Carcass traits, meat yield and fatty acid composition of adipose tissues and Supraspinatus muscle in goats fed blend of canola oil and palm oil

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Abstract

Background: Dietary fats can alter the deposition and distribution of body fats in ruminants. The deposition and distribution of body fat play a vital role in the quality of ruminant carcasses and are of great commercial value since they influence the profitability and consumer acceptability of ruminant meat. The current study examined the effects of dietary blend of 80 % canola oil and 20 % palm oil (BCPO) on carcass characteristics, meat yield and accretion of fatty acid (FA) in subcutaneous, omental, perirenal, and mesentery adipose depots and m. supraspinatus (SS) in goats.

Methods: Twenty four Boer crossbred bucks (BW 20.54 ± 0.47 kg) were randomly assigned to diets containing on DM basis 0, 4 and 8 % BCPO, fed for 100 d and harvested.

Results: Diet had no effect (P > 0.05) on slaughter weight, dressing percentage, carcass and non-carcass components, meat yield, color, moisture and carotenoid contents and weight of adipose tissues in goats. The proportion of C18:1n-9 and cis-9 trans-11 CLA in the omental, perirenal and SS was higher (P < 0.05) in goats fed 4 and 8 % BCPO compared with the control goats. Dietary BCPO reduced (P < 0.05) the proportion of C14:0 in the omental, perirenal and mesentery depots, C18:0 in the perirenal depot, C16:0 in the SS and C16:1n-7 in the SS, omental and perirenal tissues. Dietary BCPO enhanced the proportion of C18:1 trans-11 Vaccenic and C18:3n-3 in SS and C20:5n-3 in SS and mesentery depot. No significant changes were found in the FA composition of subcutaneous depot.

Conclusions: Results indicate that dietary BCPO can be utilized to alter the FA composition of adipose tissues without detrimental effects on carcass characteristics in goats. Nonetheless, dietary BCPO is not an effective repartitioning agent for body fats in goats.

Keywords: Fat color, Mesentery, Omental, Perirenal, Subcutaneous

Background

Dietary fat is a popular means of increasing the energy density of diet in ruminant nutrition and can influence adipose depots and carcass composition [1–3]. Dietary fat can also be used to modify the fatty acid composition of meat and milk to fulfill the nutritional demands of consumers [4, 5]. The deposition and distribution of fat play a vital role in the quality of ruminant carcasses [2, 3, 6] and are of great commercial value since they influence profitability and consumer acceptability of ruminant meat [3, 6].

Goats deposit more visceral fat and less subcutaneous, inter and intra muscular fat compared with sheep and cattle [7, 8]. The deposition of more visceral fats aside its effect on product quality is expensive and represent a waste of dietary energy [3, 7, 8]. In addition, a poor subcutaneous fat cover decreases grading of goat carcasses and could instigate carcass evaporative losses [7, 8]. Albeit, the low intramuscular fat in goat meat is concordant with the present day consumers’ demands [7], a low
intramuscular fat is responsible for the low juiciness and tenderness of goat meat [8, 9].

Although, there are large discrepancies, dietary fat can influence deposition of body fats and fatty acid composition of adipose tissue in ruminants [2, 3, 10]. In this respect, conjugated linoleic acid (CLA) has been identified as a potent modulator and repartitioning agent in fat metabolism [11, 12]. The CLA can be synthesized in the rumen by the biohydrogenation of linoleic and linolenic acids [13, 14]. The CLA can also be synthesized endogenously in the tissue by the action of Δ-9 desaturase on trans-vaccenic acid [13, 14]. The C18:1 trans-11 Vaccenic is a mutual intermediate product of biohydrogenation of C18:1n-9, C18:2n-6 and C18:3n-3 [4, 13, 14]. Thus, oils rich in linoleic, linolenic and/or oleic acids could alter adipose depots in ruminants [4, 13]. Canola oil is an excellent source of oleic (59 %), linoleic (21 %) and linolenic (11 %) [15]. Palm oil contains about 40 % oleic acid and 11 % linoleic acid [16]. Given the attributes of both canola and palm oils, it will be of great significance for goat meat production to examine if the blend of palm oil and canola oil could affect lipid metabolism and partitioning of body fat in goats. The efficacies of various combinations of canola oil and palm oil on in vitro rumen fermentation have been investigated [Adeyemi et al. unpublished] and it has been shown that the blend of 80 % canola oil and 20 % palm oil (BCPO) had no detrimental effect on in vitro [17] and in vivo rumen fermentation and growth performance in goats [18] and yielded substantial ruminal biohydrogenation intermediates. Nonetheless, we are unaware of any study that has examined the effect of blend of canola oil and palm oil on carcass traits and tissue fatty acids in goats. Thus, the objective of this study was to determine the effects of graded levels of blend of 80 % canola oil and 20 % palm oil on fat deposition, carcass traits, tissue composition of primal cuts, fat characteristics and the fatty acid composition of omental, subcutaneous, perirenal and mesentery adipose tissues and supraspinatus muscle in goats.

**Methods**

**Animal welfare**

The study was conducted following the guidelines of research policy of the Universiti Putra Malaysia on animal welfare and ethics.

**Experimental animals and diet**

Twenty four Boer bucks (4–5 months old, 20.54 ± 0.47 kg body weight) were used in the study. Each animal was individually housed in wooden slatted floor pens (1.20 m x 0.80 m x 0.70 m) equipped with feeding and drinking facilities. The animals were randomly assigned to dietary treatments containing on dry matter basis 0, 4 or 8 % BCPO and fed for 100 d following two weeks of adaptation. All diets were formulated to meet the nutritional requirements of growing goats based on NRC [19] recommendations and animals were fed twice daily with ad libitum access to clean water. The proximate composition of the diets was determined following the method of AOAC [20] while acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined following the method of Van Soest et al. [21]. The ingredients and chemical composition of dietary treatments are presented in Table 1 while the fatty acid (FA) composition of the diets is presented in Table 2.

**Slaughtering procedure and carcass analysis**

The animals were fasted for 12 h with free access to water, weighed and slaughtered in a commercial abattoir according to the Halal procedure as outlined in MS1500:2009 [22]. After slaughter, the head, fore- and hind limbs were removed at the atlanto-occipital, carpal

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**Table 1** Ingredients and chemical composition of dietary treatments

| Ingredient (% DM) Level of BCPO (%) | 0   | 4   | 8   |
|-----------------------------------|-----|-----|-----|
| Fresh OPF<sup>a</sup>             | 40.00 | 40.00 | 40.00 |
| OPF<sup>a</sup> slilage           | 10.00 | 10.00 | 10.00 |
| Corn grain                        | 22.00 | 12.50 | 6.00  |
| Soybean meal                      | 17.00 | 19.00 | 20.00 |
| Rice bran                         | 2.00  | 7.00  | 10.50 |
| Palm kernel cake                  | 7.50  | 6.00  | 4.00  |
| BCPO<sup>b</sup>                  | 0.00  | 4.00  | 8.00  |
| Limestone                         | 0.50  | 0.50  | 0.50  |
| Salt                              | 0.50  | 0.50  | 0.50  |
| Mineral-vitamin premix<sup>c</sup> | 0.50  | 0.50  | 0.50  |

**Chemical composition, % DM**

| Dry matter                      | 67.70 | 67.90 | 68.07 |
| Organic matter                  | 93.16  | 93.42 | 93.55 |
| Metabolizable energy, MJ/Kg DM<sup>b</sup> | 11.59  | 11.61 | 11.62 |
| Crude Protein                   | 14.27  | 14.37 | 14.39 |
| Ether extract                   | 3.06   | 6.56  | 11.45 |
| Crude fibre                     | 28.48  | 27.64 | 26.81 |
| ADF                             | 35.04  | 33.28 | 32.52 |
| NDF                             | 63.52  | 62.67 | 62.06 |
| Nitrogen free extract           | 16.56  | 13.97 | 12.45 |
| Ca                              | 1.02   | 1.05  | 1.04  |
| P                               | 0.52   | 0.54  | 0.54  |
| Total carotenoid (mg/kg)        | 14.81  | 16.71 | 19.86 |

