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Original Article

Linseed oil supplemented concentrate fed to Brahman crossbred fattening steers on carcass quality traits and intramuscular fatty acid profiles

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Abstract

The objective of this study was to determine the linseed oil supplemented concentrate fed to Brahman crossbred fattening steers on carcass quality trait and intramuscular fatty acid (FA) profiles. All steers were fed 14% CP concentrate. The treatments included: (1) 7 kg/d concentrate; (2) 4 kg/d concentrate supplemented with 200 g/d palm oil (PO); (3) 4 kg/d concentrate supplemented with 100 g/d PO and 100 g/d linseed oil (LSO); and (4) 4 kg/d concentrate supplemented with 200 g/d LSO. The animals in the treatment 1 were fed ad libitum rice straw (RS), whereas the animals in other treatments were fed ad libitum fresh grass (FG). Dietary treatments had no effect on nutrient intake while oil supplement decreased dry matter intake (DMI). Inclusion of LSO did not negatively affect carcass quality, but increasing amount of LSO supplement increased the n-3 fatty acids and lowered the n-6/n-3 ratio in beef.

Keywords: beef fatty acid, linseed oil, carcass quality, n-6/n-3 fatty acid ratio

1. Introduction

Beef consumption in Thailand from Brahman crossbred is approximately 98.5%, where about 81.2% of beef come from farmers who are using a no-concentrate feeding system (DLD, 2012). As a result, some types of beef nutritional values are unsuitable for consumer health, especially fat and fatty acid profile, e.g. saturated fatty acid (SFA), n-6 polyunsaturated fatty acids (PUFA), and n-3 PUFA ratio. Beef contains approximately 50% of SFA content, which is the result of the process of ruminal biohydrogenation (Schollan *et al.*, 2001). The SFA is a major factor causing chronic diseases such as cardiovascular disease and colon cancer in the Western world (McAfee *et al.*, 2010). The FA composition of beef including muscle and subcutaneous adipose tissue can be influenced, at least in parts, by FA composition of the diet (Glaser *et al.*, 2004; Noci *et al.*, 2007). Most of the researches aimed at improving dietary quality of beef has been focused on manipulation of animal feed with attempts to increase the intramuscular n-3 PUFA content accomplished by feeding n-3 PUFA rich diets in the ruminants (Scollan *et al.*, 2006). In addition, low n-6/n-3 PUFA ratio has been showed to prevent many chronic diseases (Fernandes, 2002). Increasing the content of PUFA and reducing SFA with the net effect of increasing PUFA/SFA and reducing n-6/n-3 ratio are priorities (Scollan *et al.*, 2006). Linseed oil is a natural source of PUFA, especially C18:3n-3. In general, previous studies reported the effect of different linseed forms and concentration on performance and FA composition of muscle and adipose tissue in beef cattle (Herdmann *et al.*, 2010; Mach *et al.*, 2006; Raes *et al.*, 2004). Until now, however, no study has been done with linseed supplement in beef Thai cattle on carcass quality trait and intramuscular fatty acid profiles. Therefore, the objective of this study was to examine the effects of linseed oil supplemented concentrate fed to Brahman crossbred fattening steers on intake, performance, carcass quality trait, and intramuscular fatty acid profiles.

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2. Materials and Methods

2.1 Experimental design and treatments

Twenty steers (87.5% Brahman crossbred), averaging of 337±54 kg LW, with an average of four for body condition score (BCS) (Westendorf, 1988) and approximate two years old, were stratified by their LW and assigned to four dietary treatments. All steers were fed 14% crude protein (CP) concentrate and free accessed to clean water. The animals were individually housed in a free-stall unit. The treatments included: (1) 7 kg/d concentrate (HC); (2) 4 kg/d concentrate supplemented with 200 g/d palm oil (PO); (3) 4 kg/d concentrate supplemented with 100 g/d PO and 100 g/d linseed oil (LSO); and (4) 4 kg/d concentrate supplemented with 200 g/d LSO**.** The animals in the treatment 1 were fed *ad libitum* rice straw, whereas the animals in other treatments were fed *ad libitum* fresh grass (FG). The experiment lasted for 84 days including the first 14 days as adjustment period and the last 70 days (5 periods of a 14-day) as measurement period.

