Italian Journal of Animal Science

ISSN: (Print) 1828-051X (Online) Journal homepage: http://www.tandfonline.com/loi/tjas20

Fatty acid composition, cholesterol and antioxidant status of infraspinatus muscle, liver and kidney of goats fed blend of palm oil and canola oil

Kazeem Dauda Adeyemi, Azad Behnan Sabow, Mahdi Ebrahimi, Anjas Asmara Samsudin & Awis Qurni Sazili

To cite this article: Kazeem Dauda Adeyemi, Azad Behnan Sabow, Mahdi Ebrahimi, Anjas Asmara Samsudin & Awis Qurni Sazili (2016) Fatty acid composition, cholesterol and antioxidant status of infraspinatus muscle, liver and kidney of goats fed blend of palm oil and canola oil, Italian Journal of Animal Science, 15:2, 181-190

To link to this article: http://dx.doi.org/10.1080/1828051X.2016.1158081

Published online: 24 Mar 2016.

ITALIAN JOURNAL OF ANIMAL SCIENCE, 2016
VOL. 15, NO. 2, 181–190
http://dx.doi.org/10.1080/1828051X.2016.1158081

Taylor & Francis
Taylor & Francis Group

PAPER

OPEN ACCESS

Fatty acid composition, cholesterol and antioxidant status of infraspinatus muscle, liver and kidney of goats fed blend of palm oil and canola oil

Kazeem Dauda Adeyemi[a,b], Azad Behnan Sabow[a,c], Mahdi Ebrahimi[d], Anjas Asmara Samsudin[a] and Awis Qurni Sazili[a,e,f]

[a]Department of Animal Science, Universiti Putra Malaysia, Serdang, Selangor, Malaysia; [b]Department of Animal Production, University of Ilorin, Ilorin, Nigeria; [c]Department of Animal Resource, University of Salahaddin, Erbil, Kurdistan Region, Iraq; [d]Department of Veterinary Preclinical Sciences, Universiti Putra Malaysia, Serdang, Selangor, Malaysia; [e]Institute of Tropical Agriculture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia; [f]Halal Products Research Institute, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

ABSTRACT

The study assessed the lipid profile, cholesterol and antioxidant status of *infraspinatus* muscle, kidney and liver from goats supplemented with increasing levels of blend of 20% palm oil and 80% canola oil. Twenty-four Boer bucks were randomly assigned to diets containing 0, 4 and 8% oil blend, fed for 100 d and slaughtered. The tissues were subjected to 7 d postmortem storage at 4 °C. Diet did not affect total lipid and cholesterol content in the tissues. The proportions of C14:0 in *infraspinatus* muscle and kidney, and C15:0 in all tissues were lower ($p < 0.05$) while the proportion of C18:3n:3 was greater in supplemented goats than the control goats. Proportion of C18:1n-9 in *infraspinatus* muscle was higher ($p < 0.05$) in goats fed oil blend than the control goats. The liver and the *infraspinatus* muscle of the control goats had higher C18:1 *trans*-10 but lower C18:1 *trans*-11 compared with those fed other diets. Diet had no effect on catalase, superoxide dismutase and glutathione peroxidase activities, and the concentration of γ and δ-tocopherol and lipid oxidation in all tissues. The concentrations of α-tocopherol and total carotenoid were greater in the tissues of oil-fed goats compared with the control goats. Regardless of tissue, the catalase and superoxide dismutase activities were stable throughout storage. Lipid oxidative stability, glutathione peroxidase activity, tocopherol and carotenoid contents in the tissues decreased ($p < 0.05$) as postmortem storage progressed. Dietary 20% palm oil and 80% canola oil blend modified the fatty acids in goat meat and offal without compromising their oxidative stability.

ARTICLE HISTORY
Received 9 May 2015
Accepted 22 February 2016

KEYWORDS
Antioxidant; fatty acid; infraspinatus muscle; kidney; liver

Introduction

There is increasing preference for safer, healthier and functional meat due to increased health consciousness among consumers (Howes et al. 2015; Nantapo et al. 2015). The high proportion of saturated fatty acids (SFA) and cholesterol in red meat has been implicated in the incidence of various chronic diseases (Pan et al. 2012; Cross et al. 2013). Thus, modifying the fatty acid profile of red meat is warranted.