<sup>a</sup> Blend of 80 % canola oil and 20 % palm oil.<sup>b</sup> Oil palm frond.<sup>c</sup> Contained (g/kg) CuSO<sub>4</sub>·5H<sub>2</sub>O, 70; ZnSO<sub>4</sub>·7H<sub>2</sub>O, 240; FeSO<sub>4</sub>·7H<sub>2</sub>O, 170; MnSO<sub>4</sub>·H<sub>2</sub>O, 290; MgO, 290; CoCl<sub>3</sub>·6H<sub>2</sub>O, 510; KI, 220; NaSeO<sub>3</sub>, 130; vitamin B<sub>6</sub>, 450; pantothenic acid, 750; vitamin K<sub>3</sub>, 150; folic acid, 15; vitamin B<sub>12</sub>, 0.9; vitamin B<sub>1</sub>, 1.050; (IU) vitamin D<sub>3</sub>, 324,000; vitamin A, 620,000. <sup> calculated</sup>
and tarsal joints respectively. The animals were skinned while suspended by their achilles tendon and later eviscerated. Carcass and non-carcass components were weighed. Subcutaneous fat was sampled from inguinal region, omental fat was sampled near its free part close to the rumen (omentum majus), perirenal fat was sampled near the kidney on its great curve (between the renal fascia and renal capsule), and mesentery fat was sampled between the ileum and jejunum while pelvic fat was sampled at the left pelvic region. The *Suprabrpinatus* muscle was sampled from the right forelimb. The weight of gut fill was estimated by subtracting the weight of empty gut from the weight of full gut. Empty body weight was estimated as the difference between the slaughter weight and weight of gut fill. Dressing percentage (based on full live body weight and empty body weight) was estimated as described by Kadim et al. [23]. Dressed carcasses were weighed (hot carcass weight) within 45 min postmortem, chilled at 4 °C for 24 h and reweighed (cold carcass weight). Chilling loss was estimated as the difference between hot and cold carcass weight expressed as percentage. Carcasses were split along the midline into right and left halves. The right half was separated into neck, shoulder, breast flank, loin and leg cuts. Each cut was separated into lean, fat and bone. *Longissimus* muscle area (rib eye area) was measured between the 12th and 13th ribs using tracing paper and estimated using two-dimension polygons area calculator software as described by Branscome and Jesseeeman [24]. Carcass linear measurements were determined as outlined by Fisher and De Boer [25] and Laville et al. [26]. These measurements were used to estimate carcass compactness (cold carcass weight/internal carcass length), shoulder compactness (shoulder weight/length of shoulder) and leg compactness (leg weight/leg length) as described by Carrasco et al. [27]. Saleable meat yield (SMY) was estimated as SMY% = (100 – fat %) × (meat:bone)/((meat:bone) + 1) as outlined by Purchas [28].

**Fat color and moisture content**

The color coordinates of adipose tissues were measured with a ColorFlex spectrophotometer (Hunter Lab Reston, VA, USA) based on the International Commission on Illumination (CIE) Lab-values (also known as L*, a*, b*) with D65 illuminant and 10° standard observer. The device was calibrated against black and white reference tiles prior to use. The moisture content of the adipose tissue was measured in accordance to the method of AOAC [20].

**Total carotenoid**

Total carotenoid in feed and adipose tissues was determined in accordance to the method described by Okonkwo [29]. One gram of each sample was homogenized with 5 mL acetone. The content was stirred for 30 min and two 2.5 mL aliquot of acetone was used to rinse the flask and re-extract the residue. The extracts were pooled and 1 mL of deionized water was added. The mixture was transferred into 5 mL n-hexane and centrifuged at 3000 g for 10 min. The absorbance of the hexane layer was read at 450 nm using spectrophotometer (Secomam, Domont, France). Total carotenoid content was estimated by the following formula

\[
\text{Conc. (µg/g)} = \left( A \times V \times 10^4 \right) / (2592 \times W)
\]

Where A = absorbance

\[V = \text{Volume of n–hexane(mL)}\]

\[W = \text{Weight of sample}\]

**Fatty acid (FA) analysis**

The total lipids in feed and tissue samples was extracted in chloroform:methanol (2:1, v/v) mixture following the method of Folch et al. [30] modified by Rajion et al. [31]. The fatty acids were transmethylated into their fatty acid methyl esters (FAME) using 0.66 N KOH in methanol and 14 % methanolic boron trifluoride (BF₃) in accordance with the method of AOAC [20]. Heneicosanoic acid was used as the internal standard. The FAME was separated in a gas chromatograph (Agilent 7890A) equipped with a flame ionization detector (FID) and a splitless injector. The column used was fused silica capillary (Supelco SP-2560, 100 m, 0.25 mm ID, 0.20 mm film thickness). High purity nitrogen was used as the carrier gas at 40 mL/min. Compressed air and high purity hydrogen were used for the FID in the chromatograph. To

| Table 2 Fatty acid composition (g/kg DM) of dietary treatments |
|---------------------------------------------------------------|
| **Parameter**       | **Level BCPO* (%)** |
|---------------------|---------------------|
| C12:0, lauric       | 0.01 0.03 0.04      |
| C14:0, myristic     | 0.53 0.51 0.51      |
| C16:0, palmitic     | 2.79 5.98 7.78      |
| C16:1, palmitoleic  | 0.08 0.11 0.15      |
| C18:0, stearic      | 0.56 1.12 1.43      |
| C18:1n-9, oleic     | 3.82 14.87 25.23    |
| C18:2n-6, linoleic  | 7.05 11.87 13.07    |
| C18:3n-3, linoenic  | 1.06 2.61 4.23      |
| Total FA            | 15.89 37.09 52.27   |
| FA sums and ratios  |                     |
| ∑SFA                | 3.89 7.79 9.79      |
| ∑UFA                | 12.00 29.31 42.52   |
| ∑PUFA               | 8.11 14.49 16.19    |
| n-6:n-3            | 6.65 4.54 3.08      |

*blend of 80 % canola oil and 20 % palm oil. ∑SFA = (C12:0 + C14:0 + C16:0 + C18:0), ∑UFA = (C16:1 + C18:1 + C18:2n-6 + C18:3n-3), n-6:n-3 = (C18:2n-6÷C18:3n-3)*
facilitate optimal separation, the oven temperature was set
at 100 °C, for 2 min and warmed to 170 °C at 10 °C/min,
held for 2 min, warmed to 230 °C at 5 °C/min, and then
held for 20 min. Identification of sample fatty acids was
done by comparing the relative retention times of FAME
peaks from samples with those of standards. The indices
of Δ 9 desaturase enzyme activities (ID16 and ID18) and
elongase enzyme activity in tissues were estimated as
described by Malau-Aduli et al. [32] as follows: ID16 =
100(C16:1)/(C16:0 + C16:1), ID18 = 100(C18:1)/C18:0 +
C18:1) and Elongation index = 100[(C18:0 + C18:1 n-9)/
(C18:0 + C18:1 n-9 + C16:0 + C16:1)].

Statistical analysis
The experiment followed a completely randomized de-
sign. Data obtained for all parameters were subjected to
the generalized linear model (GLM) procedure of SAS
[33]. Slaughter weight was used as a covariate. However,
the covariate analysis was not significant. Orthogonal
contrasts (linear and quadratic effects) were tested with
coefficients estimated based on the level of dietary oil.

