore (*Bos taurus indicus*), 22 months old, being 24 steers (393.2 ± 15 kg) and 24 heifers (278.4 ± 8 kg). The animals were distributed in a completely randomized design in a 4 × 2 factorial scheme (lipid levels in diet 55-, 65-, 75-, and 85-g/kg dry matter obtained by whole sunflower grain *Helianthus annuus* and two sexes). Increased amounts of sunflower grain in diet linearly reduce the proportion of saturated fatty acids (FA) in longissimus thoracis. Diets containing up to 85 g/kg of lipid can be used without negative effects on intake, carcass, and meat quality of Beefalo-Nellore steers and heifers and can be an effective strategy to reduce the proportion of saturated FA and increase unsaturated FA on the meat, which can be beneficial for human consumption.

Keywords Fatty acids · Lipid · Meat quality · Oilseeds

Introduction

Lipid sources are provided to ruminants in form of grains or co-products by oil extraction with the purpose of increasing the energy density of the diet and enriching the lipid profile of meat and milk produced. In this context, maximum levels of 16 to 20% of diet metabolizable energy of lipid inclusion to preserve rumen microbial metabolism, fatty acid absorption, oxidation, and feed intake should be considered (Palmquist 1994). In addition, the strategic use of lipid sources can have different implications for the performance and product quality of different genetic resources and these implications must be evaluated.

Ruminant meat has low polyunsaturated fatty acid content (Enser et al. 1996). In the rumen, the unsaturated FAs are extensively hydrogenated prior to their absorption and incorporation into muscle and milk fat (Lashkari et al. 2020a; Lashkari et al. 2020b; Lashkari et al. 2020c). Thus, the definition of appropriate diets and rumen conditions to promote the accumulation of polyunsaturated FA and their intermediates in beef is a challenge (Mapiye et al. 2013).

Technological processing, in order to protect feed fat or intact fat sources like oilseeds, could lead to better absorption of the FA in the intestine (Chilliard et al. 2007). This can reduce ruminal modification of dietetic FA (Aldrich et al. 1997), and increase their absorption in the intestine and deposition in the muscle (Gibb et al. 2004; Mir et al. 2003; Wood et al. 2004).

Feeding whole sunflower grain shown to be an effective approach to produce meat with interesting FA profile (linoleic acid, vaccenic acid, and conjugated linoleic acid) from the human health perspective (Ivan et al. 2001; Mapiye et al. 2013; Almeida et al. 2015). Moreover, whole sunflower grain is highly effective in reducing both protozoa numbers and ammonia N concentrations in rumen fluid (Ivan et al. 2003), which would improve N utilization by ruminants. However, the extent of biohydrogenation of FA supplied by oilseeds can

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be affected by different factors and no information was found in the literature about the optimum level of dietary whole sunflower grain required for the production of hybrid Beefalo × Nellore cattle fed a sorghum-based diet. In addition, studies need to be carried out to determine accurately the differences that may possibly exist due to genotypic factors.

Our hypothesis was that increasing unsaturated FA intake by feeding increasing levels of whole sunflower grain could have benefits on meat characteristics and FA profile. Therefore, the aim of this study was to evaluate intake, performance, carcass traits, FA profile on the meat of Beefalo × Nellore steers and heifers fed diets with four lipid contents (55, 65, 75, and 85 g/kg), obtained by the inclusion of different levels of whole sunflower grain.

Materials and methods

Ethical considerations

The experiment was carried out at Dom Bosco Catholic University and the Federal University of Mato Grosso do Sul between the months of July and October. All animal care and handling procedures were ethically standardized and approved by the Animal Care and Use Committee of the Federal University of Mato Grosso do Sul (Protocol 654/2014).

Animals and experimental diets

Forty-eight 22-month-old F1 Beefalo (*Bos taurus taurus* × *Bison bison* hybrid) × Nellore (*Bos taurus indicus*) cattle were used. After 21 days of adaptation to individual pens and diets, 24 steers averaging 393.2 ± 15 kg of body weight (BW) and 24 heifers averaging 278.4 ± 8 kg of BW, the animals were distributed in a completely randomized design in a 4 × 2 factorial scheme. Experimental treatments consisted of four lipid levels (55-, 65-, 75-, and 85-g/kg DM, Table 1) and two sexes (heifers and steers).

