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Original Article

Performance, carcass quality and fatty acid profile of crossbred brahman beef steers receiving palm or rice bran oil

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Abstract

Twelve crossbred Brahman steers were randomly stratified into 3 treatment groups to determine the effect of palm or rice bran oil supplementation on the performance and fatty acid profile in beef. The steers averaged 300±38 kg live weight and 18±3 months old. All steers were fed 6 kg/d of 12% crude protein concentrate with *ad libitum* rice straw. The treatments were 1) control concentrate, 2) control concentrate plus 200 g/d of palm oil (PO), and 3) control concentrate plus 200 g/d of rice bran oil (RO). The study demonstrated that supplementation of PO or RO did not influence carcass and muscle characteristics or sensory and physical properties. However, PO and RO significantly increased net energy intake, C16:0, C18:1n-9, monounsaturated fatty acids, and total fatty acid intakes. Beef marbling scores also increased significantly by PO or RO supplementation. The C18:2n-6, *trans10, cis12* C18:2 CLA, and polyunsaturated fatty acids were significantly higher in cattle on RO than PO.

Keywords: palm oil, rice bran oil, carcass quality, sensory evaluation, fatty acids, Brahman beef steers

1. Introduction

Previously, the aim of plant and animal oil supplementation was to increase energy density in the feed and hence the animal receives increased energy to meet the requirements for production. However, recently the objective of oil supplementation is to modify fatty acid composition in animal products, i.e. increase conjugated linoleic acid (CLA) (Suksombat & Chullanandana, 2008a,b) and omega-3 fatty acids (FAs) (Noci *et al.,* 2007; Raes *et al.,* 2004; Scollan *et al.,* 2006; Suksombat *et al.,* 2013, 2014). In addition, the recommended polyunsaturated fatty acid (PUFA)/saturated fatty acid (SFA) (P:S) ratio should be above 0.45 which indicates healthy food for human consumption (Department of Health, 1994). A lower value than the recommended value indicates less healthy food, especially in relation to cardiovascular disease. Since some meats naturally have a P:S ratio of around 0.1, meat has been implicated in causing the imbalanced fatty acid intake of today's consumers. For this reason, ways to improve the P:S ratio during meat production are required.

A reduction in the consumption of SFAs with an increase in the consumption of PUFAs (fatty acids with more than one double bond) is encouraged, while monounsaturated fatty acids MUFAs (fatty acids with one double bond) are generally regarded as beneficial for human health (Department of Health, 1994). The main sources of supplementary FAs in ruminant rations are plant oils and oilseeds. Supplementation of plant oils or oilseeds rich in oleic acid could increase oleic acid in beef fat.

The beef quality is determined by FA composition of feedstuffs. Moreover, shelf-life, palatability, and nutritive value of beef are affected by FA composition in the beef. For instance, oleic acid seems to be beneficial for reducing plasma total cholesterol and total low-density lipoprotein cholesterol in humans (Grundy, 1989), and it contributes to better taste panel evaluations of cooked beef (Dryden & Marchello, 1970).

Challenges in increasing oleic acid content of ruminant tissues and products are of interest. In addition to the issues of the effects of unsaturated fatty acids (UFAs) on the stability and sensory acceptability of products, these FAs

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inhibit various essential anaerobic bacteria of the rumen, especially those involved in fiber digestion, biohydrogenation of UFAs, and methanogenesis (Palmquist & Jenkins, 1980). Therefore, supplementation of palm oil (PO) and rice bran oil (RO) rich in C18:1n-9 would increase C18:1n-9 in muscle lipid. Thus, the objective of the present study was to examine the effect of PO or RO supplementation on the performance and beef fatty acid profile of Brahman crossbred beef steers.

2. Materials and Methods

2.1 Animals, experimental design, and treatments

Twelve Brahman crossbred fattening steers (75% Brahman) were selected for the experiment. The average live weight was 300±38 kg and they were approximately 18 months old. They were stratified by their live weight into 3 groups and each group was randomly assigned to three dietary treatments. All steers were fed approximately 6 kg/d of 12% crude protein (CP) meal concentrate with *ad libitum* rice straw and had free access to clean water and were individually housed in a free-stall unit. The treatments were 1) control meal concentrate, 2) control meal concentrate plus 200 g/d of PO, and 3) control meal concentrate plus 200 g/d of RO. The chemical compositions of meal concentrate used in the experiment are presented in Table 1. The fatty acid compositions of the feed and oils used in the present study are presented in Table 2.

The basal diet was formulated to meet National Research Council (NRC, 2000) requirements. All steers were individually housed in a free-stall unit and individually fed according to treatments. The experiment lasted for 104 days with the first 14 days for adjustment followed by a measurement period of 90 days.

2.2 Measurements, sample collection, and chemical analysis

Feed offered to each steer was weighed daily and feed refused by individual steers was weighed on 2 consecutive days every 2 weeks to calculate dry matter intakes (DMI). At the end of the experiment, feed samples were pooled to make representative samples for proximate (Association of Official Analytical Chemists [AOAC], 1995) and detergent analyses (Van Soest *et al.,* 1991). The chemical analysis was expressed on the basis of the final DM. Fatty acid composition of concentrates and rice straw were determined by gas chromatography.

All animals were slaughtered and approximately 1 kg each of *Longissimus dorsi* (LD) and *Semimembranosus* (SM) muscles were taken from the left side of each animal for further analyses.