Results
Ingredients, chemical and fatty acid composition of
experimental diets
The ingredients and chemical composition of the exper-
imental diets are shown in Table 1 while the fatty acid
composition is shown in Table 2. In each treatment, oil
palm fronds (OPF) accounted for 50 % of the total ration.
The OPF is obtained from oil palm (Elaeis guineensis) tree
and constitute one of the main by-products of the oil palm
industry in Malaysia [34]. The OPF is made up of three
main components namely the petioles, leaflets and rachis.
The petiole is the main structure of the OPF and accounts
for about 70 % of the dry matter (DM) of OPF. The prox-
imate analysis of OPF used in the current study showed
that it contained on DM basis: 4.6 % crude protein, 2 %
ether extract, 39 % crude fiber, 78.5 % NDF, 56.4 % ADF,
3.2 % ash, and 5.7 MJ/kg metabolizable energy. As a per-
centage of total FA, the OPF contained 31.3 % C16:0,
5.4 % C16:1, 4.4 % C18:0, 20.9 % C18:1n-9, 16 % C18:2n-6,
17 % C18:3n-3 and 5 % other FA. The concentrate portion
of the diets consisted of various ingredients which were
adjusted to make the experimental diets isocaloric and iso-
nitrogenous since the addition of graded level of BCPO
would increase the energy content of the diet. This was
done to prevent confounding experimental results that
could accompany changing the protein and energy status
of the diets. Thus, responses by animals can be attributed
to the addition of BCPO to the diets. In addition, the var-
ied ingredients (corn, soybean meal, palm kernel cake and
rice bran) are not fat sources and thus contributed 1.74
and 1.67 % FA to the total FA in the 4 and 8 %
BCPO diets respectively. Hence, the FA composition
of such ingredients would not be a confounding factor in
the current trial. Similar experimental design (control diet
vs. oil based diets) which necessitates altering the composi-
tion of other dietary ingredients was used in goats [35],
sheep [36, 37] and cattle [1, 2, 5, 38, 39]. The chemical
composition of the experimental diets met the minimum
requirements for growing goats recommended by NRC
[19]. As expected, the total FA in the supplemented diets
was greater than the control diet. Notably, addition of
BCPO increased the concentration (g/kg DM) of
C16:0, C18:1n-9, C18:3n-3 and C18:2n-6 but lowered the
n6/n3 ratio.

Car cass traits and fat depo ts
The carcass traits of goats fed varying levels of BCPO
are presented in Table 3. Dietary BCPO did not affect
(P > 0.05) live, empty body and carcass weights, dressing
percentage and meat yield in goats. Similarly, the rib eye
area and other carcass linear measurements (Table 3),
non-carcass components (Table 4) and proportion,
weight and tissue composition of primal cuts (Table 5)
were unaffected (P > 0.05). The back fat thickness, intra-
muscular fat (Table 3) of supraspinatus muscle, and the
weights of perirenal, omental, mesentery and pelvic adi-
pose depots (Table 4) were not influenced (P > 0.05) by
diets. The carotenoid and moisture contents and color
coordinates of all adipose tissues (Table 6) were similar
(P > 0.05) across dietary treatments.

Fatty acid composition of Supraspinatus muscle
The FA composition of Supraspinatus (SS) muscle from
goats fed varying level of BCPO is shown in Table 7. Re-
gardless of the diet, the most abundant FA in SS was
C18:1n-9 followed by C16:0 and C18:0 in that order. The
proportion of C16:0 and C16:1n-7 decreased (P < 0.05)
while that of C18:1n-9, C18:1-11, CLA cis-9 trans-
11, C18:3n-3 and C20:5n-3n increased (P < 0.05) as the
level of BCPO increased in diet. The proportion of C18:0,
C18:2n-6 and C20:4n-6 was not influenced (P > 0.05) by
diet. The total saturated fatty acids (SFA), the n-6/n-3 ra-
tio and ID 16 decreased (P < 0.05) while the total mono-
unsaturated fatty acids (MUFA), PUFA/SFA ratio, ID 18
and elongation index increased (P < 0.05) with increase in
the level of BCPO in diet.

Fatty acid composition of adipose tissues
The FA composition of omental, perirenal, mesentery
and subcutaneous adipose tissues from goats fed
graded levels of BCPO is shown in Tables 8, 9, 10and
11 respectively. The major fatty acids in all examined adi-
pose tissues were C16:0, C18:0 and C18:1n-9.
In the omental depot, the proportion of C14:0,
C16:1n-7 and C18:1 trans-11 decreased (P < 0.05) as the
level of BCPO increased in diet. Goats fed 4 and 8 %
BCPO had similar ($P > 0.05$) proportion of cis-9 trans-11 CLA which was greater ($P < 0.05$) than those fed the control diet. The proportion of C18:3n-3 was greater ($P < 0.05$) in goats fed 4 % BCPO compared with those fed 0 and 8 % BCPO. The proportion of C20:5n-3 increased ($P < 0.05$) while the n-6/n-3 decreased ($P < 0.05$) with increasing level of BCPO in diet. Proportions of C16:0, C18:0, C18:2n-6, C20:4n-6, trans-10 cis-12 CLA, C22:5n-3 and C22:6n-3, total FA, sums and ratios of FA and the estimated elongase and desaturase indices were not affected ($P > 0.05$) by diet.

In the perirenal depot, the proportion of C14:0, C16:1n-7, C18:0 and total SFA decreased ($P < 0.05$) as the level of BCPO increased in diet. The proportion of C18:1n-9 and CLA cis-9 trans-11, total MUFA and UFA:SFA increased ($P < 0.05$) with increasing level of BCPO in diet. The control goats had higher ($P < 0.05$) ID 16 compared to those fed 4 and 8 % BCPO. The ID 18 increased linearly ($P < 0.05$) as the level of BCPO increased in diet. No significant ($P > 0.05$) changes were observed for total FA, proportion of C16:0, C18:2n-6, C18:3n-3, C20:4n-6, C22:5n-3, C22:6n-3 and trans-10 cis-12 CLA and the estimated elongase activity across the treatments.

In the mesentery depot, the proportion of C14:0 decreased ($P < 0.05$) as the level of BCPO increased in diet. The proportion of C18:1n-9 in goats fed 8 % BCPO was significantly higher ($P < 0.05$) compared with those fed 0 and 4 % BCPO. Goats fed 4 and 8 % BCPO had greater ($P < 0.05$) proportion of C20:5n-3 than the control goats. No significant differences ($P > 0.05$) were observed between diets with respect to the proportions of C16:0, C16:1n-7, C18:0, C18:2n-6, C20:4n-6, C18:3n-3, C22:5n-3, C22:6n-3, C18:1 trans-11, cis-9 trans-11 CLA and trans-10 cis-12 CLA and total FA. Similarly, estimated elongase and desaturase indices were not affected ($P > 0.05$) by diet.

### Table 3 Least square means for the carcass traits of goats fed graded levels of blend of 80 % canola oil and 20 % palm oil

| Parameter                        | Level of BCPO (%) | SEM | P value  |
|----------------------------------|-------------------|-----|----------|
|                                 | 0                 | 4   | 8        | Overall | Linear | Quadratic |
| Slaughter weight (Kg)            | 29.58             | 32.19 | 31.33    | 0.91    | 0.144  | 0.064     | 0.511     |
| Empty body weight (Kg)           | 24.87             | 26.18 | 25.72    | 0.81    | 0.515  | 0.284     | 0.691     |
| Hot carcass weight (kg)          | 13.56             | 14.21 | 13.78    | 0.42    | 0.542  | 0.408     | 0.467     |
| Cold carcass weight (kg)         | 13.21             | 13.90 | 13.48    | 0.41    | 0.497  | 0.352     | 0.469     |
| Chilling loss (%)                | 2.60              | 2.17  | 2.19     | 0.21    | 0.304  | 0.127     | 0.955     |
| Dressing percentage$^a$          | 45.81             | 44.41 | 44.02    | 1.62    | 0.366  | 0.177     | 0.694     |
| Dressing percentage$^b$          | 54.56             | 54.52 | 53.55    | 0.94    | 0.701  | 0.654     | 0.479     |
| Back fat thickness (mm)          | 2.17              | 2.28  | 2.29     | 0.20    | 0.844  | 0.598     | 0.484     |
| Rib eye area (cm$^2$)            | 13.08             | 13.92 | 13.41    | 0.54    | 0.568  | 0.407     | 0.527     |
| Saleable meat yield (%)          | 68.86             | 69.24 | 69.34    | 1.45    | 0.700  | 0.581     | 0.620     |
| IMF$^d$                          | 2.78              | 2.76  | 2.79     | 0.03    | 0.221  | 0.551     | 0.761     |