All diets were isonitrogenous (104-g/kg DM) and isoenergetic (11.6 MJ of ME/kg DM). Diets were offered twice a day (09h00 a.m. and 03h00 p.m.) ad libitum, allowing 50 g/kg (as fed) of refusals. Intake was recorded daily. Freshwater was available throughout the experiment. The concentrate to roughage rate was sorghum silage 373 g/kg:concentrate 627 g/kg.

Animals were weighed at the beginning and every 4 weeks until the end of the experiment after an overnight fast (feed and water). The experimental trial lasted 84 days.

Slaughter and carcass evaluation

At the end of the experiment, prior to the slaughter, animals have fasted for 24 h. All animals were slaughtered in a commercial slaughterhouse located in Campo Grande-MS, Brazil, according to the procedures described by Ludke et al. (2012), i.e., after arriving at the slaughterhouse, they were at full rest for 24 h before slaughter to do fasting of feed and water. After slaughter, the carcasses were stored at 4 °C for 24 h. Thereafter, carcasses were weighed to obtain carcass yield.

Samples were collected from the cross section between the 9th and 13th rib on the left side of the carcass to estimate physical carcass composition (proportions of muscle in *longissimus thoracis* (LT), fat, and bone, expressed as a percentage of the total weight of the rib). Subcutaneous fat thickness (SFT) was measured using a caliper ruler on the left side of the carcass, between the 12th and 13th ribs, and 11 cm from

Table 1 Diet and chemical composition of the total mixed diets of Beefalo × Nellore cattle fed different lipid levels in the diet dry matter

Ingredients	Lipid level (g/kg DM)			
	55	65	75	85
Diets composition (g/kg DM)				
Sorghum silage	373	373	373	373
Sunflower grain	47	71	95	119
Ground corn grain	485	469	453	437
Soybean meal	81	74	66	58
Mineral premixa	14	13	13	13
Chemical composition of diets				
DM (g/kg)	503.6	502.7	505.8	507.6
OM (g/kg DM)	956.1	957.1	955.4	962.2
CP (g/kg DM)	112.7	110.3	117.1	116.5
EE (g/kg DM)	54.8	64.6	74.6	84.7
NDF (g/kg DM)	585.8	604.2	570.4	622.7
ADF (g/kg DM)	258.1	256.9	261.7	263.1
Fatty acid profile of diets (g/kg EE)				
Myristic acid ($C_{14:0}$)	0.2	0.2	0.2	0.2
Palmitic acid ($C_{16:0}$)	80.9	78.8	76.6	74.4
Stearic acid ($C_{18:0}$)	34.7	34.0	33.2	32.4
Oleic acid ($C_{18:1\omega9}$)	265.3	266.2	266.9	267.7
Linoleic acid ($C_{18:2\omega6}$)	233.9	237.9	2415	245.0
Linolenic acid ($C_{18:3\omega3}$)	16.5	16.1	15.7	15.3
ΣSFA	115.9	113.0	110.0	106.9
ΣUFA	515.6	520.2	524.1	528.0
ΣMUFA	265.3	266.2	266.94	267.7
ΣPUFA	250.4	254.0	257.2	260.3

DM, dry matter; *OM*, organic matter; *CP*, crude protein; *EE*, ether extract; *NDF*, neutral detergent fiber; *ADF*, acid detergent fiber inclusive of residual ash; *SFA*, saturated fatty acids (ΣC14:0, C16:0, C18:0); *UFA*, unsaturated fatty acid (C18:1ω9, C18:2ω6, C18:3ω3); *MUFA*, monounsaturated fatty acid (C18:1ω9); *PUFA*, polyunsaturated fatty acid (ΣC18:2ω6, C18:3ω3)

[a] Contained (per kg, as-is basis) Ca 150g, P 90g, S 50 g, Na 72g, Co 20 mg, Cu 250 mg, Fe 2000 mg, I 28 mg, Mn 600 mg, Se 9 mg, F 900 mg, and Zn 1800 mg

the carcass midline. The rib eye area (REA) was measured between 12th and 13th ribs in LT, by tracing it in a paper and then processing it in AUTOCAD® (AUTOCAD® software, Autodesk, Inc., San Rafael, CA, USA). Marbling was scored with photographic standards on a six-point scale, where 1 = extremely low marbling and 6 = extremely high marbling (Herring et al. 1994).