The major way of altering tissue lipids in ruminants is the use of dietary oils (Bessa et al. 2007; Nute et al. 2007). However, the major drawback in enhancing the unsaturated fatty acid (UFA) in red meat is the high susceptibility of UFA to lipid oxidation (Nute et al. 2007). Lipid oxidation can reduce the shelf life (Nute et al. 2007; Olorunsanya et al. 2011) and jeopardize the nutritive and eating quality of meat (Ponnampalam et al. 2014). Thus, enhancing the beneficial UFAs in meat necessitates the need to prevent the UFA from lipid oxidation. Synthetic antioxidants are effective in curbing postmortem lipid oxidation in muscle foods but they are very scarce and expensive particularly in developing countries (Olorunsanya et al. 2011; Adeyemi et al. 2013). In addition, there are concerns about the adverse effects of synthetic antioxidants on human health (Shahidi & Zhong 2010). Thus, the use of natural antioxidants could be a viable alternative in curbing oxidative spoilage in foods (Shahidi & Zhong 2010; Sola-Ojo et al. 2013).

Incorporation of antioxidant-rich vegetable oils in animals' diets has been suggested as an effective and economical way of curbing postmortem lipid oxidation and an alternative way of enhancing antioxidants in human diet (Soler-Velasquez et al. 1998; Kang et al. 2001). Albeit, vitamin E and other antioxidant vitamins play important role in the regulation of oxidation of

CONTACT Dr. Awis Qurni Sazili awis@upm.edu.my, awisqurni@gmail.com Department of Animal Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

UFA in tissues, various protective antioxidant enzymes such as glutathione peroxidase, catalase and superoxide dismutase are also involved (Renerre et al. 1999). The efficacies of various oil blends in altering tissue lipids in ruminants have been documented (Bessa et al. 2007; Kim et al. 2007; Jerónimo et al. 2009). Nonetheless, information regarding the effects of blend of palm oil and canola oil on lipid composition and oxidative stability of liver, kidney and *infraspinatus* muscle in goats has not been elucidated. Canola oil contains about 59% oleic acid, 21% linoleic acid and 13% linolenic acid while the saturated fatty acids account for about 7% (Lin et al. 2013). Canola oil contains about 0.53–0.97% plant sterols and about 700–1200 ppm tocopherols (Dupont et al. 1989; Lin et al. 2013). Palm oil is the richest natural plant source of lipid-soluble antioxidants such as carotenoids (α- and β-carotenes, lycopenes), vitamin E (α-, β-, δ-tocotrienols and tocopherol) and ubiquinone (Oguntibeju et al. 2009; Atawodi et al. 2011). Palm oil contains 44% oleic acid, 10% linoleic acid and about 40% palmitic acid (Siew & Ng 2000). Based on the fatty acid profile and antioxidant contents of palm oil and canola oil, we propose that a blend of these oils will modify the lipid and antioxidant profile of chevon and offal.

Companion *in vitro* (Adeyemi et al. 2015a) and *in vivo* (Adeyemi et al. 2015c) trials have shown that the blend of 20% palm oil and 80% canola oil had no detrimental effect on rumen metabolism, feed intake and growth performance in goats. In addition, the serum biochemical indices and antioxidant status were not compromised (Adeyemi et al. 2016). Therefore, the objective of this study was to determine the effects of dietary supplementation of blend of 20% palm oil and 80% canola oil, and postmortem conditioning on lipid profile, cholesterol content and antioxidant status of *infraspinatus* muscle, liver and kidney in goats.

Materials and methods

Animal welfare

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

Animals and diets

Twenty-four, 4–5 months old Boer bucks weighing 20.54 ± 0.474 kg (mean ± standard deviation) were used in this study. The goats were drenched against parasites and randomly assigned to diets containing 0, 4 and 8% oil blend on a dry matter basis of the basal diet (complete ration mix) and fed for 100 d following a 14 d adaptation period. Each diet was made up of 50% forage (fresh oil palm frond) and 50% concentrate on a dry matter basis (Adeyemi et al. 2015c). The ingredients in the concentrate portion were adjusted to make the diets isocaloric and isonitrogenous (Table 1). The oil-supplemented diets were prepared by manually incorporating the oil blend into the ground concentrate thoroughly to ensure homogenous distribution of the oil in the ration. The diets were prepared fresh twice a day and no antioxidant was added. The diets were offered as complete ration mix (forage and concentrate) in two equal meals at 0830 and 1430 hours. All goats had free access to water.

