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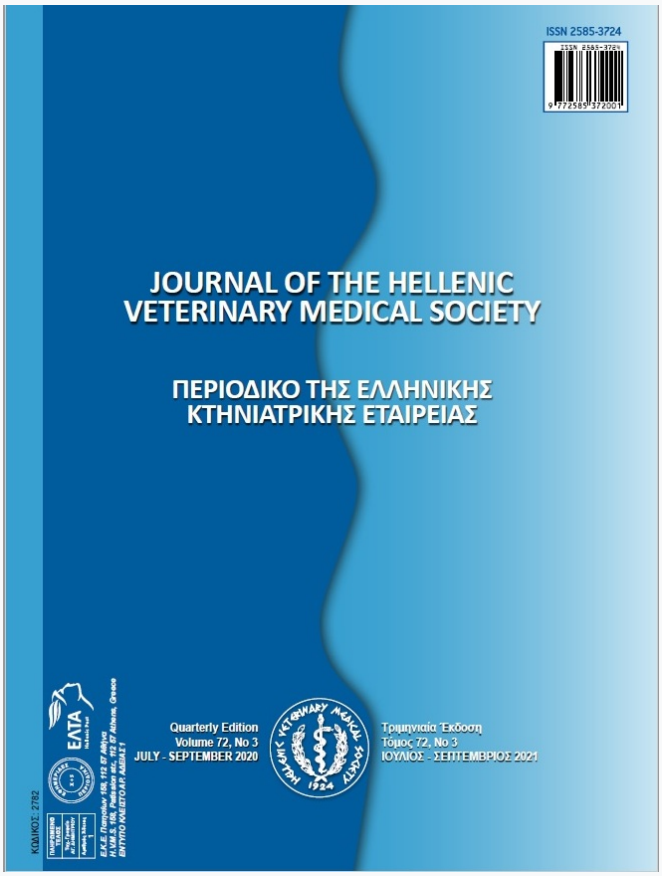

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Research article
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Effect of supplementing flaxseed oil on growth and carcass traits of Friesian bulls

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ABSTRACT: This study aimed to evaluate effects of supplementing flaxseed oil (FSO) on growth and carcass traits, as well as meat chemical composition, quality, and fatty acids (FA) profile in Friesian bulls. The bulls (n = 30) were randomly divided into 3 groups (G1-G3, n = 10/group). In G1 (control), animals fed basal diet, while in G2 and G3, they were supplemented with 2% and 4% FSO, respectively, for ~ 7 months. The obtained results revealed that bulls fed diet supplemented with 2% (G2) and 4% (G3) FSO had significantly higher TDN intake ($P < 0.01$) and average daily gain ($P < 0.05$) than G1. Additionally, G3 showed significantly higher hot carcass weight ($P<0.001$), dressing % ($P<0.05$), fat weight ($P<0.05$), boneless meat weight ($P<0.001$), 9-11th ribs cut weights ($P<0.05$), DM ($P<0.01$), CP ($P<0.05$), and CF ($P<0.05$) in eye muscle, and general cooked meat quality ($P<0.05$) than G1. However, meat of G3 had significantly ($P<0.05$) lower water-holding capacity than G1. Meat contents of C20:0 and C22:0 SFAs were significantly higher in G3 ($P<0.05$) than G1, while C14:0, C15:0, and C17:0 were significantly ($P<0.05$) lower in G3 and G2 than G1. C16:1 trans-9 MUFA was significantly higher in G3 ($P<0.01$) and G2 ($P<0.05$) than G1, while C18:1 cis-9 +trans-13-14 and C20:1 cis-11 were significantly lower in G3 ($P<0.001$) and G2 ($P<0.05$) than G1. Among the 2 treated groups, only G3 had significantly higher C17:1 cis-9 ($P<0.05$), C18:1 cis-11+trans15 ($P<0.01$), and C18:1 cis-15+trans-16 ($P<0.01$) and significantly lower C16:1 cis-7 ($P<0.05$) and C18:1 trans-12 ($P<0.01$) than G1. Meat contents of C18:3 n-3 (ALA), C22:5 n-3 (EPA) and C22:6 n-3 (DHA) was significantly higher in G3 ($P<0.0001$) and G2 ($P<0.05$) than G1. The total n-3 FAs content in meat was significantly ($P<0.0001$) higher in G3 and G2 than G1, while only G3 showed significantly higher total PUFA ($P<0.05$) than G1. The n-6:n-3 ratio was significantly ($P<0.0001$) lower in G3 and G2 than G1. With these results, we could conclude that flaxseed oil supplementation in bull diets could improve growth performance, and carcass quality and increase omega-3 FA in animal meat.

Keywords: Friesian bulls; carcass traits; meat quality; fatty acid profile.