The meat pH (pH meter model UB-5, Denver Instrument, Germany) was determined in the LD and SM muscles at 45 min and 24 h. After dissection, the LD and SM samples were cut into 2.5 cm thick slices, put into polyethylene bags, chilled at 4 °C for 48 h and then stored in the refrigerator outside of the bag for 1 h ('blooming') before conducting color measurements using a Hunter Lab colorimeter (Color Quest XE, Kable, United Kingdom).

Table 1. Chemical compositions of the experimental diets.

Items	Concentrate	Palm oil	Rice bran oil	Rice straw
Dry matter	93.3			91.1
	----------% of DM----------			
Ash	6.6			15.9
Crude protein	11.8			1.3
Ether extract	4.5	100	100	1.5
Crude fiber	13.5			34.9
Neutral detergent fiber	47.3			73.6
Acid detergent fiber	32.2			59.2
Neutral detergent in soluble N	0.1			0.1
Acid detergent insoluble N	0.2			0.2
Acid detergent lignin	3.6			10.4
TDN_{1X} (%)[2]	68.6	184.2	184.2	35.9
DE_{1X} (Mcal/kg DM)[3]	3.1	7.7	7.7	1.7
ME (Mcal/kg DM)[4]	2.6	5.8	5.8	1.4
NE (Mcal/kg DM)[5]	1.0	3.1	3.1	0.2

[1] kg/100 kg concentrate: 30 dried cassava chip, 4 ground corn, 10 rice bran, 25 palm meal, 15 coconut meal, 6 dried distillers grains with solubles, 0.5 sodium bicarbonate, 6 molasses, 1 dicalciumphosphate (16%P), 1.5 urea, 0.5 salt and 0.5 premix. Premix: provided per kg of concentrate including vitamin A, 5,000 IU; vitamin D3, 2,200 IU; vitamin E, 15 IU; Ca, 8.5 g; P, 6 g; K, 9.5 g; Mg, 2.4 g; Na, 2.1 g; Cl, 3.4 g; S, 3.2 g; Co, 0.16 mg; Cu, 100 mg; I, 1.3 mg; Mn, 64 mg; Zn, 64 mg; Fe, 64 mg; Se, 0.45 mg.

[2] Total digestible nutrients, TDN_{1X} (%) = tdNFC + tdCP + (tdFA x 2.25) + tdNDF – 7 (NRC, 2000)

[3] Digestible energy, DE_{1X} (Mcal/kg) = [(tdNFC/100)x4.2]+[(tdNDF/100) x 4.2]+[(tdCP/100) x 5.6]+[(FA/100) x 9.4] –0.3

[4] Metabolisable energy, ME = 0.82 x DE (NRC, 2000)

[5] Net energy, $NE = 1.42ME – 0.174ME^2 + 0.0122ME^3 – 1.65$ (NRC, 2000)

Table 2. Fatty acid compositions (g/100 g fat) of concentrate, rice straw and oils used in the experiment.

Fatty acids	Concentrate	Rice straw	Palm oil	Rice bran oil
C12:0	22.76	6.44	0.19	ND
C14:0	7.84	8.15	0.96	0.23
C16:0	16.76	45.67	38.29	14.35
C18:0	2.49	ND	4.42	1.27
C18:1 n-9	29.42	24.92	40.61	41.17
C18:2 n-6	17.07	11.75	13.66	39.73
C18:3 n-3	0.29	ND	0.26	1.50
Others	3.37	3.07	1.61	1.75
SFA[1]	53.22	63.33	45.47	17.60
MUFA[2]	29.42	24.92	40.61	41.17
PUFA[3]	17.36	11.75	13.92	41.23
total n3[4]	0.29	ND	0.26	1.50
total n6[5]	17.07	11.75	13.66	39.73
PUFA:SFA	0.33	0.19	0.31	2.34
n6/n3	58.86	-	52.54	26.49

[1] SFA = Sum of saturated fatty acid from C12:0 – C18:0

[2] MUFA = Monounsaturated fatty acid from C18:1

[3] PUFA = Sum of polyunsaturated fatty acid from C18:2 – C18:3

[4] Sum of n6 fatty acid C18:2 n-6 – C18:3 n-6

[5] n3 fatty acid from C18:3 n-3

ND = Not detected.