Table 1. Chemical and fatty acid composition and contents of antioxidant compounds in dietary treatments.

	Levels of oil blend (%)		
	0	4	8
Chemical composition			
Dry matter, %	67.70	67.90	68.07
Crude protein, % DM	14.27	14.37	14.39
Ether extract, % DM	2.30	6.35	11.11
Organic matter, % DM	93.16	93.42	93.55
Nitrogen free extract, % DM	16.56	13.97	12.45
Acid detergent fibre, % DM	35.04	33.28	32.52
Neutral detergent fibre, % DM	63.52	62.67	62.06
Metabolizable energy, MJ/kg DM	11.59	11.61	11.62
Ca, % DM	1.02	1.05	1.04
P, % DM	0.52	0.54	0.54
Fatty acid, % of total fatty acid			
C12:0	0.07	0.07	0.08
C14:0	3.35	1.38	0.99
C16:0	17.64	16.14	14.92
C16:1	0.52	0.31	0.29
C18:0	3.53	3.02	2.74
C18:1n-9	24.19	40.10	50.37
C18:2n-6	44.59	32.01	23.08
C18:3n-3	6.70	7.04	7.90
n-6:n-3	6.66	4.54	2.92
Total fatty acid, g/kg DM	15.83	37.09	52.27
Antioxidant, mg/kg			
Total carotenoid	14.81	16.71	19.86
α-Tocopherol	101.12	112.47	123.21
γ-Tocopherol	10.22	34.55	49.17
δ-Tocopherol	1.21	3.45	5.93

n-6:n-3 = (C18:2n-6 ÷ C18:3n-3).

Feed samples (400 g) were collected weekly and stored at −20 °C until analysis. Feed samples were dried at 60 °C for 48 h to determine the dry matter content, ground to pass a through a 1 mm screen and analyzed for ether extract, crude protein and ash according to the method of AOAC (1990). Neutral detergent fibre and acid detergent fibre were analysed by the method of Van Soest et al. (1991). The chemical and the fatty acid composition of the dietary treatments are presented in Table 1.

The growth performance, nutrient intake and digestibility, and rumen fermentation have been assessed in a companion feeding trial (Adeyemi et al. 2015c). The oil blend had no effect on growth performance, feed

efficiency and the intake and digestibility of dry matter, crude protein, neutral detergent fibre, acid detergent fibre and organic matter but enhanced the intake and digestibility of crude fat (Adeyemi et al. 2015c). The mean final body weight of goats fed 0, 4 and 8% oil blend were 30.75, 32.00 and 30.94 kg, respectively (Adeyemi et al. 2015c).

Slaughtering, tissue sampling and postmortem storage

At the end of the feeding trial, the goats were fasted overnight with *ad libitum* access to water and slaughtered in accordance to the Halal slaughter procedures outlined in MS1500:2009 (Department of Standards, Malaysia, 2009). After evisceration and carcass dressing, the carcasses and offal were subjected to postmortem aerobic refrigerated storage at 4 °C. The liver samples were obtained from the right lobe of the liver while the kidney samples were obtained from the renal cortex of the right kidney. The *infraspinatus* muscle, central to the scapula spine, was excised from the left forelimb. On day 0, about 10 g of each sample was excised, snap frozen in liquid nitrogen and store at −80 °C until further analysis while the remaining portions were left intact until a particular postmortem storage was reached. On 4 and 7 d postmortem, 10 g of each sample was excised, snap frozen in liquid nitrogen and stored at −80 °C until further analysis.

Determination of lipid oxidation

Lipid oxidation in the tissues was measured as 2-thiobarbituric acid reactive substances (TBARS) using QuantiChrom™ TBARS Assay Kit (DTBA-100, BioAssay Systems, Hayward, CA) following the procedure of the manufacturer.