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INTRODUCTION

It is beneficial for our health to consume meat with low content of saturated fatty acids (SFA) and high content of polyunsaturated fatty acids (PUFAs) and monounsaturated fatty acids (MUFAs). Among the most important PUFAs, omega-3 FAs come at the top due to their role in decreasing bad cholesterol (LDH) and increasing good cholesterol (HDL), thereby reducing cardiovascular diseases. Omega-3 FAs are essential fats because human and animal body can not build them, and the only source is food (Palmquist, 2009). The most common types of omega-3 FAs are alpha-linolenic acid (ALA, C18:3 n-3), docosahexaenoic acid (DHA, C22:6 n-3), and eicosapentaenoic acid (EPA, C20:5 n-3). Additionally, conjugated linoleic acid (CLA, C18:2 cis-9, trans11+trans-7, cis-9+trans-8, cis-10) and linoleic acid (LA, C18:2 n-6) are two important members of omega-6, which are also essential FAs and are very important for our health (Baba et al., 2016). The recommended ratio of omega-6 (n-6) to omega-3 (n-3) in human food is 4: 1. If this ratio increased above 5:1, human body would be more susceptible to hypercholesteremia and cardiovascular diseases. Hence, it is crucial to elevate PUFA:SFA and to decrease n-6:n-3 ratio to get healthy meat (Scollan et al., 2006).

Ruminant meat is rich in high quality proteins, fats (especially omega-3 FAs), vitamins and minerals (Ebrahimi et al., 2014; Oliveira et al., 2012; Scollan et al., 2014). The main source for meat omega-3 FAs is the consumption of diet supplemented with omega-3 FAs-enriched vegetable oils (Deng et al., 2017). Additionally, Palmquist, (2009) and Scollan et al., (2006) found that cattle fed diet supplemented with n-3 PUFA or LA had significantly higher n-3 PUFA and CLA contents in their meat fat. Similarly, animals fed diets supplemented with linseed oil (LSO), which contains a high content of ALA, had significantly higher ALA content in their meat fat (Mach *et al*., 2006; Herdmann *et al*. 2010). Moreover, dietary supplementation of vegetable oils also enhances rumen metabolism, nutrients digestibility, and growth performance (Kowalsk *et al*., 1997). Indeed, dietary supplementation of sunflower oil increased the final body weight and average daily gain in goats (Saqhiret al. 2012).

Flaxseed oil (FSO), which is rich in PUFAs particularly ALA, is considered as the main constituent of some enzymes involved in the metabolism of protein and growth of organs, and thus it could be beneficial for growth performance and immune response (Abu El-Hamd et al., 2019). FSO can also effectively enhance the nutritional value of PUFAs (Scollan et al. 2014) and increase carcasses grading choice and marbling scores in beef (LaBrune, 2000). Moreover, the meat of bulls fed diet supplemented with FSO had significantly higher EPA and DHA content than bulls fed control diet (Renna et al., 2018). Herdmann et al. (2010) and Simopoulos (2011) also found that cattle fed FSO had a lower n-6:n-3 PUFA ratio than control cattle.

Apart from these previous studies which mainly performed on cattle breeds other than Friesian, little is known regarding the effect of FSO supplementation on growth performance, carcass characteristics, meat quality, and fatty acids profile of Friesian bulls. Therefore, this study was conducted to evaluate this effect.

MATERIALS AND METHODS

The present study was carried out at Sakha Animal Production Research Station, belonging to the Animal Production Research Institute, Agricultural Research center, Ministry of Agriculture, and Animal Production Department, Faculty of Agriculture, Kafrelsheikh University during the period from August 2016 to March 2017. This study was conducted after an agreement from the Animal Care and Ethics Committee of Kafrelsheikh University, Egypt (license number, KFS1345/10).

Experimental design

A total of 30 Friesian bulls, with an average live body weight of (LBW) 265.35±12.36 kg and age of 8 months. All bulls were free of physical defects and diseases and had normal external genitalia. The animals were kept freely under semi-open sheds and were managed according to the recommendations of Animal Production Research Institute (APRI, 1997).

Animals were randomly divided into three groups (G1-G3, n = 10 per group). Each 10 animals per group were subdivided into 3 replicates, each replicate had 3 animals except the last one contained 4 animals. Each animal replicate (3-4 animals) was individually housed in a free-stall unit. Bulls in G1 (control) were fed a basal diet, while those in G2 and G3 were fed basal diet supplemented with 2% and 4% DMI flaxseed oil (FSO), respectively, for 208 days (~ 7 months). The basal diet contained concentrate feed mixture (CFM), corn silage (CS), berseem hay (BH),

and rice straw (RS) and was formulated based on the recommendation of the NRC (1980). CFM included 37.5% yellow corn, 20% soybean meal, 15 % corn gluten, 22.5% wheat bran, 3% molasses. 0.5% premix and 1.5% common salt. The chemical composition of feedstuffs and experimental rations (DM, CP, CF, EE, NFE, and ash) was analyzed according to A.O.A.C. official method (2012) and the results were shown in Tables 1 and 2. The NDF, ADF, and ADL were analysed according to Mertens (2002), AOAC (2004) and Van Soest et al. (1991), respectively. Dry matter (DM) intake was determined by weighing feed refusals from each animal replicate on 2 consecutive days weekly.

At the end of the experimental period (at the age of 14 months), 6 bulls (2 from each replicate) in each group with an average of 475±23.50 Kg LBW were slaughtered after fasting for 16 h (Sharawy, 2005).