2.2 Fattening steers and slaughter procedures

All experimental procedures were carried out following the animal welfare standards of Department of Livestock Development, Ministry of Agriculture and Cooperative, Royal Thai Government. At the end of feeding trial, the animals were weighed, and three animals per each treatment were randomly sampled and transported to a commercial abattoir to slaughter at Nakhon Ratchasima slaughterhouse, Nakhon Ratchasima, Thailand, following procedures outlined by Jaturasitha (2004). Muscle samples cutting from outside *Longissimus dorsi* (LD; 6-12th rib) muscle and *Semimembranosus* (SM) muscle were prepared from the left carcass side in order to study beef quality in muscles.

2.3 Laboratory analyses

Feed offered and residues after eating of individual steer were weighed on two consecutive days weekly to calculate dry metter (DM) intakes. Feed samples were pooled to make representative samples for proximate (AOAC, 1990) and detergent analyses (Van Soest *et al.*, 1991). Beef pH was determined in LD and SM at 45 min and 24 hrs post slaughtering using a pH meter (pH meter model UB-5, Denver Instrument, Germany). After dissection, the LD and SM samples were cut in to 2.5 cm thick slices, put into polyethylene bags, chilled at 4°C for 48 hrs and then stored in the refrigerator outside of the bag for 1 hr ('blooming') before conducting color measurements using a hunter lab (Color Quest XE, Kable, United Kingdom). Water-holding capacity (WHC) was assessed via sample losses occurring during different procedures. For the determination of the grilling loss, 2.5 cm thick slices were grilled in a convection oven (model 720, Mara, Taipei, Taiwan) at 150°C until an internal temperature of 70°C was reached. In the LD, additionally drip loss according to Honikel (1987) was determined. In the boiled samples, shear forces were measured after cooling and drying. A steel hollow-core device with a diameter of 1.27 cm was punched parallel to the muscle fibers to obtain six pieces from each muscle sample. Measurements were carried out on a material testing machine by Texture analyzer (TA-TX2 Texture Analyzer, Stable Micro Systems, UK) using a Warner-Bratzler shear. A crosshead speed of 200 mm/min and a 5 kN load cell calibrated to read over a range of 0x100 N were applied. Samples of the LD and SM were minced and analyzed in duplicate for moisture, fat, and protein contents according to AOAC (1990). Fatty acids in feed and beef samples were extracted using a modified method used by Folch *et al.* (1957) and Metcalfe *et al.* (1966). Fatty acid methyl esters (FAME) were prepared by the procedure described by Ostrowska *et al.* (2000) for analyzing by gas chromatography (7890A GC System, Agilent Technology, USA) equipped with a 100 m × 0.25 mm × 0.2 μm film fused silica capillary column (SP1233, Supelco Inc, Bellefonte, PA, USA). Injector and detector temperatures were 250°C. The column temperature was kept at 70°C for 4 min, then increased at 13°C/min to 175°C and held at 175°C for 27 min, then increased at 4°C/min to 215°C and held at 215°C for 17 min, then increased at 4°C/min to 240°C and held at 240°C for 10 min. Susceptibility of the lipids to oxidation was assessed by the 2-thiobarbituric acid (TBARS, thiobarbituric acid reactive substances) method (Rossell, 1994).

2.4 Statistical analysis

All data were statistically analyzed by completely randomized design using ANOVA procedure of SAS (2001). Significant differences among treatment were assessed by Duncan's new multiple range test. A significant level of $p<0.05$ was used (Steel and Torrie, 1980).