**Linear measurements**

| Carcass length (cm)              | 79.34             | 78.00 | 78.40    | 1.09    | 0.691  | 0.428     | 0.805     |
| Internal carcass length (cm)     | 71.34             | 70.00 | 70.40    | 1.09    | 0.691  | 0.428     | 0.805     |
| Carcass compactness (g/cm)       | 184.78            | 200.56 | 192.14   | 8.62    | 0.477  | 0.315     | 0.515     |
| Shoulder width (cm)              | 45.33             | 46.33 | 45.67    | 0.94    | 0.757  | 0.584     | 0.634     |
| Shoulder length (cm)             | 24.33             | 23.17 | 22.84    | 0.92    | 0.403  | 0.415     | 0.581     |
| Shoulder compactness (g/cm)      | 177.97            | 189.47 | 190.89   | 7.20    | 0.617  | 0.569     | 0.511     |
| Leg width (cm)                   | 40.00             | 40.23 | 40.53    | 0.49    | 0.754  | 0.548     | 0.681     |
| Leg length (cm)                  | 46.03             | 46.41 | 46.00    | 0.92    | 0.457  | 0.415     | 0.581     |
| Leg compactness (g/cm)           | 95.22             | 98.84 | 92.47    | 7.47    | 0.837  | 0.963     | 0.568     |

**Carcass composition**

| Lean (%)                         | 68.60             | 69.41 | 69.08    | 0.86    | 0.453  | 0.366     | 0.391     |
| Bone (%)                         | 23.81             | 22.93 | 22.56    | 0.42    | 0.132  | 0.620     | 0.057     |
| Subcutaneous fat (%)             | 2.33              | 2.54  | 2.58     | 0.21    | 0.687  | 0.597     | 0.511     |
| Intramuscular fat (%)            | 4.91              | 5.34  | 5.44     | 0.44    | 0.686  | 0.589     | 0.515     |

$^a$Blend of 80 % canola oil and 20 % palm oil.
$^b$Estimated based on full live body weight.
$^c$Estimated based on empty body weight (Kadim et al., 2003).
$^d$ Intramuscular fat of supraspinatus muscle. SEM = standard error of means. Values are least square means for 8 goats per diet.
In the subcutaneous depot, dietary BCPO was not a significant source of variation \((P > 0.05)\) influencing the proportions of all FA, sums and ratios of FA and the estimated elongase and desaturase indices. However, the proportions of C14:0 and C16:1n-7 tended \((P = 0.07)\) to increase while that of C22:5n-3 tended \((P = 0.07)\) to decrease with increase in the level of BCPO in diet.

**Discussion**

**Carcass traits, meat yield and adipose tissue partitioning**

Dietary BCPO had no effect on live, empty and carcass weights, carcass linear measurements, and meat yield in goats. This finding could be due to the similarity in the slaughter weight across dietary treatments. Slaughter weight is one of the major determinants of carcass weight and meat yield in ruminants [23, 37]. The similarity in slaughter weight was likely due to the similar nutrient composition of diets fed to the goats. This finding could be consistent with the similarity in the feed efficiency and average daily gain observed in a companion feeding trial [18]. As found in the current study, dietary sunflower oil (2.5 %) compared with the control diet did not affect the dressing percentage and carcass measurements in goats [3]. Similarly, Bock et al. [10] observed that 3.5 % tallow or soybean soap stock versus control diet did not affect dressing percentage in steers. Also, goats fed 4.5 % soybean oil or sunflower oil had similar carcass traits as those fed control diet [35]. In contrast, decreased dressing percentage and hot carcass weight were observed in steers fed 4 % soybean oil [40] and 4 and 8 % animal-vegetable oil blends [39] while carcass yield increased in steers fed 3.5 % soybean oil, tallow or yellow grease versus steers fed control diet [2] and Nellore steers fed soybean and linseed oils or their calcium salts compared to those fed control diet [1]. The dressing percentage (based on empty body weight) of the goats ranged from 53.55 to 54.56 %. These values are similar to those reported by Marinova et al. [3] and Kadim et al. [23].

The similarity in the back fat thickness, intramuscular fat and the weights of adipose tissues across dietary treatments suggests that dietary supplementation of BCPO did not alter the deposition and distribution of fat in the adipose tissues of goats. This finding could be

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**Table 4** Least square means for the weight of non-carcass components from goats fed graded levels of blend of 80 % canola oil and 20 % palm oil

| Parameter (Kg) | 0 % | 4 % | 8 % | SEM Overall | Linear | Quadratic |
|---------------|-----|-----|-----|-------------|--------|-----------|
| Head          | 2.36| 2.46| 2.25| 0.09        | 0.257  | 0.9545    |
| Feet          | 1.00| 1.04| 0.98| 0.03        | 0.379  | 0.871     |
| Skin          | 3.40| 3.65| 3.23| 0.15        | 0.168  | 0.818     |
| Heart         | 0.11| 0.12| 0.12| 0.01        | 0.785  | 0.494     |
| Lungs         | 0.24| 0.22| 0.23| 0.01        | 0.606  | 0.357     |
| Kidney        | 0.07| 0.07| 0.08| 0.01        | 0.548  | 0.325     |
| Liver         | 0.43| 0.43| 0.45| 0.02        | 0.612  | 0.830     |
| Reticulo-rumen| 1.25| 1.29| 1.46| 0.07        | 0.120  | 0.179     |
| Intestine     | 0.84| 0.87| 1.01| 0.05        | 0.187  | 0.176     |
| Omental fat   | 0.24| 0.29| 0.27| 0.02        | 0.357  | 0.188     |
| Perirenal fat (K) | 0.10| 0.12| 0.09| 0.02        | 0.654  | 0.763     |
| Mesentery fat | 0.24| 0.26| 0.24| 0.01        | 0.195  | 0.318     |
| Pelvic fat (P) | 0.15| 0.19| 0.18| 0.03        | 0.440  | 0.243     |
| Heart fat (H) | 0.07| 0.07| 0.07| 0.01        | 0.771  | 0.825     |
| KPH(%)        | 2.42| 2.73| 2.52| 0.12        | 0.423  | 0.560     |

*blend of 80 % canola oil and 20 % palm oil. *estimated based on percentage of cold carcass weight. SEM = standard error of means. Values are least square means for 8 goats per diet.

**Table 5** Least square means for the proportion, weight and tissue composition of primal cuts from goats fed graded levels of blend of 80 % canola oil and 20 % palm oil

| Parameters          | 0 % | 4 % | 8 % | SEM Overall | Linear | Quadratic |
|---------------------|-----|-----|-----|-------------|--------|-----------|
| Proportion (%)<sup>b</sup> | 6.43| 6.54| 6.75| 0.52        | 0.5722 | 0.909     |
| Shoulder            | 32.77| 31.58| 31.53| 2.54    | 0.8369 | 0.656     |
| Loin                | 10.06| 9.78| 10.16| 0.28    | 0.9263 | 0.643     |
| Breast              | 17.56| 19.35| 19.21| 0.57    | 0.8413 | 0.987     |
| Leg                 | 33.16| 32.73| 32.34| 2.61    | 0.9917 | 0.747     |
| Shoulder (kg)       | 4.33| 4.39| 4.25| 0.29    | 0.6252 | 1.000     |
| Lean (%)            | 71.73| 73.17| 73.33| 4.65    | 0.3524 | 0.234     |
| Bone (%)            | 22.18| 21.71| 21.58| 2.18    | 0.6556 | 0.242     |
| Fat (%)             | 5.81| 5.12| 5.08| 0.97    | 0.7557 | 0.569     |
| Lean (Kg)           | 1.33| 1.36| 1.37| 0.07    | 0.2994 | 0.715     |
| Bone (%)            | 67.40| 67.97| 67.89| 2.69    | 0.8436 | 0.474     |
| Fat (%)             | 21.93| 20.96| 20.34| 0.66    | 0.7529 | 0.162     |
| Lean (%)            | 10.67| 11.07| 11.77| 2.20    | 0.4219 | 0.659     |
| Neck (Kg)           | 0.85| 0.91| 0.91| 0.04    | 0.5459 | 0.310     |
| Lean (%)            | 74.72| 78.20| 77.22| 2.52    | 0.3116 | 0.369     |
| Bone (%)            | 21.64| 20.18| 17.27| 0.99    | 0.3683 | 0.054     |
| Fat (%)             | 5.55| 5.17| 5.52| 0.48    | 0.6094 | 0.740     |
| Leg (kg)            | 4.38| 4.55| 4.36| 0.11    | 0.2992 | 0.963     |
| Lean (%)            | 70.41| 68.97| 69.23| 0.62    | 0.7893 | 0.567     |
| Bone (%)            | 23.03| 24.90| 24.31| 0.95    | 0.7279 | 0.776     |
| Fat (%)             | 6.56| 6.13| 6.02| 0.36    | 0.6233 | 0.476     |
| Lean (Kg)           | 62.09| 61.97| 62.00| 2.05    | 0.4640 | 0.821     |
| Bone (%)            | 29.23| 30.09| 29.86| 0.54    | 0.4768 | 0.744     |
| Fat (%)             | 8.68| 7.94| 8.14| 2.10    | 0.8383 | 0.723     |