Growth traits

The initial and final body weight of bulls was recorded at the beginning (at the age of 8 months) and end (at the age of 14 months) of the experiment, respectively. Bulls were weighed before morning feeding and after holding off feed and water for 16 h. The total body weight gain was then calculated by subtracting initial body weight from final body weight. The average daily gain (ADG) of bulls was calculated by dividing the total body weight gain by experiment duration (208 days)

Carcass traits

Fasting body weight was recorded before slaughter. Subsequently, weights of hot carcass and edible organs (liver, kidney, heart and, spleen) were recorded. Each carcass was divided into 4 quarters (2 fore and 2 hind quarters) between the 11th and 12th ribs. Dressing % and boneless meat for each carcass were estimated according to the following formulas: dressing % without edible offal = carcass weight / fasting weight x 100. Dressing % with edible offal = carcass weight + edible offal (liver + heart + kidneys) / fasting weight X100.

Table 1. Chemical composition of feedstuffs.

Feedstuffs	Chemical composition on dry matter basis					
	Ash	NFE	EE	CF	CP	OM
CFM	8.50	64.11	2.48	8.41	16.50	91.50
CS	9.09	61.62	2.56	17.21	9.52	90.91
BH	11.88	43.57	2.38	29.01	13.16	88.12
RS	15.49	49.06	1.10	31.82	2.53	84.51

Data was presented as averages.
NFE: nitrogen free extract; EE: ether extract; CF: crude fiber; CP: crude protein; OM: organic matter; CFM: concentrate feed mixture; CS: corn silage; BH: berseem hay; RS: rice straw

Table 2. Chemical composition of experimental rations on dry matter basis.

Chemical composition	Experimental groups		
	G1	G2	G3
OM	90.28	90.49	90.22
CP	13.38	13.39	13.33
CF	14.63	14.58	14.62
EE	2.31	4.01	6.07
NFE	59.69	58.51	56.20
Ash	9.92	9.51	9.56
NDF	39.19	39.54	39.44
ADF	20.30	20.46	20.41
ADL	4.07	4.12	4.38

Data was presented as averages.
OM: organic matter; CP: crude protein; CF: crude fiber; EE: ether extract; NFE: nitrogen free extract; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent liginin.

The eye muscle area was determined by a planimeter from tracing taken on the cut surface over the 9th rib. The 9 -11th rib samples were weighed cold and used for chemical analysis and estimation of meat quality. Tenderness and water-holding capacity were measured as previously described (Owen et al. 1982). The color intensity of the meat samples was calculated at 542 nm by a spectrophotometer. The pH of *Longissimus dorsi* muscle was determined in 2.5 cm thick muscular slices by a digital pH-meter (Jenway, 3010) at room temperature (Suksombat et al., 2016). The 9, 10, and 11th rib cuts were dissected into lean, fat, and bone and their weights were recorded. Chemical composition (DM, CP, CF, ash, and moisture) of the *Longissimus dorsi* muscle minced samples was determined based on A.O.A.C. official method (2012).

Meat quality

Meat quality parameters, including flavor, juiciness, color, taste, and tenderness of cooked meat were evaluated by 10 members of our lab using a five-point scale (Chambaz, et al. 2003). General meat quality was calculated according to the following formula: general meat quality = (taste grade + flavor grade + juiciness grade + tenderness grade + color grade) /5.

Fatty acids composition

Total lipids in *Longissimus dorsi* samples were extracted using chloroform-methanol as previously described (Suksombat et al., 2016). Preparation of fatty acids methyl esters (FAME) was performed as previously described (Ostrowska et al., 2000). Based on this method, hexane was used to extract FAME. The fatty acids profile of meat samples was measured by gas chromatography (GC, Perkin-Elmer Auto syst-X.L) equipped with silica capillary column. Injector and detector temperatures were 240°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. Results were expressed as g/100 g total fatty acids.

Statistical analysis

Statistical analysis of the obtained data was analyzed by one-way analysis of variance (ANOVA) using the Statistical Analysis System (SAS). Duncan multiple range test had used to determine the significant differences among groups. A significant level of $p<0.05$ was used.

RESULTS AND DISCUSSION

Effect of flaxseed oil dietary supplementation on feed intake

Bulls fed diet supplemented with 2% and 4% flaxseed oil (FSO) in G2 (6.02±0.12 kg/h/d, $P < 0.01$) and G3 (6.34±0.11 kg/h/d, $P < 0.0001$) had significantly higher TDN intake than G1 (5.46±0.13 kg/h/d) (Table 3). However, no significant ($P > 0.05$) difference was noticed in DM and DCP intake or feed conversion among the three groups. These results agreed with Huerta-Leidenz et al. (1991) and Suksombat et al., (2016) who found no significant difference in DM and DCP intake and feed conversion among animals fed diet supplemented with linseed oil (LSO) and whole cotton seed, respectively, with fat contents below or equal to 5.0%. On the other hand, other previous studies showed that fat contents above 5% of the diet significantly reduced DM intake and digestion (Rule et al. 1989).