Meat quality and chemical composition

Samples (500 g) from the LT were taken from each animal and frozen at − 8 °C for further chemical and physical analyses. In order to determine thawing and cooking losses, three steaks of 20 mm thick were cut from the rib eye and kept frozen at − 8 °C. Each steak was weighed into aluminum trays and thawed for 24 h at 4 °C to obtain thawing loss. Steaks were then cooked at 170 °C until reaching 71 °C in the center. The temperature was determined with individual T-thermocouples inserted in the geometric center of each stake. Samples were then removed from the oven, blotted, and weighed to obtain cooking losses according to the American Meat Science Association recommendations (American Meat Science Association 1995).

Another portion of the LT was kept at − 80 °C and freeze-dried. Dried meat samples were crushed in a 1-mm screen mill for chemical analysis. AOAC (2000) methods for determinations of moisture (No. 930.15), ash (No. 942.05), protein (No. 976.05), and fat (No. 920.39) contents were used. Moisture content was calculated by the difference between 1000 g/kg of fresh meat sample and its content of dry matter. In the same way, organic matter content was obtained by the difference between 1000 g/kg of sample and its mineral matter content. Neutral detergent fiber (NDF) was determined according to Mertens (2002), using thermostable amylase, without sodium sulfite, and expressed in residual ash. Acid detergent fiber (ADF) inclusive of residual ash and lignin concentrations were determined by solubilization of cellulose with sulfuric acid (H_2SO_4).

An aliquot of the lipid extracted from feed ingredients and diets using hexane was dried out (ca. 40 mg) for the analysis of the FA profile. Intramuscular fat from muscle samples was extracted based on the method of Bligh and Dyer (1959). Freeze-dried samples of meat (4 g) were homogenized in 25 mL of methanol and 5 mL of chloroform using a tissue homogenizer set at 540 g (Model Q220 Quimis, Diadema São Paulo, SP, Brazil) for 30 min. The extracts were evaporated under 55 °C and lipids were stored at − 80 °C until methylated. Sodium methoxide (10 mL), acetic acid (1 mL), and heptane (10 mL) were added to the mixture prior to a second homogenization carried out for 60 min. Samples were allowed to settle, and 2 mL of lipid was collected from the upper heptane phase. FA were methylated according to Christie (1982), using sodium methoxide in methanol (1:25) as an agent of esterification and methyl acetate (1 mL) plus heptane (10 mL) to minimize saponification. Fatty acid methyl esters (FAME) were quantified by gas chromatography (Agilent Technologies GC, model 6890 N Network GC System, Santa Clara, CA, USA) using an HP-88 capillary column (100 m × 0.25 mm i.d., 0.20-m film thickness). The column parameters were as follows: initial temperature of 160 °C was maintained for 1 min; the temperature was then programmed at 6 °C/min to 230 °C, and this temperature was maintained for 23 min. Injector and detector temperatures were 225 °C and 285 °C, respectively, and the volume of injection was 2 uL. The carrier gas was helium at 1.5 mL/min. Hydrogen flow to the detector was 35 mL/min, airflow was 450 mL/min, and the flow of N_2 makeup gas was 30 mL/min. The FAME identification was done by comparison with the retention times of pure methyl ester standards (FAME mix components, Supelco, Bellefont, PA, USA).

The major fatty acids were reported and minors were removed and the proportion of fatty acids was recalculating after removing the minor one. In addition, we use standards to identify elution times for major fatty acids.

Statistical analysis

All data was submitted for the analysis of variance using PROC MIXED (Statistical Analysis Systems—SAS, version 9.1, SAS Institute, Inc., Cary, NC, USA), according to a completely randomized design with eight treatments. Slaughter weight was used as covariate to analyze carcass measurements. Polynomial contrasts were used to test the linear and quadratic effects of lipid levels in the diet.

The model used was $Y_{ijkl} = \mu + T_i + S_j + TS_k + e_{ijkl}$, in which μ is the general average; T_i is the fixed treatment i, $i = 1 \ldots 4$; S_j is effect of animal sex j, $j = 1, 2$; TS_k is interaction between treatment i and animal sex j; and e_{ij} is the experimental error associated with each observation Y_{ij}.