*blend of 80 % canola oil and 20 % palm oil. *estimated based on percentage of cold carcass weight. SEM = standard error of means. Values are least square means for 8 goats per diet.
attributed to the similar metabolizable energy content of the diets. Feed energy supplied in excess of the basal requirement can increase fat deposition in animals [41]. The major substrate for de novo fatty acid synthesis in tissues is glucose [42]. Thus, diets capable of promoting glucose supply to the tissues might increase fat deposition. Propionate is a gluconeogenic precursor and thus could increase supply of glucose to the tissues [42, 43]. Erstwhile companion studies have shown that supplementation of BCPO did not affect \textit{in vitro} [17] and \textit{in vivo} [18] ruminal molar concentration of propionate. These observations lend credence to the similar fat deposition across the treatments. The current observation contrasts past studies [2, 39] wherein oil supplementation increased back fat thickness and weight of adipose tissues. In line with the current findings, dietary palm oil or its calcium soap compared with the basal diet did not affect the weights of omental and perirenal fat in lambs [37]. Marinova et al. [3] observed that dietary supplementation of 2.5 % sunflower oil did not affect the weight of perirenal fat, sweetbread and caul but increased intramuscular fat in lambs. The discrepancies between the current findings and the earlier reports could be due to differences in the amounts and fatty acid composition of the dietary lipids used.

The similarity in the weights of adipose tissues across dietary treatments corroborates the similarity in the moisture content of adipose tissues which suggests that supplementation of BCPO in diet did not play a significant role in the maturation of adipose cells. High proportion of water in adipose tissues signifies a less mature tissue [41]. Bas et al. [6] observed that the moisture content of omental and perirenal adipose tissue of goats raised indoors with concentrate (high fat diet) was lower than those raised outdoors with concentrate and grass or with only Argan pulp (low fat diet) suggesting that high fat diets may increase hyperplasia and hypertrophy of adipose cells.

Dietary BCPO had no effect on color coordinates especially yellowness and the concentration of total carotenoid in adipose tissues in goats. This observation is unexpected given the increase in dietary fat and carotenoid contents

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|c|}
\hline
Adipose tissue & Color coordinates & Level of BCPO\(^a\) (\%) & 0 & 4 & 8 & SEM & \(P\) value & \(P\) value & \(P\) value \\
\hline
\hline
Subcutaneous & L\(^*\) & 78.07 & 80.02 & 81.29 & 2.07 & 0.563 & 0.335 & 0.674 \\
& a\(^*\) & 0.92 & 0.26 & 0.40 & 0.05 & 0.646 & 0.373 & 0.847 \\
& b\(^*\) & 10.97 & 9.53 & 10.16 & 0.84 & 0.506 & 0.304 & 0.606 \\
Omental & L\(^*\) & 78.14 & 78.71 & 81.03 & 1.17 & 0.235 & 0.226 & 0.199 \\
& a\(^*\) & 1.04 & 0.96 & 1.00 & 0.25 & 0.318 & 0.384 & 0.239 \\
& b\(^*\) & 11.01 & 11.03 & 10.57 & 0.38 & 0.660 & 0.632 & 0.423 \\
Perirenal & L\(^*\) & 79.07 & 80.07 & 82.18 & 1.61 & 0.080 & 0.053 & 0.380 \\
& a\(^*\) & 3.12 & 2.34 & 2.62 & 0.55 & 0.805 & 0.064 & 0.347 \\
& b\(^*\) & 12.87 & 12.28 & 10.32 & 0.83 & 0.068 & 0.247 & 0.055 \\
Mesentery & L\(^*\) & 80.57 & 79.63 & 77.62 & 1.58 & 0.104 & 0.058 & 0.102 \\
& a\(^*\) & 1.62 & 1.46 & 1.45 & 0.39 & 0.203 & 0.726 & 0.986 \\
& b\(^*\) & 11.28 & 13.99 & 11.87 & 0.78 & 0.100 & 0.092 & 0.080 \\
\hline
Total carotenoid (mg/kg) & & & & & & & & \\
Subcutaneous & & 0.09 & 0.11 & 0.12 & 0.01 & 0.210 & 0.100 & 0.213 \\
Omental & & 0.17 & 0.19 & 0.22 & 0.01 & 0.215 & 0.200 & 0.341 \\
Perirenal & & 0.19 & 0.24 & 0.26 & 0.01 & 0.223 & 0.180 & 0.119 \\
Mesentery & & 0.18 & 0.22 & 0.24 & 0.01 & 0.190 & 0.200 & 0.401 \\
\hline
Moisture content (%) & & & & & & & & \\
Subcutaneous & & 14.87 & 13.45 & 8.04 & 2.63 & 0.233 & 0.248 & 0.196 \\
Omental & & 19.04 & 16.66 & 14.56 & 2.08 & 0.374 & 0.956 & 0.178 \\
Perirenal & & 18.75 & 13.94 & 11.15 & 2.84 & 0.239 & 0.124 & 0.512 \\
Mesentery & & 22.68 & 17.04 & 16.92 & 2.81 & 0.324 & 0.149 & 0.977 \\
\hline
\end{tabular}
\caption{Least square means for color coordinates, carotenoid and moisture contents of adipose tissues from goats fed graded levels of blend of 80 % canola oil and 20 % palm oil}
\end{table}
of the diet as the level of BCPO increased, and the 100 d feeding duration employed in this study. Diet and feeding duration are some of the important factors influencing the yellowness of adipose tissues in ruminants [44]. The absorption and deposition of carotenoid in various tissues in ferrets was positively correlated with dietary fat [45]. However, mammals differ in their ability to absorb carotenoids [46]. For example, humans can accumulate carotenes and xanthophylls [46]. In addition, Mora et al. [47] reported that goats have higher levels of jejunal and duodenal 15, 15’dioxygenase activities than cattle when fed dietary beta-carotene which may explain the lower pigmentation of adipose tissue in goats compared with cattle. The 15, 15’dioxygenase is the enzyme responsible for the conversion of beta-carotene to retinal [47].