Water-holding capacity was assessed via substance losses occurring during different procedures. Thawing and cooking losses were determined from the 2.5 cm thick slices of LD and SM frozen in polyethylene bags at -20 °C. Thawing was performed over 24 h at 4 °C. Before weighing, the sample surfaces were dried with soft paper. Afterwards, samples were sealed in heat-resistant plastic bags to be boiled in a water bath (WNE 29, Memmert, Germany) at 80 °C until an internal temperature of 70 °C was reached. 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, additional drip loss was determined. In the boiled samples, the 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 a TA-TX2 Texture Analyzer (Stable Micro Systems Ltd., 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, ash, and protein contents according to AOAC (1995). Total lipids in feed and beef samples were extracted using a modified method used by Folch *et al.* (1957). Feed and beef samples were thawed and samples were chopped coarsely and blended in a blending machine. Fifteen grams of each sample were homogenized for 2 min with 90 ml of chloroform-methanol (2:1) (Nissel AM-8 Homogenizer, Nihon-seikikaisha, LTD., Japan). Samples were then further homogenized for 2 min with 30 ml of chloroform. Samples were then separated in a separating funnel and 30 ml of deionized water and 5 ml of 0.58% NaCl were added. Fatty acid methyl esters (FAME) were prepared by the procedure described by Ostrowska *et al.* (2000), briefly, placing 30 mg of the extract into a 15 ml reaction tube fitted with a teflon-lined screw cap. One and a half ml of 0.5 M sodium hydroxide in methanol was added. The tubes were flushed with nitrogen, capped, heated at 100 ºC for 5 min with occasional shaking and then cooled to room temperature. One ml of C17:0 internal standard (2.00 mg/ml in hexane) and 2 ml of boron trifluoride in methanol were added and heated at 100 °C for 5 min with occasional shaking and 10 ml of deionized water were added. The solution was transferred to a 40 ml centrifuge tube and 5 ml of hexane were added for FAME extraction. The solution was centrifuged at 2,000 g at 10 °C for 20 min and then the hexane layer was dried over sodium sulfate and transferred into a vial for analyzing by gas chromatography (7890A GC System, Agilent Technology, USA) equipped with a 100 mx 0.25 mm, 0.2 µm film thickness fused silica capillary column (SP1233, Supelco Inc, Bellefonte, PA, USA). The 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.

Quantitative descriptive analysis was used for sensory evaluation (Stone *et al.,* 1974), 10 panelists who had undergone sensory evaluation training were selected for sensory evaluation. Grilled 2.5-cm slices of LD and SM were cut into pieces of 1.3 x 1.3 x 1.9 cm and served warm. Panelists were asked to grade samples for tenderness, juiciness, flavor, and overall acceptability. Assessments were given individually using a structured line graph and determined on a straight line. Thus, each point was on a linear scale to represent the quantity that can be measured with a ruler. Samples were served subsequently in a randomized order with respect to group and animal. The 24 samples (from 12 animals and two muscles) were tested by 8 persons.

2.3 Statistical analysis

All measured data were analysed by ANOVA for complete randomized design using the Statistical Analysis System (SAS, 2001). Significant differences among treatments were assessed by Duncan's new multiple range test. A significant level of $P<0.05$ was used (Steel & Torrie, 1980).

3. Results and Discussion

3.1 Feed composition and performance

The chemical compositions of the feeds are presented in Table 1 and the concentrate was formulated to meet the requirement of the steers. RO had the highest proportion of PUFA (41.23 g/100 g fat) while PO had the highest proportion of SFA (45.70 g/100 g fat). In the concentrate, the main SFA was C12:0 (22.76 g/100 g fat) and C16:0 (16.76 g/100 g fat), whereas C18:1n-9 was the main MUFA in PO (40.61 g/100 g fat), C18:2n-6 was the main PUFA in 12% CP concentrate (17.07 g/100 g fat), and C18:2n-6 was the main PUFA in RO (39.73 g/100 g fat) (Table 2). The supplementation of RO was chosen to reduce SFA (17.60) and to increase C18:1n-9 and C18:2n-6 (41.17 and 39.73, respectively) (Table 2).

No significant differences were found for the DM and CP intakes among the groups; however, the animals supplemented with PO and RO had greater NE intakes than those fed the control diets ($P=0.002$). The higher NE intakes of the PO and RO steers were caused by the addition of the oils. Palmquist and Jenkins (1980) concluded that fat at 5 to 10% of the diet reduced intake and digestion. Rule *et al.* (1989) also reported that DMI is often depressed when diets contain more than 8% fat. With diets containing lower levels of added fat, Huerta-Leidenz *et al.* (1991) reported no influence on daily gain, intake or feed conversion ratio when dietary whole cotton seed of 15 or 30% (3.3 and 6.6% additional fat) was supplemented. In the present trial, since the fat contents of the experimental diets were between 3.3% (control) and 5.4% (supplemented diets), it is unlikely that these levels of fat affected feed intake. When individual FA intake was calculated (Table 3), cattle on PO or RO diets consumed more C16:0, C18:1n-9, SFA, MUFA, and total FA than those cattle on the control diet. When a comparison was made between the PO and RO groups, cattle on the PO diet ate more C14:0 but less c18:3n-3 than cattle on the RO diet.

No remarkable changes were found for final live weight and live weight change among the treatments (Table 3). The amount of dietary fat did not affect live weight of the steers over the course of the trial; however, live weight increased at 0.91, 0.90, and 0.89 kg/d in the animals fed the control, PO, and RO diets, respectively (Table 3). This is partially because total NE (Mcal/d) consumption was balanced by treatment.

Table 3. DM, CP, NE and FA intakes; and performances of Brahman crossbred cattle fed palm or rice bran oil (n = 4).