Effect of flaxseed oil dietary supplementation on growth performance

Bulls fed diet supplemented with a higher dose of FSO (G3) had significantly ($P<0.05$) higher final live body weight (LBW) than other groups (Table 4). G2 (1.002±0.02 kg/h/d, $P<0.05$) and G3 (1.124±0.03 kg/h/d, $P<0.0001$) had also significantly higher average daily gain (ADG) than G1 (0.900±0.03 kg/h/d) (Table 4). These results are consistent with those reported by Abu El-Hamd et al. (2015), who also found significantly higher LBW and ADG in Friesian calves fed on ration supplemented with FSO than those fed on the control diet. Similarly, Khattab et al. (2011) found that buffalo calves fed on a black seed oil diet grew faster than those fed on a basal diet. Moreover, Maddock et al. (2004) reported that feeding beef cattle on the whole (rolled or ground) flaxseed significantly increased total body weight gain. Additionally, dietary supplementation of 10% and 20% LSO significantly improved growth traits as compared to the control group (Abuelfatah et al. 2013). In contrast, He and Armentano (2011), Noci et al. (2007) and Suksombat et al., (2016) did not find any significant difference in final LBW or ADG in animals fed diet supplemented with 5%LSO or sunflower oil (SFO), or a mixture of FSO and SFO at 5% of diet. This could be attributed to balance of the total net energy consumption by treatments.

Table 3. Effect of flaxseed oil dietary supplementation on bull feed intake

	G1	G2	G3
Total intake (kg/h/d)			
DM	9.37±0.45	8.97±0.49	9.06±0.39
TDN	5.46±0.13	6.02±0.12[a]	6.34±0.11[b]
DCP	0.877±0.04	0.867±0.03	0.892±0.04
Feed conversion			
Kg DM /kg gain	9.83±0.67	9.72±0.70	8.53±0.82
Kg TDN / kg gain	6.89±0.45	6.52±0.48	5.97±0.51
Kg DCP / kg gain	0.986±0.05	0.939±0.04	0.840±0.06

Data are presented as means ± SEM (n = 10/group). [a] P < 0.01, [b] P < 0.0001 (vs G1).
DM: dry matter; TDN: total digestible nutrients; DCP: digestible crude protein.

Table 4. Effect of flaxseed oil dietary supplementation on bull growth performance

	G1	G2	G3
Duration (day)	208	208	208
Initial body weight (kg)	265.5±10.2	264.8±11.4	264.5±10.8
Final body weight (kg)	452.7±9.6	473.3±8.5	498.3±12.6[a]
Total gain (kg)	187.2±8.4	205.5±7.8	233.8±9.5[b]
Average daily gain (kg/h/d)	0.900±0.03	1.002±0.02[a]	1.124±0.03[c]

Data are presented as means ± SEM (n = 10/group). [a] P < 0.05, [b] P < 0.01, [c] P < 0.0001 (vs G1). ADG: average daily gain

Table 5. Effect of flaxseed oil dietary supplementation on bull carcass traits

	G1	G2	G3
Fasting body weight (kg)	446.67±6.5	463.3±5.6	493.3±5.1[cB]
Hot carcass weight (kg)	242±5.7	261±6.7	290±8.1[bA]
Dressing % without edible offal	54.18±1.2	56.33±1.1	58.79±1.1[a]
Dressing % with edible offal	59.61±1.4	62.25±1.7	65.69±1.8[a]
Boneless meat weight (kg)	197.7±6.8	212±7.4	244±7.8[bA]
Fat weight (kg)	22.4±1.4	25.6±2.4	29.5±1.9[a]
Bone weight (kg)	44.3±2.7	49±3.1	46±3.4
Boneless meat (%)	81.69±1.4	81.23±1.3	84.13±1.4
Bone (%)	18.31±1.3	18.77±1.4	15.86±2.1
Boneless meat: bone ratio	4.46	4.33	5.31

Data are presented as means ± SEM (n = 6/group). [a] P < 0.05, [b] P < 0.001, [c] P < 0.0001 (vs G1); [A] P < 0.05, [B] P < 0.01 (vs G2).

Effect of flaxseed oil dietary supplementation on carcass traits

Effect of FSO supplementation on carcass traits (fasting body weight, hot carcass weight, dressing % with or without edible offal, boneless meat weight and %, bone weight and %, fat weight and %, and boneless meat: bone ration) were presented in Table 5. The obtained results showed that G3 had significantly higher fasting body weight (493.3±5.1kg; P<0.0001 vs G1 and P<0.01 vs G2) than G1 (446.67±6.5kg) and G2 (463.3±5.6kg). Additionally, G3 showed a significantly higher hot carcass weight (290±8.1kg; P<0.001 vs G1 and P<0.05 vs G2) than G1 (242±5.7kg) and G2 (261±6.7). G3 had a significantly higher dressing % without (58.79±1.1%, P<0.05) or with edible offal (65.69±1.8%, P<0.05) and fat weight (29.5±1.9kg; P<0.05) than G1 (54.18±1.2% and 59.61±1.4%, respectively). Besides, G3 had significantly higher boneless meat weight (244±7.8kg; P<0.001 vs G1 and P<0.05 vs G2) than G1 (197.7±6.8kg) and G2 (212±7.4kg). However, FSO treatment did not significantly affect other carcass characteristics (boneless meat %, bone weight and %, and boneless meat: bone ratio). Consistent with these findings, LaBrune, (2000) found that FSO supplementation to basal diet of finishing cattle increased the percentage of carcasses grading choice and improved marbling scores due to its high content of α-linolenic acid. In contrast, Noci et al. (2007) and Suksombat et al., (2016) reported that cattle fed a mixture of 150 g/d SFO and 150

g/d LSO or 5% LSO, respectively, showed no significant differences in carcass weight and dressing%.