3. Results and Discussion

3.1 Feed fatty acid composition

Lipid from fresh grass provided high proportions of C18:3n-3 and PUFA and lowerd proportions of C18:2n-6 and monounsaturated fatty acids (MUFA) compared to 14% CP concentrate and rice straw. Linseed oil had the highest proportion of PUFA while PO had the highest proportion of SFA. In all feeds, the main SFA was C16:0, whereas C18:1n-9 was the main MUFA in PO, C18:2n-6 was the main PUFA in 14% CP concentrate, C18:3n-3 was the main PUFA in LSO, and MO, respectively (Table 1).

3.2 Animal performance and nutrient intake

Final body weight, average daily intake, energy gain, and feed:gain ratio were unaffected by dietary treatments (Table 2). According to He and Armentano (2011) Noci *et al.* (2007) reported the oil supplements did not affect perform-

Table 1. Fatty acid compositions of the experimental feeds.

Fatty acid (% of total FA)	14%CP	FG	RS	PO	MO	LSO
C8:0	0.74	ND	ND	0.05	0.03	0.05
C10:0	1.14	ND	ND	0.02	ND	ND
C12:0	17.96	1.42	ND	0.19	0.10	ND
C14:0	6.38	0.74	1.28	0.96	0.49	0.06
C16:0	17.85	19.66	47.49	38.29	21.11	4.91
C18:0	2.71	3.18	8.57	4.42	3.96	3.46
C18:1n-9*c*	31.90	6.55	16.76	40.61	29.26	17.88
C18:2n-6*c*	20.33	19.03	19.88	13.66	15.76	16.73
C20:0	0.00	0.54	0.00	0.04	0.14	ND
C18:3n-3	0.35	48.89	6.03	0.26	27.87	55.87
C18:3n-6	0.66	ND	ND	0.11	0.17	0.24
SFA[1]	46.77	25.53	57.34	44.05	25.94	8.70
MUFA[2]	31.90	6.55	16.76	41.07	29.61	17.96
PUFA[3]	21.34	67.92	25.91	14.89	44.45	73.34
total n-3[4]	0.35	48.89	6.03	0.43	28.09	56.20
total n-6[5]	20.99	19.03	19.88	14.46	16.30	17.04
PUFA:SFA	0.46	2.66	0.45	0.34	1.72	8.43
n-6/n-3	60.01	0.39	3.30	33.69	0.58	0.30

CP: crude protein, FG: fresh grass, RS: rice straw, FO: palm oil, MO: mixture of palm oil and linseed oil, LSO: linseed oil, ND: non-detectable.[1] SFA = Sum of saturated fatty acids from C4:0 – C20:0. [2] MUFA = Sum of monounsaturated fatty acids from C14:1 – C22:1. [3] PUFA = Sum of polyunsaturated fatty acids from C18:2 – C22:6. [4] Sum of n-6 fatty acids from C18:2n-6 – C22:4n-6. [5] Sum of n-3 fatty acids from C18:3n-3 – C22:6n-3.

Table 2. Effect of linseed oil supplementation on performance and nutrient intake of steers.

Item	Treatments[1]				SEM	P-value
	HC	200 g/d PO	200 g/d MO	200 g/d LSO		
Initial LW, kg	337	336	338	338	11.17	0.998
Final LW, kg	430	402	409	402	10.91	0.956
Average daily gain, kg/d	1.30	0.90	1.00	0.90	0.06	0.783
Energy gain[2]	6.22	4.13	4.63	4.04	0.06	0.730
FCR	0.12	0.15	0.13	0.16	0.01	0.606
Dry matter intake, kg/d						
Total	11.22^{a}	9.52^{b}	9.44^{b}	9.76^{b}	0.32	0.038
DMI, g/$BW^{0.75}$	131.19^{a}	110.97^{b}	109.19^{b}	113.51^{b}	2.81	0.011
Crude protein intake , g/d						
Total	1,135	1,107	1,097	1,130	14.99	0.769
Ether extract intake, g/d						
Total	301^{b}	450^{a}	448^{a}	454^{a}	0.29	<0.01
NE_g intake, Mcal/d						
Total	6.65^{b}	7.51^{a}	7.45^{a}	7.66^{a}	0.09	<0.01