Items	Control	200 g/d PO	200 g/d RO	SEM	P-value
DM intake (kg/d)					
Concentrate	5.6	5.6	5.6	-	-
Rice straw	3.8	3.6	3.4	0.22	0.510
Oil	-	0.2	0.2		
Total	9.4	9.4	9.2	0.22	0.350
CP intake (g/d)					
Concentrate	666	666	666	-	-
Rice straw	50	47	45	3.2	0.560
Total	716	713	711	2.9	0.722
NE intake (Mcal/d)					
Concentrate	9.8	9.8	9.8	-	-
Rice straw	2.7	2.7	2.3	0.15	0.440
Oil	-	6.3	6.3		
Total	12.5^{b}	18.8^{a}	18.4^{a}	0.35	0.002
FA intake (g/d)					
C12:0	28.7	35.1	28.9	2.15	0.103
C14:0	9.9^{b}	18.1^{a}	10.9^{b}	1.04	0.031
C16:0	25.2^{b}	70.7^{a}	63.1^{a}	4.95	0.001
C18:0	3.5^{b}	3.5^{b}	7.9^{a}	0.56	0.036
C18:1n-9	48.8^{b}	73.2^{a}	88.2^{a}	4.25	0.004
C18:2n-6	32.8	44.0	45.3	4.58	0.293
C18:3n-3	0.8^{b}	0.8^{b}	1.0^{a}	0.04	0.003
Others	4.7^{b}	7.8^{a}	6.3^{ab}	0.61	0.043
SFA	72.1^{b}	135.1^{a}	117.0^{a}	6.60	0.001
MUFA	48.8^{b}	73.1^{a}	88.2^{a}	4.62	0.003
PUFA	33.6	44.8	46.3	5.13	0.428
Total FA intake	309.0^{b}	506.0^{a}	503.0^{a}	18.97	0.002
Initial weight(kg)	330	320	310	21.0	0.807
Final weight (kg)	412	400	390	18.6	0.711
Live weight change (kg/d)	0.91	0.90	0.89	0.05	0.951
Slaughter weight (kg)	400	388	378	18.6	0.792
Warm carcass weight (kg)	220	226	217	15.0	0.925
% warm carcass	55.0	58.2	57.4	1.82	0.524
Cold carcass weight (kg)	216	221	213	12.8	0.678
% cold carcass	53.9	57.1	56.2	0.73	0.935
Marbling score[1]	2.14^{b}	2.65^{a}	2.55^{a}	0.13	0.015
Loin eye area (cm^2)	71.02	69.72	79.01	5.92	0.224
Back fat thickness (cm)	0.47	0.46	0.42	0.04	0.742

PO = palm oil; RO = rice bran oil; SEM = standard error of the mean
[1] 1 = very scarce, 12 = very abundant (Japanese Meat Grading Association)

3.2 Carcass Quality

Slaughter weight, warm carcass weight, % warm carcass, cold carcass weight, and % cold carcass were not significantly different among the treatments (Table 3). However, beef marbling scores of steers fed PO or RO diets were significantly higher (P=0.015) than steers fed the control diet. Loin eye area and 12th rib back fat thicknesses 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 muscle mass. Late-maturing muscles were used to represent the muscle tissue development rate. Thus, the *longissimus* is the most suitable muscle for analysis because, in addition to its late maturation, it is easy to measure. The similar eye muscle area for all treatments was possible because the animals received over-requirements of energy and protein from the rations. Zinn *et al.* (2000) did not observe effects on eye muscle area and fat thickness cover using Holstein steers fed diets containing protected fat or animal fat as a lipid source up to 60.0 g/kg.

3.3 Beef quality

The initial (45 min post slaughter) and final pH (24 h post slaughter) values were not different among the treatments (Table 4). The initial pH was considered ideal and final pH values were also found in the interval considered to be normal (5.4 to 5.8) for beef (Mach *et al.,* 2008). The final pH corresponds to the accumulation of lactic acid resulting from the production of adenosine triphosphate (ATP) from glucose encountered in the form of glycogen reserves. In general, cattle supplemented with grains possess a greater availability of glycogen at the time of slaughter and a lower final pH in the beef (Neath *et al.,* 2007). The final pH values suggested that there was no elevated stress prior to slaughter, because acidification of the muscle occurred as expected, and that the level of substitution of oil supplement evaluated did not affect the final pH. Drip loss, thawing loss, grilled and moisture cooking losses both in the LD and SM muscles were unaffected by oil addition to the diets.

The chemical compositions of beef composed of moisture, protein, fat, and ash were not significantly different among the treatments (Table 4). The amounts of fat in the muscle typically result from a balance between dietary energy and metabolic requirements of the animal (Oliveira *et al.,* 2012). If energy intake is higher than its metabolic demands, this excess will be stored as fat. In the present study, the greater supply of lipids in the diet was not enough to increase the deposition of fat in the muscle and back fat. The literature suggests that the total protein content is less variable in bovine meat, with values of approximately 20% observed in the *longissimus dorsi* muscle without the fat cover, and this is independent of food, breed, the genetic group, and the physiological condition (Marques *et al.,* 2006).

Table 4. Beef characteristics of Brahman crossbred cattle fed palm or rice bran oil.