For all variables, P values lower than or equal to 0.05 were declared significant, and P values lower than 0.10 were considered tendencies. The mean procedure of SAS was used for means test.

Results

There was no lipid level effect ($P > 0.05$) on DM intake, but there was a sex effect ($P < 0.05$) for DMI. There was no effect of treatment ($P > 0.05$) on the NDF intake ($P < 0.05$). Likewise, slaughter and carcass weights, and gains were similar among diets for both steers and heifers ($P > 0.05$).

There was no effect ($P > 0.05$) of lipid levels on carcass weight and slaughter. However, there was an effect of treatment on weight gains for steers and heifers. There were effects of lipid levels on fatty acid intake, presenting linear increase

Table 2 Nutrient intake and performance of Beefalo × Nellore cattle fed 55, 65, 75, or 85 g/kg of lipid in the diet dry matter

	Steers				Heifers				SEM	*P* value			
	Lipid level (g/kg DM)				Lipid level (g/kg DM)					Lipid level effect		Sex effect	Lipid level × sex
	55	65	75	85	55	65	75	85		Linear	Quadratic		
Intake													
DM (kg/day)	10.4	10.1	10.1	10.0	8.5	8.7	8.6	8.8	0.06	0.551	0.677	0.001	0.001
CP (kg/day)	1.2	1.1	1.2	1.2	1.0	1.0	1.0	1.0	0.02	0.577	0.660	0.001	0.062
EE (kg/day)	0.6	0.6	0.8	0.8	0.5	0.6	0.6	0.7	0.02	0.001	0.635	0.001	0.654
NDF (kg/day)	4.1	4.6	4.2	3.8	5.0	5.3	4.9	5.5	0.10	0.538	0.720	0.001	0.001
ADF (kg/day)	2.6	2.5	2.6	2.5	2.2	2.2	2.3	2.3	0.07	0.507	0.766	0.001	0.154
SFA (g/day)	60.1	71.2	82.2	93.3	49.4	60.3	71.1	81.9	0.02	0.001	0.845	0.001	0.215
UFA (g/day)	283.4	335.2	386.6	438.1	259.5	310.6	361.5	412.4	0.02	0.001	0.985	0.001	0.545
MUFA (g/day)	144.6	171.0	197.3	223.6	122.6	148.7	174.7	200.7	0.02	0.001	0.888	0.001	0.455
PUFA (g/day)	138.8	164.1	189.3	214.4	116.8	141.9	166.8	191.7	0.02	0.001	0.950	0.001	0.650
Performance													
SW (kg)	528.7	510.0	514.0	498.0	355.5	363.0	358.7	366.3	8.46	0.343	0.559	0.001	0.152
CW (kg)	265.2	251.5	260.5	246.8	174.7	174.2	168.0	167.5	4.27	0.533	0.571	0.001	0.215
WG (kg)	120.0	109.5	114.5	108.0	77.1	84.6	80.3	87.9	2.74	0.565	0.527	0.001	0.001
ADG (kg/day)	1.5	1.4	1.4	1.4	0.9	1.0	1.0	1.0	0.06	0.578	0.528	0.001	0.001

DM, dry matter; *CP*, crude protein; *EE*, ether extract; *NDF*, neutral detergent fiber inclusive of residual ash; *ADF*, acid detergent fiber inclusive of residual ash; *SFA*, saturated fatty acids; *UFA*, unsaturated fatty acid; *MUFA*, monounsaturated fatty acid; *PUFA*, polyunsaturated fatty acid; *SW*, slaughter weight; *CW*, carcass weight; *WG*, weight gain; *ADG*, average daily gain; *SEM*, standard error of the mean

for all of them (SFA, UFA, MUFA, and PUFA) accompanying the consumption of lipids (Table 2).

There was an interaction ($P < 0.05$) between lipid level and sex in muscle, bone, rib REA, marbling score, and SFT. Diet had no effect on REA, marbling score, and SFT of the carcasses of steers and heifers ($P > 0.05$, Table 3), proportions of muscle, fat, and bone ($P > 0.05$, Table 3).

The chemical composition of meat were similar among diets for steers and heifers ($P > 0.05$). Cooking and thawing losses were also not affected by lipid levels ($P > 0.05$). There was a sex effect ($P < 0.05$) on thawing losses (Table 4).