LW: live weight, FCR: feed conversion ratio, DMI: dry matter intake, $BW^{0.75}$: metabolic body weight, NEg: net energy for growth, SEM: standard error of mean[1] HC: 7 kg/d concentrate, PO: 200 g/d palm oil, MO: 100 g/d PO and 100 g/d linseed oil, LSO: 200 g/d linseed oil. [2] Energy gain was calculated by the equation of NRC (1984) as reviewed by NRC (1996). [a, b] Mean within row which different superscripts are significant difference ($P<0.05$).

ance and nutrient intakes. However, the total dry matter intake, DMI, (kg/d) in the HC treatment was significantly higher ($P<0.01$) which is the result of the higher concentrate intake compared with the other treatments. According to Jenkins and McGuire (2006), the main effects of lipid addition on intake reduction are related to modifications in rumen fermentation. Specifically, a reduction in the digestibility of fiber in the rumen leads to an increase in the retention time of the nutral detergent fiber (NDF), which results in greater rumen fill.

3.3 Carcass quality traits

High oil to the concentrate did not affect carcass weight, moisture and fat content of the LD muscle (Andrae *et al.*, 2001; He and Armentano, 2011; Noci *et al.*, 2005; Noci *et al.*, 2007). Loin eye area and 12th rib fat thickness were not significantly different among the treatments (Table 3). The eye muscle area can be used as a representative measure of the quantity, quality, and distribution of the muscle mass. Initial (45 min post slaughter) and final pH (24 hour post slaughter) values were not different among the treatments (Table 3). Beef color mostly unaffected by the treatments with the exception of higher redness (a*) on SM originating from the 200 g/d LSO supplement than other groups (Table 3). Adding LSO to concentrates used to fattening steer has proved effective in increasing the percentage of n-3 PUFA in the intramuscular fat (Scollan *et al.*, 2001). PUFA are more susceptible to oxidation (Mahecha *et al.*, 2010). Oxidation is considered the major cause of beef quality deterioration affecting colour (Li & Liu, 2012). PUFA being more prone to oxidation during the display of beef, lipids destabilize the metmyoglobin MbFe(III) molecule when meat is on display, resulting in lipid oxidation by a mechanism involving direct exposure of the heme group to the lipids (Baron *et al.*, 2002). Subsequently, the products of these reactions promote oxidation by myoglobin and fatty acids (Faustman *et al.*, 2010), decreasing the shelf life of beef. However, 200 g/d LSO supplement with *ad-libitum* fresh grass have increased n-3 PUFA, they also have increased á-tocopherol, carotenoid, and sometimes flavonoid concentrations in their muscle compared to HC treatment (Table 3). These stabilize the beef,

Table 3. Effect of linseed oil supplementation on carcass quality traits and colour traits of *Longgissimus dorsi* (LD) and *Semimembranosus* (SM) muscles.

Item	Treatments[1]				SEM	P-value
	HC	200 g/d PO	200 g/d MO	200 g/d LSO		
Live weight (kg)	484	374	373	426	17.58	0.226
Hot carcass weight (kg)	264	205	202	224	8.12	0.154
Hot carcass (%)	54.58	54.76	54.21	52.66	0.36	0.294
Dressing (%)	52.95	53.12	52.59	51.09	0.35	0.292
Loin eye area (cm^2)	59.90	61.00	62.00	60.60	0.33	0.301
12th rib fat	0.85	0.25	0.43	0.60	0.11	0.343
pH						
45 min						
LD	6.26	6.22	6.37	6.48	0.06	0.512
SM	6.58	6.89	6.68	6.52	0.11	0.670
24 hr						
LD	5.61	5.57	5.51	5.60	0.04	0.845
SM	6.13	5.69	5.74	5.71	0.05	0.073
Colour trait						
*Lightness, L**						
LD	44.42	40.40	37.56	50.42	2.89	0.511
SM	45.36	42.67	42.79	39.68	0.85	0.277
*Redness, a**						
LD	8.01	6.32	9.22	6.31	0.63	0.404
SM	8.21^{b}	6.00^{c}	6.65^{c}	9.85^{a}	0.19	<0.01
*Yellowness, b**						
LD	5.97	3.23	7.02	8.79	0.88	0.293
SM	6.32	5.94	4.02	7.21	0.48	0.263