Items	Control	200 g/d PO	200 g/d RO	SEM	P-value
No. of cattle	4	4	4		
Longissimus dorsi					
pH 45 min.	7.36	7.23	7.21	0.15	0.762
pH 24 h	5.21	5.57	5.62	0.13	0.723
Drip loss (%)	3.75	4.13	3.82	0.22	0.455
Thawing loss (%)	4.35	4.41	4.37	0.54	0.839
Grilled cooking loss (%)	36.42^{a}	37.32^{a}	35.14^{b}	0.28	0.015
Moisture cooking loss (%)	25.64	25.38	25.57	1.21	0.772
Moisture content (%)	73.42	73.23	73.92	0.54	0.963
Crude protein (%)	22.09	21.99	21.88	0.34	0.903
Ash (%)	1.32	1.12	1.09	0.08	0.457
Fat (%)	3.17^{ab}	3.66^{a}	3.11^{b}	0.18	0.049
Semimembranosus					
pH 45 min.	7.25	7.43	7.09	0.11	0.122
pH 24 h	5.38	5.48	5.36	0.10	0.705
Drip loss (%)	4.13	4.08	4.22	0.65	0.477
Thawing loss (%)	4.28	4.36	4.18	0.82	0.831
Grilled cooking loss (%)	35.12	33.41	35.53	0.92	0.335
Moisture cooking loss (%)	25.43	25.39	24.97	0.34	0.735
Moisture content (%)	73.35	73.15	73.98	0.50	0.504
Crude protein (%)	22.03	21.68	21.41	0.51	0.761
Ash (%)	1.26	1.46	1.11	0.12	0.438
Fat (%)	3.36	3.71	3.50	0.47	0.344

PO = palm oil; RO = rice bran oil; SEM = standard error of the mean

The sensory tenderness, juiciness, beef flavor, color firmness, and texture were unaffected by the treatments. When steers were fed diets that had similar base components, but the diets differed in the amount or composition of fatty acids through the addition of different oils, lipid and color stability were more closely associated with fatty acid composition and greater abnormal flavors and rancidity scores (Scollan *et al.,* 2006). Scheeder *et al.* (2001) evaluated the beef of bulls fed different sources of fat and found that the beef of animals fed with linseed oil tended to be juicier and possessed a more agreeable aroma. These results may be due to the higher proportions of n-3 PUFA in these animals, triggering odor precursors that are activated by oxidation during heating. However, changes in PUFA concentrations in the present experiment would not likely have been large enough to have affected taste panel assessments.

Beef color remained unaffected by treatments (Table 5). Values encountered in the literature for L*, a*, and b* were used to measure beef color in the CIELAB space (Lightness, L*; redness, a*; yellowness, b*; CIE, 1978) in the following ranges of variation: 33 to 41, 11.1 to 23.6, and 6.1 to 11.3, respectively. Values obtained in the present study were within the ranges given. The lack of differences in beef color can be attributable to similar roughage source, i.e. rice straw for all treatments which had no effect on beef color when compared to fresh grass.

Table 5. Sensory and physical evaluations of beef from Brahman crossbred cattle fed palm or rice bran oil.

Items	Control	200 g/d PO	200 g/d RO	SEM	P-value
No. of cattle	4	4	4		
Longissimus dorsi					
Tenderness	3.62	3.71	3.38	0.16	0.723
Juiciness	3.54	3.62	35.6	0.11	0.815
Beef flavor	5.41	5.29	5.53	0.17	0.894
Color	4.79	4.80	4.88	0.04	0.687
Firmness	4.16	4.14	4.19	0.05	0.721
Texture	4.14	4.29	4.17	0.08	0.654
L*	33.72	33.68	34.26	0.78	0.832
a*	13.19	12.65	13.45	0.65	0.685
b*	6.43	6.41	6.84	0.34	0.627
Shear force (kg/cm^2)	3.53	3.88	3.96	0.35	0.159
Semimembranosus					
Tenderness	3.64	3.76	3.51	0.14	0.756
Juiciness	3.59	3.66	3.63	0.12	0.623
Beef flavor	5.37	5.33	5.29	0.14	0.801
Color	4.81	4.85	4.92	0.05	0.726
Firmness	4.13	4.17	4.15	0.06	0.658
Texture	4.23	4.31	4.28	0.06	0.786
L*	33.66	33.41	35.31	0.64	0.133
a*	12.74	13.09	13.55	0.55	0.607
b*	6.98	6.65	7.00	0.35	0.145
Shear force (kg/cm^2)	3.44	3.52	3.91	0.37	0.646

PO = palm oil; RO = rice bran oil; SEM = standard error of the mean Tenderness, Juiciness, Beef flavor, Color, Firmness and texture: 1 = extremely though, dry, bland, pink, firm and fine respectively; 8 = extremely tender, juicy, intense, dark red, soft and coarse, respectively.

The shear forces of LD and SM muscle were unaffected by the addition of PO and RO in the diets (Table 5). Beef tenderness is a trait considered to be of great relevance for consumers while shear force is an objective measure of tenderness. Bovine meat is considered to have an acceptable tenderness if its shear strength values are below 8 N (Swan *et al.,* 1998). The beef in the report by Santana *et al.* (2014) was considered tender regardless of the lipid supplementation adopted because the average values obtained were 7.5 N. The present trial found shear force values between 3.44 and 3.96 kg/cm^2 which were considered to be tender (Table 5). These values were closely related to the values obtained from sensory perception of tenderness by trained panelists (3.38 to 3.76) (Table 5). Such variations in the shear force values may be caused by differences in the thicknesses of the blades utilized in the analysis.

3.4 Beef Fatty Acid Profile

In LD muscle, PO significantly increased the C12:0 and C14:0 compared to the control ($P<0.05$) but similar to RO. However, PO had no effect on other fatty acids including SFA, MUFA, PUFA, total CLA, and PUFA:SFA. RO diets had no effect on C12:0-C18:1n-9, c9,t11 CLA, SFA, UFA, MUFA, total CLA, and UFA:SFA but significantly increased C18:2n-6, t10,c12 CLA, and PUFA compared to the PO and control groups.