There was an interaction ($P < 0.05$) between lipid level and sex for myristic acid (C14:0), myristoleic acid (C14:1), palmitoleic acid (C16:1$_{\omega7}$), linoleic acid (C18:2$_{\omega6}$), linolenic acid (C18:3 $_{\omega3}$), and polyunsaturated fatty acid (PUFA) in the meat of the LT muscle (Table 5). There was no effect ($P > 0.05$) of lipid level on for myristic acid (C14:0), myristoleic acid (C14:1), and palmitoleic acid (C16:1$_{\omega7}$). There was linear effect ($P < 0.05$) of lipid level on linoleic acid (C18:2$_{\omega6}$), linolenic acid (C18:3 $_{\omega3}$), and PUFA.

The saturated fatty acid myristic (C14:0), palmitic (C16:0), and stearic (C18:0) decreased linearly with higher contents of

Table 3 Carcass traits of Beefalo × Nellore cattle fed 55, 65, 75, or 85 g/kg of lipid in the diet dry matter

	Steers				Heifers				SEM	*P* value			
	Lipid level (g/kg DM)				Lipid level (g/kg DM)					Lipid level effect		Sex effect	Lipid level × sex
	55	65	75	85	55	65	75	85		Linear	Quadratic		
Muscle (%)	59.4	59.9	56.9	56.3	57.2	61.9	62.1	61.3	0.91	0.253	0.562	0.007	0.018
Fat (%)	19.0	18.5	21.8	19.0	19.8	17.8	18.0	18.1	0.75	0.523	0.561	0.716	0.031
Bone (%)	21.7	21.6	21.3	24.7	23.0	20.3	19.9	20.6	0.82	0.302	0.572	0.001	0.001
Rib eye area (cm2)	71.0	66.0	71.5	69.3	58.7	58.7	62.4	62.2	0.96	0.311	0.554	0.001	0.186
Marbling score (points)	3.5	3.7	3.9	3.1	2.4	2.9	2.6	2.8	0.12	0.278	0.561	0.001	0.001
SFT (mm)	5.6	4.9	5.7	6.4	5.9	4.9	3.6	3.3	0.20	0.273	0.528	0.001	0.001

DM, dry matter; *SEM*, standard error of the mean; *SFT*, subcutaneous fat thickness

Table 4 Chemical composition and meat traits of Beefalo × Nellore cattle fed 55, 65, 75 or 85 g/kg of lipid in the diet dry matter

	Steers				Heifers				SEM	*P* value			
	Lipid level (g/kg DM)				Lipid level (g/kg DM)					Lipid level effect		Sex effect	Lipid level × sex
	55	65	75	85	55	65	75	85		Linear	Quadratic		
DM (%)	27.7	28.5	27.4	26.1	26.0	26.8	28.4	28.0	0.52	0.095	0.180	0.988	0.997
OM (% DM)	93.7	94.2	92.9	92.4	94.4	91.9	93.0	95.5	0.90	0.390	0.100	0.989	0.999
Fat (% DM)	19.6	15.0	19.3	18.4	21.2	15.8	14.3	19.3	2.08	0.439	0.170	0.938	0.969
Protein (% DM)	74.1	79.2	73.6	74.0	73.3	76.1	78.6	76.2	3.57	0.304	0.155	0.971	0.999
Ash (% DM)	6.3	5.8	7.1	7.6	5.6	8.1	7.0	4.5	0.89	0.255	0.090	0.842	0.814
Thawing loss (g/kg)	20	19	15	22	33	44	43	35	0.39	0.235	0.155	0.048	0.906
Cooking loss (g/kg)	215	213	211	225	239	199	196	204	5.91	0.336	0.125	0.920	0.994

DM, dry matter; *OM*, organic matter; *SEM*, standard error of the mean

lipids in the diet ($P < 0.05$). Inversely, a linear increase was observed for the unsaturated FA oleic (C18:1ω9) and linoleic (C18:2ω6) ($P < 0.05$). This data behavior was observed similarly for steers and heifers. The totality of saturated fatty acids showed a linear reduction, and, consequently, there was a linear increase for the total of unsaturated fatty acids, both monounsaturated and polyunsaturated when the content of lipids of the diet increased ($P < 0.05$).