### Tissue fatty acid composition

The management strategies employed in the current study were successful in ensuring similar carcass weight,

| Parameter | Level of BCPO (%) | SEM | Overall | Linear | Quadratic |
|-----------|------------------|-----|---------|--------|-----------|
| C14:0, myristic | 2.98 2.17 2.11 | 0.03 | 0.213 0.421 0.212 |
| C16:0, palmitic | 24.53 21.63 17.34 | 1.14 | 0.011 0.031 0.330 |
| C16:1n-7, palmitoleic | 3.29 2.16 1.09 | 0.01 | 0.046 0.002 0.175 |
| C18:0, stearic | 17.93 17.35 15.39 | 1.54 | 0.541 0.472 0.112 |
| C18:1n-9, oleic | 28.13 31.93 36.44 | 3.00 | 0.021 0.041 0.331 |
| C20:5n-3, eicosapentaenoic | 1.06 1.04 1.05 | 0.01 | 0.012 0.012 0.221 |
| Total FA (mg/g of muscle) | 2.11 2.34 2.18 | 0.03 | 0.112 0.574 0.378 |

**FA ratios and sums**

| Parameter | SEM | Overall | Linear | Quadratic |
|-----------|-----|---------|--------|-----------|
| ∑SFA | 45.44 41.15 34.84 | 4.21 | 0.001 0.002 0.019 |
| ∑MUFA | 33.26 37.11 42.31 | 3.21 | 0.005 0.001 0.003 |
| ∑PUFA | 21.13 21.76 22.55 | 3.11 | 0.213 0.445 0.318 |
| ∑n-3 | 3.63 4.32 4.78 | 0.76 | 0.014 0.047 0.231 |
| ∑n-6 | 16.16 15.60 15.84 | 1.21 | 0.223 0.345 0.186 |
| n-6:n-3 | 4.45 3.61 3.31 | 0.50 | 0.034 0.041 0.176 |
| UFA:SFA | 1.20 1.43 1.86 | 0.07 | 0.013 0.045 0.124 |
| PUFA:SFA | 0.46 0.52 0.65 | 0.01 | 0.025 0.019 0.332 |

Desaturase and elongase indices

| Parameter | SEM | Overall | Linear | Quadratic |
|-----------|-----|---------|--------|-----------|
| ID16 | 11.83 9.08 5.91 | 1.20 | 0.032 0.001 0.664 |
| ID18 | 61.07 64.29 70.30 | 5.11 | 0.041 0.045 0.716 |
| Elongation Index (EI) | 68.46 67.44 73.76 | 6.72 | 0.045 0.043 0.212 |

**Table 7 Least square means for the fatty acid composition (% of total FA) of supraspinatus muscle in goats fed graded levels of blend of 80 % canola oil and 20 % palm oil**

**Note:** Means having different superscript along the row are significantly different (P < 0.05).

∑SFA = (C14:0 + C16:0 + C18:0), ∑MUFA = (C16:1+ C18:1+ C18:1 -11), ∑PUFA = (C16:1+ C18:1+ C18:1 -11+ CLA cis-9 trans-11+ CLA cis-12), ∑n-3 = (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), ∑n-6 = (C18:2n-6 + C20:4n-6), n-6:n-3 = (C18:2n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), UFA:SFA = (∑UFA)/∑SFA, PUFA:SFA = (∑PUFA)/∑SFA, ID16 = (Δ 9 desaturase enzyme activity on C16:0) = 100(C16:1)/(C16:0 + C16:1), ID18 = (Δ 9 desaturase enzyme activity on C18:0) = 100(C18:1)/(C18:0 + C18:1), EI = 100[(C18:0 + C18:1 n-9)/(C18:0 + C18:1 n-9 + C16:0 + C16:1)], SEM = standard error of means. Values are least square means for 8 goats per diet. Blend of 80 % canola oil and 20 % palm oil.
carcass fatness and total fatty acids in all the tissues ex- 
amined. Thus, the observed FA composition in the exam- 
ine tissues was not confounded by carcass fatness.

Regardless of the diet, the most abundant FA in SS was 
C18:1n-9 and its concentration was influenced by diet. This 
observation is in tandem with previous studies in 
goats [35], sheep [36] and cattle [38] in which C18:1n-9 
was identified as the most abundant FA in muscle follow- 
ing dietary oil supplementation. The increase in C18:1n-9 
in response to BCPO could be due to the increase in diet- 
ary C18:1n-9 and/or increase in the Δ 9 desaturase enzyme 
activities (ID 18) necessary for the de novo conversion of 
C18:0 to C18:1n-9. This observation is consistent with 
those observed in a companion in vitro study where the 
ruminal concentration of C18:1n-9 after 24 h incubation 
increased as the level of BCPO increased in the substrate 
[17]. As found in the current study, supplementation of 
3.3 % canola oil, canolamide or canola oil-canolamide mix 
oil increased the concentration of C18:1n-9 in bovine milk 
[5]. Conversely, 3 % dietary canola oil compared with 3 % 
palm oil did not affect the concentration of C18:1n-9 in 
longissimus lumborum muscle from goats [48].

Dietary supplementation of BCPO depressed the con- 
centration of C16:0 and C16:1n-7 in SS muscle. These

| Parameter                  | Levels of BCPO (%) | SEM     | Overall | Linear | Quadratic |
|----------------------------|--------------------|---------|---------|--------|-----------|
|                            | 0                  | 4       | 8       |        |           |
| C14:0, myristic             | 5.55a              | 4.18b   | 4.04b   | 0.30   | 0.003     | 0.001     | 0.757     |
| C16:0, palmitic             | 26.67              | 21.87   | 24.57   | 1.92   | 0.232     | 0.158     | 0.331     |
| C16:1n-7, palmitoleic       | 2.94a              | 2.25b   | 2.01c   | 0.12   | <0.0001   | <0.0001   | 0.176     |
| C18:0, stearic              | 31.24              | 35.41   | 32.42   | 1.86   | 0.092     | 0.142     | 0.096     |
| C18:1n-9, oleic             | 24.99c             | 29.67a  | 31.07a  | 2.85   | 0.006     | 0.037     | 0.730     |
| CLA cis-9 trans-11 Vaccenic | 4.77a              | 0.78b   | 0.61c   | 0.79   | 0.001     | 0.0004    | 0.882     |
| CLA trans-cis-12            | 0.29               | 0.31    | 0.39    | 0.04   | 0.197     | 0.200     | 0.198     |
| C18:2n-6, linoleic          | 3.14               | 3.40    | 3.96    | 0.42   | 0.387     | 0.306     | 0.357     |
| C18:3n-3, linolenic         | 0.17               | 0.25    | 0.18    | 0.02   | 0.055     | 0.189     | 0.039     |
| C20:4n-6, arachidonic       | 0.11               | 0.10    | 0.11    | 0.01   | 0.560     | 0.418     | 0.483     |
| C20:5n-3, eicosapentaenoic  | 0.08c              | 0.16b   | 0.56c   | 0.08   | 0.001     | 0.008     | 0.002     |
| C22:5n-3, docosapentaenoic  | 0.20               | 0.29    | 0.40    | 0.13   | 0.574     | 0.383     | 0.561     |
| C22:6n-3, docosahexaenoic   | 0.15               | 0.08    | 0.09    | 0.05   | 0.463     | 0.223     | 0.894     |
| Total FA (mg/g of fat)      | 651.60             | 610.23  | 697.51  | 117.30 | 0.871     | 0.987     | 0.604     |

FA ratios and sums

∑SFA = (C14:0 + C16:0 + C18:0),
∑MUFA = (C16:1+ C18:1+ C18:1 trans-11),
∑PUFA = (C18:1 trans-11+ CLA cis-9 trans-11+ CLA cis-12 trans-10 + Σn-3 + Σn-6),
∑SFA = (C16:1 + C18:1 + C18:1 trans-11) + CLA cis-9 trans-11 + CLA cis-12 trans-10 + Σn-3 + Σn-6),
Σn-3 = (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), Σn-6 = (C18:2n-6 + C20:4n-6) + Σn-3 = (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3),
∑PUFA = (ΣPUFA/ΣSFA), PUFA:SFA = (ΣPUFA/ΣSFA). ID16, (Δ 9 desaturase enzyme activity on C16:0) = 100(C16:1)/(C16:0 + C16:1), ID18, (Δ 9 desaturase enzyme activity on C18:0) = 100(C18:1)/(C18:0 + C18:1). EI = 100[(C18:0 + C18:1 n-9)/(C18:0 + C18:1n-9 + C16:0 + C16:1)]. SEM = standard error of means. Values are least square means for 8 goats per diet. a,b,c means having different superscript along the a row are significantly different (P < 0.05).
observations concur with those of Loor et al. [5] and Ferlay et al. [49]. Depression of medium chain FA in response to dietary unsaturated fats could be due to the inhibition of the activities of lipogenic enzymes required for the synthesis of medium chain FA or the preferential incorporation of long chain FA from diet and/or adipose tissues [4, 5, 49, 50]. This lends credence to the significant decrease in the Δ9 desaturase activity (ID 16) which coincides with the linear decrease in the concentration of C16:0 and C16:1 as BCPO increased in diet. Palmitic acid (C16:0) can be converted to C16:1 by Δ9 desaturase [51].