The diets containing RO resulted in greater LD and SM C18:2n-6, t10, c12 CLA, and PUFA that were 5.34, 5.48 and 0.14; and 7.48, 7.69, and 0.14%, respectively, of the total beef FA. The concentration of C18:2n-6 that ranged from 5.34 to 7.48% in LD and SM muscles were slightly higher than the 4.78% reported for the subcutaneous adipose tissue of Hanwoo steers fed linseed oil meal (Kim *et al.,* 2009) and higher than the 1.43% reported in heifers fed different vegetable oils (Noci *et al.,* 2007).

Despite higher intake of C16:0, C81:1n-9, MUFA, and total FA, there were no significant differences in these FAs in both the LD and SM muscles. Fatty acid elongase and stearoyl-CoA desaturase activity in cattle occur in bovine subcutaneous adipose tissue (St. John *et al.,* 1991), and these enzymes work in concert to convert C16:0 to C18:0. Choi *et al.* (2013) also reported that dietary palm oil did not increase adipose tissue or muscle concentrations of C16:0 in steer fed corn-based diets. In contrast, Partida *et al.* (2007) reported an increase in C16:0 in intramuscular fat of bulls fed hydrogenated palm oil although the total SFA concentration was similar to control bulls.

The lack of diet effect on C81:1n-9 in LD and SM muscles relates to microbial biohydrogenation of C81:1n-9 to not only C18:0 but also *trans* C18:1 positional isomers (Mosley *et al.,* 2002). Jenkins (2000) fed high oleic canola oil (78% oleic acid) to lactating Jersey cows and found a significant increase in the *trans* C18:1 concentration in milk fat. The increase in *trans* C18:1 content in milk fat could possibly be that the isomers were formed during the biohydrogenation of oleic acid in the rumen.

SFA, UFA, and MUFA in LD and SM muscles were unaffected by the dietary treatments. The percentages of *trans*-10, *cis*-12 C18:2 CLA in LD and SM were increased by RO treatment compared with the control and PO treatments ($P<0.05$) (Tables 6 and 7). The increases in *trans*-10, *cis*-12 C18:2 CLA may be due partly to an increase in delta-9 desaturase activity which would have been reflected in muscle concentrations of MUFA and SFA. Treatments had no effect on total or individual SFA in LD and SM (Tables 6 and 7). The predominant SFA across all diets in LD and SM was C16:0, followed by C18:0 and C14:0. SFA relates to changes in endogenous FA synthesis that may not have been differentially affected by diet (Mapiye *et al.,* 2013). Oliveira *et al.* 2012 fed different oils to Nellore young bulls and reported lower percentages (about 45%) of SFA. Beef generally has unfavorably low values for the P:S ratio

according to the Department of Health (1994) guidelines which recommend a value of 0.45 for the diet as a whole. The P:S ratios found in the present study were far less than the recommended value. However, since it is the P:S ratio in the diet as a whole which is most significant, it can be argued that people can readily offset deficiencies in the meat component by varying the intakes of other significant and readily available sources of SFA and PUFA.

Table 6. Fatty acid composition (g/100 g fat) of *Longissimus dorsi* muscle from Brahman crossbred cattle fed palm or rice bran oil.

Items	Control	200 g/d PO	200 g/d RO	SEM	P-value
No. of cattle	8	8	8		
Longissimus dorsi					
C12:0	0.09[b]	0.26[a]	0.15[ab]	0.04	0.041
C14:0	3.72[b]	4.99[a]	4.26[ab]	0.29	0.046
C16:0	30.31	32.78	31.00	0.89	0.203
C16:1	3.78	3.17	2.71	0.59	0.307
C18:0	16.05	16.41	16.97	0.64	0.483
C18:1n-9	41.54	38.89	39.43	1.34	0.442
C18:2n-6	4.39[ab]	3.40[b]	5.34[a]	0.46	0.049
CLA c9,t11	0.03	0.06	ND	0.01	0.052
CLA t10,c12	0.09[ab]	0.04[b]	0.14[a]	0.02	0.046
SFA[1]	50.17	54.44	52.38	2.00	0.383
UFA[2]	49.83	45.56	47.62	1.28	0.061
MUFA[3]	45.32	42.06	42.14	1.93	0.484
PUFA[4]	4.51[ab]	3.50[b]	5.48[a]	0.41	0.024
Total CLA[5]	0.12	0.10	0.14	0.02	0.078
UFA:SFA	0.99	0.84	0.91	0.05	0.081
PUFA:SFA	0.09[ab]	0.06[b]	0.10[a]	0.01	0.042

PO = palm oil; RO = rice bran oil; SEM = standard error of the mean
[1] Sum of saturated fatty acid from C12:0 – C18:0; ND = Not detectable
[2] Sum of unsaturated fatty acid from MUFA and n-6 PUFA
[3] Sum of monounsaturated fatty acid from C16:1 – C18:1
[4] Sum of n-6 PUFA and total CLA
[5] Sum of CLA from CLA c9,t11 and CLA t10,c12

Table 7. Fatty acid composition (g/100 g fat) of *Semimembranosus* muscle from Brahman crossbred cattle fed palm or rice bran oil.