Discussion

We observed that male and female DM and NDF intake were not affected according to the increased inclusion of sunflower seed. It is known that fat causes a depressing effect on the consumption and digestibility of dry matter. Particularly, NDF can be severely affected by the effects of excess metabolized unsaturated fatty acids in the rumen (Palmquist, 1994).

Table 5 Proportion (g/kg of FA) of principal fatty acids found in *longissimus thoracis* of Beefalo × Nellore cattle fed 55, 65, 75, or 85 g/kg of lipid in the diet dry matter

	Steers				Heifers				SEM	*P* value			
	Lipid level (g/kg DM)				Lipid level (g/kg DM)					Lipid level effect		Sex effect	Lipid level × sex
	55	65	75	85	55	65	75	85		Linear	Quadratic		
Myristic acid (C14:0)	29.9	30.3	30.6	28.9	40.6	33.7	32.6	26.1	0.01	0.293	0.688	0.001	0.001
Myristoleic acid (C14:1)	8.7	12.4	10.5	8.6	13.5	11.5	10.6	6.8	0.01	0.268	0.421	0.041	0.001
Palmitic acid (C16:0)	233.8	234.9	237.7	239.3	229.3	232.0	230.4	235.4	0.02	0.025	0.549	0.001	0.998
Palmitoleic acid (C16:1ω7)	34.6	35.2	39.1	40.2	42.4	40.4	40.3	28.9	0.01	0.134	0.334	0.001	0.001
Stearic acid (C18:0)	172.2	161.7	156.5	147.4	172.4	157.8	156.5	147.6	0.02	0.001	0.550	0.001	0.809
Oleic acid (C18:1ω9)	436.8	445.0	456.2	467.2	427.7	440.8	439.7	459.3	0.02	0.001	0.580	0.473	0.999
Linoleic acid (C18:2ω6)	29.8	21.9	16.2	22.0	30.8	39.5	43.2	49.2	0.01	0.022	0.078	0.001	0.001
Linolenic acid (C18:3ω3)	16.4	9.5	6.7	2.9	6.7	6.7	7.7	10.6	0.01	0.002	0.332	0.001	0.001
Eicosapentaenoic acid (C20:5ω3)	22.1	33.0	31.2	28.9	24.1	24.1	24.8	24.2	0.01	0.145	0.234	0.541	0.888
Docosahexaenoic acid (C22:6ω3)	15.7	16.1	15.3	14.6	12.5	13.5	14.2	11.9	0.01	0.137	0.265	0.564	0.976
ΣSFA	435.9	427.0	424.7	415.5	442.2	423.5	419.5	409.1	0.02	0.047	0.633	0.851	0.996
ΣUFA	564.1	573.0	575.3	584.5	557.8	576.5	580.5	590.9	0.02	0.047	0.605	0.861	0.986
ΣMUFA	480.1	492.6	505.9	516.0	483.6	492.8	490.6	495.0	0.02	0.015	0.650	0.057	0.466
ΣPUFA	84.0	80.4	69.4	68.5	74.2	83.7	89.9	95.9	0.01	0.001	0.305	0.001	0.001

DM, dry matter; *SEM*, standard error of the mean; *SFA*, saturated fatty acids (ΣC14:0, C16:0, C18:0); *UFA*, unsaturated fatty acid (ΣC14:1, C16:1ω7, C18:1ω9, C18:2ω6, C18:3ω3, C20:5ω3, C22:5ω3, C22:6ω3); *MUFA*, monounsaturated fatty acid (ΣC14:1, C16:1ω7, C18:1ω9); *PUFA*, polyunsaturated fatty acid (ΣC18:2ω6, C18:3ω3, C20:5ω3, C22:5ω3, C22:6ω3)

In our study, we did not observe such an effect, even when we supply lipids in the amount of 85-g/kg DM.

Higher DM intake was observed in the steers. Males have more fibers in the same muscle when compared to females. Testosterone regulates the increase in the number of fibers in males at the beginning of the fetal cell differentiation process (Kelly and Jones, 2013). This provides males with greater consumption and greater gains in daily weight. In our study, a sex effect was evident in all performance characteristics. These factors reflected in the carcass traits (muscle and bone), REA, and SFT. Nevertheless, these did not reflect on the amount of fat. Studying Nellore-Angus steers and heifers, Augusto et al. (2019) also found the same amount of fat for animals of different sexes.