The concentration of C18:1 trans-11 Vaccenic and CLA cis-9 trans-11 in SS increased as BCPO increased in diet. This observation could be due to the increase in the dietary concentration of unsaturated fatty acids. Both C18:1 trans-11 Vaccenic and CLA cis-9 trans-11 are intermediate products of ruminal biohydrogenation of unsaturated FA [4, 13, 14]. Feeding unsaturated FA causes incomplete biohydrogenation of unsaturated FA accompanied with biohydrogenation intermediates [13, 14]. In addition, it has been established that Δ9 desaturation of C18:1 trans-11 Vaccenic in adipose tissue could yield CLA cis-9 trans-11 [4, 16, 17]. In line with the

| Parameter                  | Level of BCPO (%) | SEM  | P value     |
|----------------------------|-------------------|------|-------------|
|                            | 0                 | 4    | 8           |
| C14:0, myristic            | 6.02±             | 3.87±| 3.85±       |
| C16:0, palmitic            | 23.44             | 25.74| 24.18       |
| C16:1n-7, palmitoleic      | 2.94±             | 1.99±| 1.83±       |
| C18:0, stearic             | 40.18±            | 38.92±| 30.64±      |
| C18:1n-9, oleic            | 17.69±            | 21.03±| 29.05±      |
| C18:1 trans-11 Vaccenic    | 4.27              | 3.55 | 5.15        |
| CLA cis-9 trans-11         | 0.80±             | 1.09±| 1.11±       |
| CLA trans-10 cis-12        | 0.36              | 0.36 | 0.33        |
| C18:2n-6, linoleic         | 3.52              | 3.20 | 3.70        |
| C18:3n-3, linolenic        | 0.27              | 0.32 | 0.28        |
| C20:4n-6, arachidonic      | 0.08              | 0.06 | 0.08        |
| C20:5n-3, eicosapentaenoic | 0.76              | 0.53 | 0.52        |
| C22:5n-3, docosapentaenoic | 0.15              | 0.47 | 0.32        |
| C22:6n-3, docosahexaenoic  | 0.11              | 0.30 | 0.24        |
| Total FA (mg/g of fat)     | 544.47            | 673.58| 692.52      |

FA ratios and sums

∑SFA = (C14:0 + C16:0 + C18:0), ∑MUFA = (C16:1 + C18:1 + C18:1 trans-11), ∑PUFA = (C18:1 trans-11 + CLA cis-9 trans-11 + CLA cis-12 trans-10 + Σ3 + Σ6), ∑PUFA = (C18:1 trans-11 + CLA cis-9 trans-11 + CLA cis-12 trans-10 + Σ3 + Σ6), ∑n-3 = (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), Σn-6 = (C18:2n-6 + C20:4n-6) n-6:n-3 = (C18:2n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), UFA:SFA = (∑UFA/∑SFA), PUFA:SFA = (∑PUFA/∑SFA). ID16, (Δ9 desaturase enzyme activity on C16:0) = 100(C16:1)/(C16:0 + C16:1), ID18, (Δ9 desaturase enzyme activity on C18:0) = 100(C18:1)/C18:0 + C18:1). EI = 100(C18:0 + C18:1 n-9)/(C18:0 + C18:1n-9 + C16:0 + C16:1). SEM = standard error of means. Values are least square means for 8 goats per diet. *blend of 80 % canola oil and 20 % palm oil.

Table 9 Least square means for the fatty acid (FA) composition (% of total FA) of perirenal adipose tissue in goats fed graded levels of blend of 80 % canola oil and 20 % palm oil.
current observation, supplementation of 3.3 % canola oil, canolamide or canola oil-canolamide mix (Loor et al. [5] and 1 kg/day canola oil [50] increased the concentration of C18:1 trans-11 Vaccenic and CLA cis-9 trans-11 in bovine milk compared with the control diet.

The proportion of C18:0, C18:2n-6 and C20:4n-6 in SS was not influenced by diet. In contrast, the concentration of C18:3n-3 and C20:5n-3 increased linearly in response to dietary BCPO. Similarly, Karami et al. [48] found that 3 % canola oil compared with 3 % palm oil did not affect the concentration of C18:0, C18:2n-6 and C20:4n-6 but enhanced the concentration C18:3n-3 in longissimus lumborum muscle from goats. However, the authors did not observe increment in the concentration of long chain n-3 FA. The linear increase in the proportion of C18:3n-3 in goats fed 4 and 8 % BCPO relative to those fed control diet could be responsible for the increase in the proportion of C20:5n-3 in their muscles since the FA is a metabolite of C18:3n-3 [4] suggesting in vivo elongation and desaturation. This coincides with the linear increase in the elongation index in response to supplementation of BCPO. This observation is consistent with those of Gjerlaug-Enger et al. [52] who observed that dietary rapeseed products enhanced the

| Parameter                     | Level of BCPO (%) | SEM  | Overall | Linear | Quadratic |
|-------------------------------|-------------------|------|---------|--------|-----------|
| C14:0, myristic               | 6.67              | 5.70 | 5.04    | 0.53   | 0.048     | 0.049 | 0.395 |
| C16:0, palmitic               | 27.06             | 27.05| 24.22   | 1.18   | 0.170     | 0.334 | 0.104 |
| C16:1n-7, palmitoleic         | 3.49              | 3.44 | 2.74    | 0.44   | 0.409     | 0.461 | 0.266 |
| C18:0, stearic                | 26.10             | 25.28| 24.42   | 2.56   | 0.898     | 0.814 | 0.693 |
| C18:1n-9, oleic               | 19.09             | 18.98| 26.30   | 2.42   | 0.050     | 0.044 | 0.377 |
| C18:1 trans-11 Vaccenic       | 3.48              | 4.27 | 4.87    | 0.73   | 0.422     | 0.569 | 0.239 |
| CLA cis-9 trans-11            | 1.30              | 1.51 | 1.20    | 0.22   | 0.612     | 0.337 | 0.841 |
| CLA trans-10 cis-12           | 1.54              | 2.08 | 1.72    | 0.39   | 0.618     | 0.521 | 0.463 |
| C18:2n-6, linoleic            | 3.63              | 3.65 | 3.53    | 0.53   | 0.986     | 0.878 | 0.953 |
| C18:3n-3, linolenic           | 1.56              | 1.44 | 1.71    | 0.23   | 0.712     | 0.417 | 0.952 |
| C20:4n-6, arachidonic         | 1.89              | 1.62 | 2.13    | 0.52   | 0.784     | 0.491 | 0.980 |
| C20:5n-3, eicosapentaenoic    | 1.87              | 2.78 | 2.91    | 0.39   | 0.043     | 0.011 | 0.051 |
| C22:5n-3, eicosapentaenoic    | 1.42              | 1.67 | 2.11    | 0.42   | 0.501     | 0.458 | 0.365 |
| C22:6n-3, docosahexanoic      | 1.92              | 1.87 | 2.29    | 0.52   | 0.824     | 0.574 | 0.804 |
| Total FA (mg/g of fat)        | 842.23            | 925.87| 982.87  | 160.09 | 0.827     | 0.804 | 0.577 |

FA sums and ratios
\[\Sigma SFA = (C14:0 + C16:0 + C18:0), \Sigma MUFA = (C16:1+ C18:1+ C18:1 trans-11), \Sigma PUFA = (C18:1 cis-9 trans-11 + CLA cis-9 trans-11 + CLA cis-12 trans-10 + \Sigma n-3 + \Sigma n-6), \Sigma UFA = (\Sigma EPA + \Sigma DHA), \Sigma n-3 = (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), n-6:n-3 = (C18:2n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), UFA:SFA = (\Sigma UFA)/\Sigma SFA, PUFA:SFA = (\Sigma PUFA)/\Sigma SFA, ID16 = 100(C16:1)/(C16:0 + C16:1), ID18 = 100(C18:0 + C18:1 n-9)/(C18:0 + C18:1 n-9 + C16:0 + C16:1), EI = 100[(C18:0 + C18:1 n-9)/(C18:0 + C18:1 n-9 + C16:0 + C16:1)], SEM = standard error of means.