Effect of flaxseed oil dietary supplementation on characteristics and chemical composition of eye muscle

The region of the eye (*Longissimus dorsi*) muscle is often utilized as a meaningful indicator of the size, quality and muscle mass distribution. Longissimus dorsi is the most relevant muscle for chemical analysis because it is a late mature muscle and easy to measure. Effect of FSO supplementation on carcass characteristics of the eye muscle (9-11th ribs cut weights and their contents of meat, bone, and fat, water-holding capacity, and pH) and chemical composition were presented in Table 6. G3 had significantly higher 9-11th ribs cut weights (13.9±0.3kg, P<0.05) than G1 (12.0±0.5kg). In contrast to our findings, Zinn et al. (2000) and Suksombat et al., (2016) did not find significant effects on eye muscle area in steers fed diets supplemented with LSO or animal fat.

Water-holding capacity have significantly decreased in G3 (6.74±0.08 cm^2, P<0.05) as compared to G1 (7.12±0.09 cm^2). In contrast, no significant change in pH was observed among the three groups. Consistent with these findings, Suksombat et al., (2016) also did not observe a significant change in the pH in the eye muscle of steer following LSO dietary supplementation.

The chemical composition of *Longissimus dorsi* of FSO-supplemented bulls was better than the control animals. G3 had significantly higher DM in eye muscle (27.95± 0.82%, P<0.01 vs G1 and P<0.05 vs G2) than G1 (25.34±0.78%) and G2 (27.56±0.62%). Moreover, G3 had significantly higher CP (82.65±1.7%, P<0.05), and CF (13.68±0.9%, P<0.05) in eye muscle than G1 (76.48±1.6% and 10.52±0.7%, respectively). However, no significant differences were noticed in moisture and ash percentages among the three groups. Consistent with our findings, previous studies also showed significantly higher CF and CP in the meat of animals fed diet supplemented with FSO as compared to those fed the control diet (Corazzin et al. 2012; Barahona et al. 2016, Abdel-Gawad and El-Emam 2018). However, other researchers did not find any significant changes in chemical composition of eye muscle between LSO-fed steers and non-supplemented steers (Suksombat et al., 2016).

Table 6: Effect of flaxseed oil dietary supplementation on characteristics and chemical composition of *Longissimus dorsi* muscle of bulls

	G1	G2	G3
Weight of the 9th -11th ribs cut (Kg)	12.0±0.5	13.4±0.6	13.9±0.3^a
Meat (kg)	8.45±0.7	9.47 ±0.8	9.96±0.5
Bone (kg)	2.15±0.21	2.40±0.23	2.32±0.24
Fat (kg)	1.40±0.12	1.53±0.14	1.62±0.11
Water-holding capacity (cm^2)	7.12±0.09	6.92±0.08	6.74±0.08^a
pH	5.54±0.24	5.65±0.32	5.47±0.26
Chemical composition of eye muscle			
Dry matter (%)	25.34±0.78	27.56±0.62^a	27.95± 0.82^b
Crude protein (%)	76.48±1.6	77.14±1.5	82.65±1.7^a
Crude fat (%)	10.52±0.7	11.73±0.8	13.68±0.9^a
Ash (%)	3.33±0.24	3.59±0.21	3.76±0.15
Moisture (%)	74.66±1.6	72.44±1.5	72.05±1.7

Data are presented as means ± SEM (n = 6/group). ^{a}P < 0.05, ^{b}P < 0.01 (vs G1).

Table 7. Effect of flaxseed oil dietary supplementation on bull meat quality

	G1	G2	G3
Taste	7.7±0.5	7.6±0.5	8.12±0.4
Color	6.12±0.4	8.7±0.6	8.56±0.5
Flavor	7.46±0.4	7.78±0.4	8.42±0.4
Drumming	7.6±0.5	7.62±0.3	8.24±0.6
Exterior	7.62±0.4	7.84±0.4	8.3±0.5
General meat quality	7.30±0.2	7.91±0.2	8.33±0.3^a

Data are presented as means of grades ± SEM (n = 6/group). ^{a}P < 0.05 (vs G1).