SEM: standard error of mean. [1] HC: 7 kg/d concentrate, PO: 200 g/d palm oil, MO: 100 g/d PO and 100 g/d linseed oil, LSO: 200 g/d linseed oil. [a, b] Mean within row which different superscripts are significant difference ($P<0.05$).

extending color shelf life and reducing fat oxidation during the time of retail display (Descalzo & Sancho, 2008).

No treatment effects were found in WHC, with the exception of the higher drip loss percentage in the LD muscle from the 200 g/d LSO supplement than others (P<0.01) (Table 4). The WHC, given that up to one-third of the loss of WHC is caused by decreases in pH (Fiorentini *et al.*, 2012). Oliveira *et al.* (2012) observed that the meat of bulls fed with LSO had the highest WHC value (P<0.05) in comparison to soybean oil and protected linseed oil. The shear force in SM muscle in the HC was significantly higher than those in the other treatments (P<0.01) (Table 4). Almost reports considered tender regardless of the lipid supplementation adopted because the average values obtained were 7.5 N (Aferri *et al.*, 2005 Fiorentini *et al.*, 2012; Santana *et al.*, 2014;). Furthermore, levels of TBARS increased with storage time, and LD muscle in 200 g/d LSO treatment was the highest compared with other treatments (P<0.01) (Table 4). The TBARS values were used as an index of oxidation of muscle lipids, at a biochemical level. Campo *et al.* (2006) proposed that TBARS values increase in beef that has previously been frozen due to damage of some cellular structures thus leading to oxidation. Increasing the muscle concentration of long chain PUFA as occurred in the present experiment, may therefore result in a significant increase in lipid oxidation. Habeanu *et al.* (2014) and Chriki *et al.* (2012) analyzed muscle lipids and showed that total lipid in *Longissimus thoracis* muscle (79.4% of total lipids) was higher (P<0.001) when compared to *semitendinosus* muscle (72.6%). Higher content of total lipid in *Longissimus thoracis* muscle being known to be more oxidative than *Semitendinosus* muscle.

3.4 Fatty acid composition of beef

Feeding 200 g/d LSO increased total n-3 PUFA (P< 0.01) in LD and SM muscle and C18:3n-3 in SM muscle (P<0.01) compared with HC treatment. Overall feeding 200 g/d LSO led to a triple of total n-3 PUFA in LD and SM muscle in relative to HC. The lack of dietary effects on PUFA in LD and SM indicates that LSO supplement had no effect on rates of lipolysis in the rumen. Although the finding of no difference in total and individual n-6 PUFA in LD and SM lipids, given the different amount in dietary treatment supply of C18:2n-6 (greater in concentrate, fresh grass and rice straw), indicates a high efficiency of biohydrogenation in the rumen. In contrast, the higher total n-3 PUFA found in LD and SM when feeding 200 g/d LSO may indicate that either the rate of lipolysis and/ or the initial step in C18:3n-3 biohydrogenation were reduced, and these desirable effects confirm previous observations when feeding linseed (Mach *et al.*, 2006). Feeding 200 g/d LSO increased C22:5n-3 (DPA) content when compared with HC. The lack of dietary effect on C22:6n-3 (DHA) in LD

Table 4. Effect of linseed oil supplementation on Water-holding capacity, Warner-Bratzler shear force (N), and texture-related properties of *Longgissimus dorsi* (LD) and *Semimembranosus* (SM) muscles.