\(a, b, c\) means having different superscript along the a row are significantly different (\(P < 0.05\)).
concentration of C18:3n-3, C20:5n-3 and C22:5n-3 in longissimus dorsi muscle of pork compared with the control diet.

The linear increase in total n-3 PUFA was accompanied by a linear decrease in n6/n3 ratio as the level of BCPO increased in the diet. The n6/n3 ratio for the 4 and 8 % BCPO was within the range of the recommended value (<4) for healthy diet [53]. Dietary BCPO enhanced the total MUFA and decreased the total SFA in SS muscle. Diet had no effect on the total PUFA and total FA. The PUFA/SFA ratio increased with increase in dietary BCPO. This could be attributed to the decrease in the SFA in BCPO based diets. Regardless of diet, the PUFA/SFA ratio of SS was within the range of the recommended value (>0.4) [53]. The major fatty acids in all adipose tissues were C16:0, C18:0 and C18:1n-9. This observation is in line with those of Bas et al. [6] and Castro et al. [37]. The decrease in the proportion of C14:0 and C16:1n-7 in the perirenal and omental fats from goats fed 4 and 8 % BCPO relative to the control goats could be due to the reduction in the mRNA abundance and activity of lipogenic enzymes required for synthesis of medium chain FA [4]. The decrease in the proportion of C16:1n-7

| Parameter                      | 0      | 4      | 8      | SEM   | P value  |
|--------------------------------|--------|--------|--------|-------|----------|
| C14:0, myristic                | 5.64   | 4.96   | 4.32   | 0.34  | 0.379    |
| C16:0, palmitic                | 25.52  | 20.09  | 20.03  | 2.68  | 0.114    |
| C16:1n-7, palmitoleic          | 3.57   | 3.20   | 2.86   | 0.24  | 0.126    |
| C18:0, stearic                 | 22.07  | 26.39  | 26.51  | 2.24  | 0.300    |
| C18:1n-9, oleic                | 24.15  | 25.28  | 23.34  | 1.44  | 0.640    |
| C18:1 trans-11 Vaccenic        | 3.15   | 3.19   | 3.45   | 0.56  | 0.833    |
| CLA cis-9 trans-11             | 1.25   | 1.56   | 1.98   | 0.31  | 0.282    |
| CLA trans-10 cis-12            | 1.88   | 2.03   | 1.74   | 0.26  | 0.739    |
| C18:2n-6, linoleic             | 3.05   | 3.47   | 3.78   | 0.58  | 0.663    |
| C18:3n-3, linolenic            | 2.04   | 1.60   | 1.63   | 0.38  | 0.679    |
| C20:4n-6, arachidonic          | 2.60   | 1.89   | 2.32   | 0.43  | 0.512    |
| C20:5n-3, eicosapentaenoic     | 2.80   | 2.20   | 3.16   | 0.68  | 0.607    |
| C22:5n-3, docosapentaenoic     | 1.63   | 2.04   | 2.58   | 0.29  | 0.098    |
| C22:6n-3, docosahexaenoic      | 1.78   | 2.71   | 2.01   | 0.48  | 0.371    |
| Total FA (mg/g of fat)         | 526.53 | 579.41 | 549.34 | 87.20 | 0.428    |

FA sums and ratios

\[
\sum_{SFA} = (C14:0 + C16:0 + C18:0), \sum_{MUFA} = (C16:1 + C18:1 + C18:1 \text{ trans-11}), \sum_{PUFA} = (C18:1 \text{ trans-11} + \text{CLA cis-9 trans-11} + \text{CLA cis-12 trans-10} + \sum_{n3} + \sum_{n6}), \sum_{\text{PUFA}} = (C18:1 \text{ trans-11} + \text{CLA cis-9 trans-11} + \text{CLA cis-12 trans-10} + \sum_{n3} + \sum_{n6}), \sum_{n3} = (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), \sum_{n6} = (C18:2n-6 + C20:4n-6) \]

\[
\sum_{n-3} = (C16:0 + C18:0 + C18:1 \text{ n-9}), \sum_{n-6} = (C18:2n-6 + C20:4n-6) \]

\[
n-6:n-3 = (C18:2n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3), \text{ UFA:SFA} = \frac{\sum_{UFA}}{\sum_{SFA}}, \text{ PUFA:SFA} = \frac{\sum_{PUFA}}{\sum_{SFA}}. \]

Desaturase and elongase indices

\[
\text{ID16} = 100(C16:1)/(C16:0 + C16:1), \text{ ID18} = 100(C18:1)/C18:0 + C18:1. \text{ EI} = 100[(C18:0 + C18:1 \text{ n-9})/(C18:0 + C18:1 \text{ n-9} + C16:0 + C16:1)]. \text{ SEM} = \text{ standard error of means}. \]

Values are least square means for 8 goats per diet. *blend of 80 % canola oil and 20 % palm oil.
coincides with the linear decrease in the Δ9 desaturase activity (ID 16) as BCPO increased in the diets. Dietary BCPO deceased the proportion of C18:0 and total SFA and enhanced the concentration of C18:1n-9, CLA cis-9 trans-11 and total MUFA in perirenal fat. In omental fat, dietary BCPO increased the concentration of CLA cis-9 trans-11, C20:5n-3 and total PUFA. In the mesentery fat, goats fed 8% BCPO had higher C18:1n-9 and Δ9 desaturase activity (ID 18) compared to other diets. Also, BCPO caused a linear increase in the proportion of C20:5n-3. The current observation is consistent with those of Stanford et al. [54] who observed that increasing the level of canola screening in diets reduced the concentration of C14:0, C16:0, C16:1n-7, C18:0 and total SFA and enhanced that of C18:1n-9, C18:3n-3, total MUFA and PUFA in perirenal adipose tissue in lambs. In contrast, dietary rapeseed oil, linseed oil and hydrogenated rapeseed oil did not alter the fatty acid composition of perirenal adipose tissues in lambs [55].

Contrary to the findings in perirenal, mesentery and omental adipose tissues, dietary BCPO did not affect the FA composition of subcutaneous adipose tissue. This finding concurs with those of Potkariski et al. [55] who observed that dietary rapeseed oil did not alter the FA composition of subcutaneous adipose tissue in lambs. Similarly, dietary fish oil did not alter the FA composition of subcutaneous adipose tissue in lambs [56]. Contrary to the present findings, earlier trials have reported significant alterations in the FA composition of subcutaneous adipose tissue when oils high in unsaturated FA were fed to sheep [57] and goats [35]. The inconsistencies observed in the FA composition of adipose tissues in response to dietary BCPO reflect variation in FA metabolism in the adipose tissues.

Conclusions

The results of this study showed that dietary supplementation of blend of 80% canola oil and 20% palm oil in diet did not affect carcass traits, fat color, and fat deposition and distribution in goats. Thus, dietary BCPO is not an effective repartitioning agent for fat in goats. However, BCPO altered the fatty acid composition of supraspinatus muscle, mesentery, omental and perirenal adipose tissues in goats.

Abbreviations

BCPO: Blend of 80% canola oil and 20% palm oil; FA: Fatty acid; SS: Supraspinatus muscle; SFA: Saturated fatty acid; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

KDA, AQS and AAS conceived the idea. KDA conducted the feeding trial, analyze the data and wrote the first draft of the manuscript. AQS and AAS supervised the study and corrected the first draft of the manuscript. KDA and ABS did the carcass fabrication. KDA and ME did the fatty acid analysis. All authors read and approved the manuscript.

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