Effect of flaxseed oil dietary supplementation on meat quality

Effect of FSO dietary supplementation on bull meat quality (taste, flavor, juiciness, tenderness, and color) was presented in Table 7. G3 showed significantly higher general meat quality (8.33±0.3 grade, P<0.05) than G1 (7.30±0.2 grade). This infers that meat consumers prefer meat produced from G3 than G1. Among the different meat quality parameters, the color of meat gains a particular interest. Redness of meat is one of most important factors taken in consideration during buying meat, as consumers correlate it with freshness status of meat (Kerry et al., 2000). In consistence with our results, a previous study by Scheeder et al. (2001) also founded that the meat of animals fed various sources of fat are juicier and have more attractive smell than animals fed control diet. This favorable meat quality could be due to higher contents of n-3 PUFA which can induce odor precursors release during heating (Scheeder et al. 2001). In contrast, Suksombat et al., (2016) reported insignificant changes in meat quality after feeding steers diets supplemented with LSO. Similarly, Nuernberg et al., (2005) found no significant changes in meat quality of bulls feeding diet supplemented with cracked linseed. Meat tenderness is accepted if the value of shear strength less than 8 N (Swan et al., 1998) regardless of lipid supplementation adopted (Santana et al. 2014). Dietary fat can positively affect fat content, growth, and carcass quality in ruminants (De Brito et al., 2017).

Effect of flaxseed oil dietary supplementation on fatty acid profile in Longissimus dorsi muscle

Table 8 shows effect of FSO dietary supplementation on SFA and MUFA. C20:0 SFA was significantly higher in G3 (0.12±0.006%, P<0.01 vs G1 and P<0.05 vs G2) than in G1 (0.09±0.004%) and G2 (0.10±0.005%). C22:0 was also significantly higher in G3 (0.15±0.006%, P<0.05) than G1 (0.12±0.005%), but no significant difference with G2 (0.14±0.006%). However, C14:0; C15:0; and C17:0 were significantly lower in G3 (1.38±0.03%, P<0.001; 2.28±0.02%, P<0.05; and 1.05±0.03%, P<0.0001, respectively) and G2 (1.43±0.02%, P<0.01; 2.29±0.03%, P<0.05; and 1.32±0.03%, P<0.05, respectively) than G1 (1.63±0.04%; 2.41±0.03%; and 1.49±0.05%, respectively). In contrast, the contents of *de novo* synthesized SFA (C10:0, C12:0, and C16:0) showed insignificant differences between the three groups. Previous studies reported a decrease in individual SFA (Mach et al. 2006; Corazzin et al. 2012), however, Rennaet al., (2018) denoted an increase in C18:0 and C20:0 following FSO supplementation.

On the other hand, meat content of C16:1 trans-9 MUFA was significantly higher in G3 (1.12±0.07%, P<0.01) and G2 (1.04±0.07%, P<0.05) than in G1 (0.73±0.06%), while C18:1 cis-9 +trans-13-14 and C20:1 cis-11 were significantly lower in G3 (17.21±0.24%, P<0.0001 and 0.10±0.004%, P<0.001, respectively) and G2 (19.05±0.25%, P<0.05 and 0.11±0.004%, P<0.05, respectively) than in G1 (20.05±0.27% and 0.13±005%, respectively). In agreement with these results, Choi et al. (2015) reported that C18:1 cis-9+trans-13-14 downregulated the expression of adipogenic gene in intramuscular preadipocytes. Among the two treated groups, only G3 had significantly higher C17:1 cis-9 (19.05±0.25%, P<0.05), C18:1 cis-11+trans15 (1.76±0.13%, P<0.01), and C18:1 cis-15+trans-16 (19.05±0.25%, P<0.01) than G1 (1.32±0.11%, 1.13±0.11 and 0.79±0.03%, respectively) and significantly lower C16:1 cis-7 (1.33±0.11%, P<0.05) and C18:1 trans-12 (1.44±0.11%, P<0.01) than G1 (1.85±0.13% and 1.13±0.11, respectively).

Table 9 shows effect of FSO dietary supplementation on PUFA. The meat content of C18:3 n-3 PUFA (ALA) was significantly higher in G3 (1.64±0.02%, P<0.0001) and G2 (1.32±0.02%, P<0.0001) than in G1 (0.76±0.01). These results agreed with Albert et al. (2014), Conteet al. (2019) and Renna et al., (2018), who found that LSO and FSO dietary supplementation resulted in a significant increase in ALA content of beef fat as compared to bulls fed control diet. It is well known that FSO is rich in ALA, and it therefore has been used effectively to enhance the nutritional impact of PUFAs in bull meat (Scollan et al. 2014). Piedmonti beef had a larger n-3 PUFA, including ALA, amount than the overall FAs, making their meat leaner but healthier than other breeds (Aldai et al. 2006; Sevane et al. 2014). In contrast, Choi et al. (2015) found that ALA downregulated the expression of adipogenic gene in intramuscular preadipocytes and Bessa et al., (2007) and Suksombat et al., (2016) found a significant decrease in ALA level in beef following LSO supplementation.