Item	Treatments[1]				SEM	P-value
	HC	200 g/d PO	200 g/d MO	200 g/d LSO		
Water-holding capacity						
Drip loss (%)						
LD	6.44^{c}	7.78^{b}	8.93^{a}	8.96^{a}	0.10	<0.01
SM	5.23^{c}	6.04^{b}	6.79^{a}	7.00^{a}	0.05	0.024
Grilling loss (%)						
LD	31.89	31.82	31.97	31.62	0.29	0.681
SM	34.34	34.10	34.17	33.64	0.26	0.804
Warner-Bratzler shear force (N)						
LD	3.27	3.49	3.68	3.86	0.09	0.260
SM	6.95^{a}	4.77^{b}	4.55^{b}	4.09^{b}	0.02	<0.01
TBARS (mg)						
Day 0						
LD	0.18^{a}	0.26^{b}	0.31^{c}	0.43^{d}	0.02	<0.01
SM	0.46	0.48	0.54	0.56	0.01	0.137
Day 6						
LD	0.22^{a}	0.28^{b}	0.39^{c}	0.47^{d}	0.02	<0.01
SM	0.46	0.58	0.63	0.69	0.02	0.060

TBARS: Thiobarbituric acid reactive substances, SEM: standard error of mean. [1] HC: 7 kg/d concentrate, PO: 200 g/d palm oil, MO: 100 g/d PO and 100 g/d linseed oil, LSO: 200 g/d linseed oil. [a,b] Mean within row which different superscripts are significant difference (P<0.05).

relates to the limited capacity for the last steps in the n-3 PUFA elongation and desaturation pathway (Raes *et al.*, 2004). The accumulation of UFA in the lumen of the rumen may inhibit the complete biohydrogenation (Beam *et al.*, 2000). Therefore, supplementing steers with UFA can increase their passage to the small intestine, which allows more absorption and the possibility of changing the FA profile of beef. Rates of lipolysis and biohydrogenation will depend on the amount, type and source of lipid supplied to the animals (Van Nevel *et al.*, 1996) and the ruminal pH (Bauman *et al.*, 2005). The average degree of ruminal biohydrogenation is 70%, and it can vary from 60 to 90% (Whigham *et al.*, 2000). Furthermore, C18:3n-3 is less effective in down-regulating SCD activity than C18:2n-6 as suggested earlier by Jacobs *et al.* (2011). The present report confirms the result of Noci *et al.* (2005) that the potential of addition of PUFA-rich plant oils or oilseeds to concentrate rations is to increase the PUFA content of ruminant meat. Baird *et al.* (2010) reported no significant difference in the total C18:3n-3 across treatment, as linseed supplementation increased, and there was a linear increase in C18:3n-3 as a proportion of total PUFA increased. It is of interest to note that the improvement in the n-6/n-3 ratio in LD and SM muscle was entirely due to increases in n-3 PUFA, as the n-6 PUFA content did not change (Table 5 and 6). In the present experiment, the strong reduction in the n-6/n-3 ratio in LD and SM when feeding 200 g/d LSO brought it into the range recommended for human health (4:1) (BDH, 1994). The n-6/n-3 ratios for the linseed-containing diets were lower than the ratio values of 14.7, 9.0, and 6.3 recorded for Holstein bulls fed concentrate containing 3.6%, 11.2%, and

Table 5. Effect of linseed oil supplementation on fatty acid composition of *Longgissimus dorsi* (LD) muscle.