Items	Control	200 g/d PO	200 g/d RO	SEM	P-value
No. of cattle	4	4	4		
Semimembranosus					
C12:0	0.21	0.22	0.24	0.03	0.752
C14:0	4.35	3.42	3.89	0.31	0.261
C16:0	31.08	30.84	29.64	0.76	0.204
C16:1	3.53	3.84	3.48	0.49	0.343
C18:0	16.56	16.11	16.28	0.69	0.501
C18:1n-9	39.33	40.87	38.78	1.36	0.568
C18:2n-6	4.78[b]	4.65[b]	7.48[a]	0.48	0.013
CLA c9,t11	0.09[a]	ND[b]	0.07[a]	0.01	0.022
CLA t10,c12	0.07[b]	0.05[b]	0.14[a]	0.02	0.029
SFA[1]	52.2	50.59	50.05	2.06	0.339
UFA[2]	47.8	49.41	49.95	1.26	0.162
MUFA[3]	42.86	44.71	42.26	2.1	0.522
PUFA[4]	4.94[b]	4.70[b]	7.69[a]	0.52	0.017
Total CLA[5]	0.16[a]	0.05[b]	0.21[a]	0.02	0.011
UFA:SFA	0.92	0.98	1	0.07	0.278
PUFA:SFA	0.09	0.09	0.15	0.03	0.314

PO = palm oil; RO = rice bran oil; SEM = standard error of the mean
[1] Sum of saturated fatty acid from C12:0 – C18:0
[2] Sum of unsaturated fatty acid from MUFA and n-6 PUFA
[3] Sum of monounsaturated fatty acid from C16:1 – C18:1
[4] Sum of n-6 PUFA and total CLA
[5] Sum of CLA from CLA c9,t11 and CLA t10,c12

4. Conclusions

Feeding dietary treatment that includes 200 g/d of oil supplement comprised of PO or RO did not negatively affect any of the performance and carcass quality of steers. The overall feed consumption of the steers was unaffected when dietary oil was provided. PO or RO supplement did not influence muscle sensory or physical characteristics. Supplementation of RO in the steer diet increased C18:2n-6, *trans10, cis12* C18:2 CLA, and PUFA compared with the PO diet. Thus, it can be concluded that 200 g/d RO can be safety supplemented to diets of steers to enrich beef with potential health beneficial FA.

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References

Association of Official Analytical Chemists. (1995). *Official Method of Analysis.* Washington, DC: Author.

Choi, S. H., Gang, G. O., Sawyer, J. E., Johnson, B. J., Kim, K. H., Choi, C. W., & Smith, S. B. (2013). Fatty acid biosynthesis and lipogenic enzyme activities in subcutaneous adipose tissue of feedlot steers fed supplementary palm oil or soybean oil. *Journal of Animal Science, 91*, 2091-2098.

CIE. (1978). *International commission on illumination, recommendations on uniform color spaces, color difference equations, psychometric color terms.* Paris, France: Author.

Department of Health. (1994). *Nutritional aspects of cardiovascular diseases* (Report on Health and Social Subjects No. 46). London, England: Her Majesty's Stationary Office.

Dryden, F. D., & Marchello, J. A. (1970). Influence of total lipids and fatty acid composition upon the palatability of three bovine muscles. *Journal of Animal Science, 31*, 36-41.

Folch, J., Lees, M., & Sloane Stanley, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biology and Chemistry, 226*, 497-509.

Grundy, S. M. (1989). Monounsaturated fatty acids and cholesterol metabolism: implications for dietary recommendations. *Journal of Nutrition, 119*(4), 529-533.

Huerta-Leidenz, N. O., Cross, H. R., Lunt, D. K., Pelton, L. S., Savell, J. W., & Smith, S. B. (1991). Growth, carcass traits and fatty acid profiles of adipose tissues from steers fed whole cottonseed. *Journal of Animal Science, 69*, 3665-3672.

Jenkins, T. C. (2000). Feeding oleamide to lactating Jersey cows. I. Effects on lactation performance and milk fatty acid composition. *Journal of Dairy Science, 83*, 332-337.

Kim, C. M., Kim, J. H., Oh, Y. K., Park, E. K., Ahn, G. C., Lee, G. Y., . . . Park, K. K. (2009). Effects of flaxseed diets on performance, carcass characteristics and fatty acid composition of Hanwoo steers. *Asian-Australasian Journal of Animal Science, 22*(8), 1151-1159.

Mach, N., Bach, A., Velarde, A., & Devant, M. (2008). Association between animal, transportation, slaughter-house practices, and meat pH in beef. *Meat Science, 78*, 232-238.

Mapiye, C., Aalhus, J. L., Turner, T. D., Rolland, D. C., Basarab, J. A., Baron, V. S., . . . Dugan, M. E. R. (2013). Effects of feeding flaxseed or sunflower-seed in high-forage diets on beef production, quality and fatty acid composition. *Meat Science, 95*, 98-109.

Marques, J. A., Prado, I. N., Moletta, J. L., Prado, I. M., Prado, J. M., Macedo, L. M. A., . . . Matsushita, M. (2006). Características fisicoquímicas da carcaça e da carne de novilhas submetidas ao anestro cirúrgico ou mecânico terminadas em confinamento. *Revista Brasileira de Zootecnia, 35*, 1514-1522.