Table (8): Effect of flaxseed oil dietary supplementation on SFA and MUF in *Longissimus dorsi* muscle of bulls

Name	G1	G2	G3
Individual and total SFA (g/100 g TFA)			
C10:0	0.13±0.02	0.12±0.02	0.13±0.02
C12:0	0.09±0.004	0.08±0.003	0.09±0.004
C14:0	1.63±0.04	1.43±0.02^{b}	1.38±0.03^{c}
C15:0	2.41±0.03	2.29±0.03^{a}	2.28±0.02^{a}
C15 *anteiso*	0.18±0.01	0.17±0.01	0.16±0.01
C16:0	18.02±0.31	18.05±0.33	18.20±0.32
C17:0	1.49±0.05	1.32±0.03^{a}	1.05±0.03^{dC}
C17 iso	0.38±0.02	0.36±0.02	0.35±0.02
C18:0	13.94±0.03	14.21±0.04	14.05±0.04
C18 iso	0.39±0.04	0.37±0.03	0.36±0.02
C20:0	0.09±0.004	0.10±0.005	0.12±0.006 ^{bA}
C22:0	0.12±0.005	0.14±0.006	0.15±0.006^{a}
Total SFA	38.87±2.7	38.64±2.4	38.32±2.5
Individual and total MUFA (g/100 g TFA)			
C14:1 cis-9	0.61±0.02	0.63±0.02	0.65±0.02
C16:1 trans-9	0.73±0.06	1.04±0.07^{a}	1.12±0.07^{b}
C16:1 cis-7	1.85±0.13	1.50±0.12	1.33±0.1^{1a}
C16:1 cis-9	0.42±0.08	0.38±0.07	0.36±0.07
C17:1 cis-9	1.32±0.11	1.49±0.12	1.94±0.13^{bA}
C18:1 trans-9	0.75±0.11	0.69±0.09	0.67±0.09
C18:1 trans-11	0.34±0.05	0.37±0.06	0.41±0.06
C18:1 trans-12	2.02±0.13	1.92±0.11	1.44±0.11^{bA}
C18:1 cis-9 +trans-13-14	20.05±0.27	19.05±0.25^{a}	17.21±0.24^{dC}
C18:1 cis-11+trans15	1.13±0.11	1.51±0.12	1.76±0.13^{b}
C18:1 cis-12	0.43±0.09	0.51±0.10	0.58±0.11
C18:1 cis-15+trans-16	0.79±0.03	0.85±0.04	1.05±0.04^{cB}
C20:1 cis-11	0.13±005	0.11±0.004^{a}	0.10±0.004^{c}
Total MUFA	30.56±2.12	30.05±2.00	28.62±2.15

Data are presented as means ± SEM (n = 6/group). ^{a}P < 0.05, ^{b}P < 0.01, ^{c}P < 0.001, ^{d}P < 0.0001 (vs G1); ^{A}P < 0.05, ^{B}P < 0.01, ^{C}P < 0.001 (vs G2).
SFA: saturated fatty acids; TFA: total fatty acids; MUFA: monounsaturated fatty acids

We did not find a significant difference in C18:2n-6 (LA) levels in meat fat following dietary supplementation with FSO, however Suksombat et al., (2016) found that LA levels were significantly decreased with increasing LSO and attributed this inverse effect to partial conversion to C18:0 in the rumen. Choi et al. (2015) found that LA inhibited the expression of adipogenic gene in intramuscular preadipocytes. On the other hand, the meat content of C20:5 n-3 (EPA), C22:6 n-3 (DHA), and C22:5 n-3 (DPA) was significantly higher in G3 (0.46±0.02%, 0.06±0.006%, P<0.0001, 0.93±0.09%, P<0.05, respectively) and G2 (0.42±0.02%, P<0.0001, 0.05±0.005% and 0.88±0.08%, P<0.05 respectively) than G1 (0.23±0.01%, 0.03±0.003%, and 0.56±0.07% respectively). Consistent with these findings, Renna et al., (2018) and Suksombatet al. (2016) reported that FSO- or LSO-fed bulls had significantly higher EPA and DHA contents in their meat than non-supplemented bulls.

In the present study, no significant change was noticed in CLA meat content following FSO supplementation. In contrast, Suksombat et al. (2016) found a significant decrease in the CLA content of *Longissimus dorsi* and *Semimembranosus* muscles after feeding animals on a ration containing LSO. However, Noci et al. (2007) reported higher CLA level in meat fat in heifers supplemented with SFO and LSO. The total SFA, MUFA, and n-6 FAs were also not affected by FSO treatment. Similarly, Raes et al., (2004), Albert et al., (2014), and Rennaet al., (2018) also found no statistical differences in total SFA and MUFA between FSO-fed bulls and the control bulls. Although PUFA/SFA ratio was not significantly changed among the three groups, its value matches the suggested

Table 9: Effect of flaxseed oil dietary supplementation on PUFA and PUFA/SFA ratio in *Longissimus dorsi* muscle of bulls.