Fatty acid (% of total FA)	Treatments[1]				SEM	P-value
	HC	200 g/d PO	200 g/d MO	200 g/d LSO		
C10:0	0.22	0.07	0.05	0.03	0.04	0.362
C12:0	0.31^{bc}	0.63^{a}	0.53^{ab}	0.19^{c}	0.04	0.027
C14:0	6.34	6.71	6.27	6.19	0.19	0.930
C15:0	0.95	0.87	1.15	0.91	0.10	0.921
C16:0	33.84	33.30	32.47	33.40	0.33	0.122
C16:1	0.20	0.29	0.27	0.17	0.02	0.260
C18:0	19.63	20.02	18.49	15.95	0.80	0.291
C18:1n-9*c*	34.24	34.95	36.38	38.23	0.94	0.394
C18:2n-6*t*	0.13	0.30	0.30	0.16	0.04	0.121
C18:2n-6*c*	2.42	1.42	1.94	1.63	0.24	0.191
C20:1	0.08	0.12	0.12	0.14	0.01	0.322
C18:3n-3	0.13	0.13	0.13	0.17	0.01	0.072
c-9,*t*-11 CLA	0.23	0.10	0.20	0.42	0.05	0.095
t-10,*c*-12 CLA	0.15	0.26	0.30	0.31	0.03	0.198
C22:0	0.36	0.13	0.14	0.35	0.06	0.757
C20:3n-6	0.00	0.04	0.08	0.01	0.02	0.448
C20:4n-6	0.71	0.63	0.99	1.15	0.11	0.162
C20:5n-3	0.04^{c}	0.05^{ab}	0.16^{bc}	0.46^{a}	0.04	0.010
C22:6n-3	ND	ND	0.05	ND	0.01	0.589
SFA[2]	61.11	61.15	58.45	56.15	0.94	0.235
MUFA[3]	34.51	33.35	36.76	38.67	0.94	0.370
PUFA[4]	3.80	2.93	4.15	4.31	0.42	0.168
total n-6[5]	3.63	2.75	3.82	3.68	0.40	0.071
total n-3[6]	0.17^{b}	0.23^{b}	0.42^{b}	0.64^{a}	0.04	0.007
PUFA /SFA	0.06	0.05	0.07	0.08	0.01	0.166
n-6/n-3	24.12^{a}	12.32^{b}	10.73^{bc}	6.11^{c}	1.23	0.002

SEM: standard error of mean. [1] HC: 7 kg/d concentrate, PO: 200 g/d palm oil, MO: 100 g/d PO and 100 g/d linseed oil, LSO: 200 g/d linseed oil. [2] SFA = Sum of saturated fatty acids from C4:0 – C20:0. [3] MUFA = Sum of monounsaturated fatty acids from C14:1–C22:1. [4] PUFA = Sum of polyunsaturated fatty acids from C18:2 – C22:6. [5] Sum of n-6 fatty acids from C18:2n-6 – C22:4n-6. [6] Sum of n-3 fatty acids from C18:3n-3 – C22:6n-3. [a, b] Mean within row which different superscripts are significant difference ($P<0.05$).

Table 6. Effect of linseed oil supplementation on fatty acid composition of *Semimembranosus* (SM) muscle.