Mosley, E. E., Powell, G. L., Riley, M. B., & Jenkins, T. C. (2002). Microbial biohydrogenation of oleic acid to *trans* isomers *in vitro*. *Journal of Lipid Research, 43*, 290-296.

Neath, K. E., Del Barrio, A. N., Lapitan, R. M., Herrera, J. R. V., Cruz, L. C., Cruz, T., . . . Kanai, Y. (2007). Difference in tenderness and pH decline between water buffalo meat and beef during post mortem aging. *Meat Science, 75*, 499-505.

Noci, F., Freach, P., Monahan, F. J., & Moloney, A. P. (2007). The fatty acid composition of muscle fat and subcutaneous adipose tissue of grazing heifers supplemented with plant oil-enriched concentrates. *Journal of Animal Science, 85*, 1062-1073.

National Research Council. (2000). *Nutrient Requirements of Beef Cattle* (7th ed.). Washington, DC: National Academy Press.

Oliveira, E. A., Sampaio, A. A. M., Henrique, W., Pivaro, T. M., Rosa, B. L. A., Fernandes, R. M., & Andrade, A. T. (2012). Quality traits and lipid composition of meat from Nellore young bulls fed with different oils either protected or unprotected from rumen degradation. *Meat Science, 90*, 28-35.

Ostrowska, E., Dunshea, F. R., Muralitharan, M., & Cross, R. F. (2000). Comparison of silver-ion high-performance liquid chromatographic quantification of free and methylated conjugated linoleic acids. *Lipids, 35*, 1147 - 1153.

Palmquist, D. L., & Jenkins, T. (1980). Fat in lactations rations: Review. *Journal of Dairy Science, 63*, 1-14.

Partida, J. A., Olletta, J. L., Sanudo, C., Alberti, P., & Campo, M. M. (2007). Fatty acid composition and sensory traits of beef fed palm oil supplements. *Meat Science, 76*, 444-454.

Raes, K., De Smet, S., & Demeyer, D. (2004). Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: A review. *Animal Feed Science and Technology, 113*(1-4), 199-221.

Rule, D. C., Wu, W. H., Busboom, J. R., Hinds, F. C., & Kercher, C. J. (1989). Dietary canola seeds alter the fatty acid composition of bovine subcutaneous adipose tissue. *Nutrition and Reproduction International, 39*, 781.

Santana, M. C. A., Fiorentinia, G., Diana, P. H. M., Canesina, R. C., Messanaa, J. D., Oliveira, R. V., . . . Berchielli, T. T. (2014). Growth performance and meat quality of heifers receiving different forms of soybean oil in the rumen. *Animal Feed Science and Technology, 194*, 35-43.

Scheeder, M. R. L., Casutt, M. M., Roulin, M., Escher, F., Dufey, P. A., & Kreuzer, M. (2001). Fatty acid composition, cooking loss and texture of beef patties from meat of bulls fed different fats. *Meat Science, 58*, 321-328.

Scollan, N. G., Hocquette, J. F., Nuernberg, K., Dannenberger, D., Richardson, R. I., & Moloney, A. P. (2006). Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Science, 74*, 17-33.

St. John, L. C., Lunt, D. K., & Smith, S. B. (1991). Fatty acid elongation and desaturation enzyme activities of bovine liver and subcutaneous adipose tissue microsomes. *Journal of Animal Science, 69*, 1064-1073.

Statistical Analysis System. (2001). SAS User' Guide: Statistics. Cary, NC: SAS Institute.

Steel, R. G. D., & Torries, J. H. (1980). *Principles and procedures of statistics: A biometeric approach* (2nd ed.). New York, NY: McGrow Hill.

Stone, H., Sidel, J., Oliver, S., Woolsey, A., & Singleto, R. C. (1974). Sensory evaluation by quantitative descriptive analysis. *Food Technology, 28*, 24-34.

Suksombat, W., & Chullanandana, K. (2008a). Effects of soybean oil or rumen protected conjugated linoleic acid supplementation on accumulation of conjugated linoleic acid in dairy cows' milk. *Asian-Australasian Journal of Animal Science, 21*(9), 1271-1277.

Suksombat, W., & Chullanandana, K. (2008b). Effects of soybean oil or whole cotton seed addition on accumulation of conjugated linoleic acid in beef of fattening Brahman×Thai-Native cattle. *Asian-Australasian Journal of Animal Science, 21*(10), 1458-1465.

Suksombat, W., Meeprom, C., & Mirattanaphrai, R. (2013). Milk production, milk composition, live weight change and milk fatty acid composition in lactating dairy cows in response to whole linseed supplementation. *Asian-Australasian Journal of Animal Science, 26*(8), 1111-1118.

Suksombat, W., Thanh, L. P., Meeprom, C., & Mirattanaphrai, R. (2014). Effects of linseed oil or whole linseed supplementation on performance and milk fatty acid composition of lactating dairy cows. *Asian-Australasian Journal of Animal Science, 27*(7), 951-959.

Swan, J. E., Esguerra, C. M., & Farouk, M. M. (1998). Some physical, chemical and sensory properties of chevon products from three New Zealand goat breeds. *Small Ruminant Research, 28*, 273-280.

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal production. *Journal of Dairy Science, 74*, 3583-3597.

Zinn, R. A., Gulati, S. K., Plascencia, A., & Salinas, J. (2000). Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. *Journal of Animal Science, 78*, 1738-1746.