Individual and total PUFA (g/100 g TFA)			
C18:2 cis-9, trans-13+cis-9, trans-14	0.20±0.01	0.32±0.0^{1d}	0.52±0.01^{dD}
C18:2 cis-9, trans-12+trans-8, cis-13	0.45±0.05	0.63±0.06	0.88±0.08^{cA}
C18:2 trans-9, cis-12	0.21±0.03	0.25±0.03	0.33±0.04
C18:2 trans-10, cis-15+trans-11, cis-15	0.36±0.08	0.66±0.10	0.80±0.1^{1a}
C18:2 n-6 (LA)	21.4±0.33	21.0±0.34	22.1±0.35
C18:2 cis-9, cis-15	0.35±0.05	0.29±0.04	0.23±0.03
C18:2 cis-9, trans11+trans-7, cis-9+trans-8, cis-10 (CLA)	0.17±0.04	0.16±0.03	0.13±0.03
C18:3 n-6 (GLA)	0.13±0.04	0.14±0.05	0.14±0.05
C18:3 n-3 (ALA)	0.76±0.01	1.32±0.02^{d}	1.64±0.02^{dD}
C20:2 n-6	0.46±0.02	0.39±0.03	0.32±0.03
C20:3 n-9	0.09±0.01	0.12±0.01	0.14±0.01^{b}
C20:3 n-6	0.71±0.04	0.62±0.04	0.42±0.03^{cB}
C20:3 n-3	0.04±0.006	0.05±0.007	0.05±0.007
C20:4 n-6	4.02±0.36	3.69±0.32	3.68±0.30
C20:5 n-3 (EPA)	0.23±0.01	0.42±0.0^{2d}	0.46±0.0^{2d}
C22:4 n-6	0.48±0.06	0.32±0.05	0.23±0.03
C22:5 n-3 (DPA)	0.56±0.07	0.88±0.08^{a}	0.93±0.09^{a}
C22:6 n-3 (DHA)	0.03±0.003	0.05±0.005^{a}	0.06±0.006^{dD}
Total n-6	27.13±1.8	26.16±1.9	26.89±1.5
Total n-3	1.62±0.06	2.72±0.08^{d}	3.14±0.10^{dB}
n-6:n-3 ratio	16.75±0.57	9.62±0.43^{d}	8.56±0.40^{d}
Total PUFA	30.58±0.63	31.31±0.55	33.06±0.6^{1a}
PUFA/ SFA ratio	0.787±0.05	0.810±0.04	0.863±0.03

Data are presented as means ± SEM (n = 6/group). $^{a}P < 0.05$, $^{b}P < 0.01$, $^{c}P < 0.001$, $^{d}P < 0.0001$ (vs G1); $^{A}P < 0.05$, $^{B}P < 0.01$, $^{C}P < 0.001$ (vs G2).

PUFA: polyunsaturated fatty acids; TFA: total fatty acids; LA: linoleic acid; CLA: conjugated linoleic acid; GLA: γ-linolenic acid; ALA: α-linolenic acid; EPA: eicosapentaenoic acid; DPA: docosapentaenoic acid; DHA: docosahexaenoic acid; SFA: saturated fatty acids.

value (0.4-1) for humans (Jimenez-Colmenero et al. 2012). While, the total PUFA was significantly higher in G3 (33.06±0.61%, P<0.05) than G1 (30.58±0.63%). The positive dietary effects on total PUFA in meat fat indicates that LSO supplementation can affect rates of ruminal lipolysis. On the other hand, the total n-3 FAs content in meat was significantly higher in G3 (3.14±0.10%, P<0.0001) and G2 (2.72±0.08%, P<0.0001) than G1 (1.62±0.06%). The higher levels of n-3 PUFA in beef fat coincided with the higher contents of C18:3n-3 in the LSO diets (Suksombat et al. 2016).

The n-6:n-3 ratio was significantly lower in G3 (8.56±0.40%, P<0.0001) and G2 (9.62±0.43%, P<0.0001) than G1 (16.75±0.57%). In support, Herdmann et al. (2010), Simopoulos (2011), and Suksombatet al. (2016) also found a similar reduction in this ratio in animals fed ration supplemented with FSO or LSO. Our data and those obtained by Herdmann et al. (2010) and Simopoulos (2011) revealed a n-6:n-3 PUFA ratio of 4:1, which is close to that recommended for human consumption. On the other hand, FSO-fed Belgian Blue cattle showed a higher ratio above 5:1 (Raes et al. 2004). Moreover, Quinn et al. (2008) found that feeding animals on diet supplemented with 4% LSO resulted in significant increase in levels of C18:2n-6 (LA) and C18:3n-3 (ALA) in meat fat of steers, but C20:4n-6 was reduced. However, Suksombatet al. (2016) reported an increased C18:3n-3 and decreased C18:2n-6 and C20:4n-6 levels in meat fat of steers following LSO supplementation. In the present study, we only found a significant increase in C18:3n-3 (ALA) following FSO supplementation.

These findings suggest that feeding animals with FSO could be essential to get healthier meat with higher PUFA content and lower n-6:n-3 PUFA ratio. FSO could facilitate the deposition of n-3 PUFA in beef muscle tissues to produce healthy meat (Baba et al. 2016). Nevertheless, PUFA enhancement may provoke more susceptibility to lipid oxidation, which can decrease organoleptic value, especially color and taste, of meat (Guyon et al. 2016).

CONCLUSION

Flaxseed oil supplementation in bulls finishing diets could improve growth performance, and carcass quality, and increase omega-3 fatty acids.

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CONFLICT OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors.

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