Fatty acid (% of total FA)	Treatments[1]				SEM	P-value
	HC	200 g/d PO	200 g/d MO	200 g/d LSO		
C10:0	0.05	0.02	0.02	0.03	0.01	0.664
C12:0	0.48	0.37	0.41	0.34	0.04	0.295
C14:0	6.25	5.50	5.69	5.32	0.34	0.584
C15:0	1.22	1.30	1.16	1.43	0.09	0.518
C16:0	32.51	30.72	32.03	32.40	0.77	0.649
C16:1	0.21	0.26	0.18	0.05	0.04	0.076
C18:0	15.99	16.21	16.94	15.16	0.70	0.660
C18:1n-9*c*	38.32	38.45	36.76	39.62	0.91	0.504
C18:2n-6*t*	0.11	0.36	0.08	0.00	0.12	0.002
C18:2n-6*c*	2.73	3.26	3.03	1.93	0.57	0.676
C20:1	0.06	0.11	0.10	0.01	0.02	0.117
C18:3n-3	0.16^{b}	0.13^{b}	0.34^{ab}	0.42^{a}	0.05	0.025
c-9,*t*-11 CLA	0.10^{b}	0.49^{a}	0.25^{ab}	0.11^{b}	0.06	0.017
t-10,*c*-12 CLA	0.25	0.36	0.28	0.35	0.05	0.695
C22:0	0.13^{ab}	0.25^{a}	0.18^{a}	0.00^{b}	0.03	0.012
C20:3n-6	0.00	0.00	0.25	0.28	0.28	0.264
C20:4n-6	1.28	1.15	1.95	1.94	0.26	0.543
C20:5n-3	0.15	0.36	0.40	0.37	0.06	0.245
C22:6n-3	0.00	0.12	0.00	0.24	0.06	0.250
SFA[2]	56.62	54.53	56.42	54.68	1.30	0.782
MUFA[3]	38.59	38.82	37.04	39.67	0.92	0.564
PUFA[4]	4.79	6.65	6.55	5.64	0.83	0.662
total n-6[5]	4.48	6.03	5.81	4.61	0.79	0.679
total n-3[6]	0.31^{c}	0.60^{bc}	0.99^{ab}	1.31^{a}	0.12	0.005
PUFA /SFA	0.09	0.12	0.12	0.11	0.02	0.714
n-6/n-3	14.50^{a}	10.53^{b}	5.91^{c}	3.33^{c}	0.69	<0.01

SEM: standard error of mean. [1] HC: 7 kg/d concentrate, PO: 200 g/d palm oil, MO: 100 g/d PO and 100 g/d linseed oil, LSO: 200 g/d linseed oil. [2] SFA = Sum of saturated fatty acids from C4:0 – C20:0. [3] MUFA = Sum of monounsaturated fatty acids from C14:1 – C22:1. [4] PUFA = Sum of polyunsaturated fatty acids from C18:2 – C22:6. [5] Sum of n-6 fatty acids from C18:2n-6 – C22:4n-6. [6] Sum of n-3 fatty acids from C18:3n-3 – C22:6n-3 [a, b] Mean within row which different superscripts are significant difference ($P<0.05$).

18.0% linseed (Mach *et al.*, 2006). However, while adding linseed lowered the n-6/n-3 ratio to close or less than 5 compared with a commercial fattening diet, the ratio was not as low as for animals fed supplemented grass (French *et al.*, 2000), grass or grass silage with different flax or fish oil supplements (Noci *et al.*, 2007; Scollan *et al.*, 2001; Warren *et al.*, 2008), or corn silage supplemented with linseed (Maddock *et al.*, 2006; Raes *et al.*, 2004). The PUFA/SFA ratios in LD and SM were unaffected ($P>0.05$, Table 5 and 6) by treatments. Furthermore, LSO supplementation increased n-3PUFA content of beef (19.35 and 41.96 mg/100 g beef; LD and SM muscle, respectively; data not shown) would not be sufficient for intake which are about 2,000-3,000 mg/day (EFSA, 2009). However, LSO supplementation decreased n-6/n-3 ratio of beef (6.11 and 2.89 of LD and SM muscle, respectively) which would be sufficient for improving cardiac health recommended a dietary n-6/n-3 ratio of 4:1 to 7.5:1 (Kafatos and Codrington, 1999; Fernandes, 2002). The differences in responses to LSO were probably due to variations in levels of oil supplementation, levels of oil in total ration and amount of linolenic acid in oils.

4. Conclusions

The accumulation of n-3 PUFA in LD and SM muscles were increased and n-6/n-3 ratio was decreased by the addition of LSO. The overall feed consumption of the steers was decreased when dietary oil was provided, leading to improvement in efficiency of growth performance. The LSO supplementation increased drip loss percentage, TBARS values.

However, LSO supplementation reduced beef color stability (a*) and beef tenderness. The fattening steer should be supplemented with 200 g/d LSO together with FG during late-mature period.

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