The lack of effect of dietary level of lipid on steers' carcass weight, carcass yield, fat thickness, and marbling score is coherent with previous studies (Basarab et al. 2007a; Shah et al. 2006). Feeding 150 g/kg of whole sunflower grain for steers on pasture or feedlot had no effect on carcass traits and organoleptic characteristics of the meat; in addition, the yield of wholesale cuts was similar for animals supplemented or not with 150-g/kg whole sunflower grain on pasture (Basarab et al. 2007b).

Despite influencing the animals' slaughter weight, carcass weight, weight gain, and average daily gain, the sex had no influence on the meat composition of steers and heifers. This effect can be attributed to the age of the animals, which is insufficient to alter the deposition of tissues and consequently the composition of the meat.

The decrease in the proportion of linoleic acid in the LT of steers fed whole sunflower grain observed in the present study does not agree with the results found by Gibb et al. (2004) who observed higher linoleic acid proportion in subcutaneous fat of steers fed 140-g/kg sunflower grain in a high concentrate diet, compared to those fed no sunflower grain. Along with alterations in FA composition of muscle, oilseeds providing 6% fat in the diet (dry matter basis) reduced subcutaneous fat and numerically decreased marbling scores, despite the increase in dietary energy due to the oil (Mir et al. 2008). Moreover, Gibb et al. (2004) reported a linear increase in DM intake and average daily gain of beef steers fed different proportions of sunflower (SG; 0, 9 and 14% of DM) in a rolled barley-based diet.

Higher hydrogenation of the dietary oil on a high forage diet, compared to a high concentrate diet, could result in a lower rumen outflow rate. Since the animals in our study were fed a high forage diet, this phenomenon may have contributed to decreasing linoleic acid reaching the intestine and leading to lower deposition of linoleic acid in the muscle. As result, partial hydrogenation of linolenic acid led to linear increases in the proportions of oleic acid and monounsaturated FA in the meat of the animals (steers and heifers) supplemented with up to 85 g/kg of lipid from whole sunflower grain in the diet. Similar increases in proportions of oleic acid and total unsaturated FA were observed by Gibb et al. (2004) working with beef steers fed a high concentrate diet and supplemented with 140 g/kg of whole sunflower grain. Proportions of saturated FA decreased with the inclusion of higher amounts of sunflower grain, mainly due to the lower proportion of palmitic and stearic acids in the muscle.

The different lipid levels of the diet of steers and heifers were not sufficient to change ($P > 0.05$) the amount of eicosapentaenoic (C20:5ω3, EPA) and docosahexaenoic (C22:6ω3, DHA) acids in the LT. The EPA and DHA are products of elongation and desaturation of alpha-linolenic acid, and health effects have been attributed to the consumption of this acid (Vahmani et al. 2017). These FA are desirable because they may also have associated with reductions of blood lipids Lopez-Huertas (2010) and reduced systolic blood pressure (Miller et al. 2014).

Regarding sex effect, increased incorporation of long-chain fatty acids in the phospholipids in the meat of heifers in response to the concentration of plasmalogens was evidenced (Bessa et al. 2015). In our study, heifers showed higher concentrations of fatty acids important for human health (linoleic and palmitoleic acids). This indicates that the meat of heifers had some aspects related to the FA profile more desirable compared to that meat from steers.

In conclusion, increasing dietary lipid by partially replacing corn and soybean meal with whole sunflower grain (55- to 85-g/kg DM) is an effective strategy to produce beef with higher contents of mono- and polyunsaturated fatty acids, which can be beneficial for human nutrition.

Author contribution LCV Ítavo and CCBF Ítavo conceived and designed research, and wrote the manuscript. AM Dias, MNB Gomes, and AG Silva conducted experiment, laboratorial analysis, and collection of samples. ES Leal, MWF Pereira, and CS Pereira conducted experiment, laboratorial analysis, and collection of samples. GT Santos conceived and designed research; all authors read and approved the manuscript.

Funding This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico—CNPq (grant number 477539/2008-4); Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul—FUNDECT (grant number 23/200.177/2009); and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—CAPES (Financing Code 001).

Declarations

Ethics approval The study was undertaken with approval from the institutional ethics committee—Animal Care and Use Committee of the Federal University of Mato Grosso do Sul (Protocol 654/2014)—for care and use of animal for research of the host institution.

Conflict of interest The authors declare no competing interests.

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