Determination of antioxidant enzyme activities

Catalase activity was measured using Cayman Catalase Assay Kit (Cat no # 707002, Cayman Chemical, Ann Arbor, MI), glutathione peroxidase (GPX) was measured with EnzyChromTM Glutathione Peroxidase Assay Kit (Cat no # EGPX-100, BioAssay Systems, Hayward, CA) while superoxide dismutase (SOD) activity was measured using Cayman SOD Assay kit (Cat no # 706002, Cayman Chemical, Ann Arbor, MI) following the procedures of the manufacturer.

Determination of cholesterol, total carotenoid and tocopherol contents

Cholesterol content in tissue was determined using the method of Rudel and Morris (1973). The carotenoid contents in feed and tissue samples were quantified as described by Okonkwo (2009). The extraction of tocopherol from feed and tissue samples was done as described by Kamal-Eldin et al. (2000). Quantification of tocopherol contents was done with Agilent 1200 series HPLC (Agilent Technologies, Inc., Santa Clara, CA) as described by Pegg and Amarowicz (2009).

Fatty acid analysis

The total fat in feed and tissue samples was extracted with chloroform:methanol (2:1, v/v) mixture following the method of Folch et al. (1957) modified by Rajion et al. (1985). The extracted fatty acids (FA) were transmethylated to their fatty acid methyl esters (FAME) using 0.66 N KOH in methanol and 14% methanolic BF_3 according to the method of AOAC (1990). The FAME was separated by a gas liquid chromatograph (Agilent 7890A, Agilent Technologies, Inc., Santa Clara, CA) equipped with a flame ionization detector using a 100 m × 0.25 mm ID (0.20-μm film thickness) Supelco SP-2560 capillary column. Helium was the carrier gas and the split ratio after the FAME injection was 10:1. The temperature of the injector and detector were programmed at 250 °C and 300 °C, respectively. The column temperature was set at 100 °C, held 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. The identification of sample fatty acids was done by comparing the relative retention times of FAME peaks from samples with those of standards.

Statistical analysis

The experiment followed a completely randomized design. Data obtained for fatty acids and cholesterol were subjected to the generalized linear model (GLM) procedure of SAS (SAS 2003). The antioxidants and lipid oxidation data were analyzed using the PROC MIXED procedure of SAS (SAS 2003) in which diet, postmortem storage and interaction between diet and postmortem storage were fitted as fixed effects in a repeated measure analysis of variance. Before that, compound symmetry covariance structure, linear and quadratic contrasts were tested in regression analysis and found to have insignificant effects. Means were separated by Tukey HSD test at a significance level of $p < 0.05$.

Table 2. Mean fatty acid composition (% of total fatty acids) and cholesterol (mg/100 g wet muscle) of *infraspinatus* muscle in goats fed graded levels of blend of 20% palm oil and 80% canola oil.

	Levels of oil blend (%)				
Parameter	0	4	8	SEM	*p* value
C14:0	2.00[a]	1.80[b]	1.63[c]	0.173	0.032
C15:0	0.78[a]	0.63[b]	0.51[c]	0.104	0.010
C16:0	21.03	20.80	19.00	1.323	0.125
C16:1n-7	2.66	2.02	2.01	0.400	0.105
C18:0	20.70	18.10	17.86	1.100	0.190
C18:1 *trans*-10	0.96[a]	0.51[b]	0.36[c]	0.297	0.044
C18:1 *trans*-11	2.12[c]	2.77[b]	3.35[a]	0.541	0.023
C18:1n-9	30.50[b]	32.73[a]	34.35[a]	1.266	0.019
CLA c9t11	0.63	0.69	0.61	0.119	0.313
CLA t10 c12	0.34	0.31	0.22	0.227	0.332
C18:2n-6	7.64	8.64	8.89	0.795	0.116
C18:3n-3	1.07[a]	1.57[b]	1.67[b]	0.274	0.029
C20:4n-6	5.39	5.38	5.40	0.001	0.134
C20:5n-3	0.67	0.75	0.79	0.064	0.062
C22:5n-3	0.72	0.74	0.63	0.067	0.101
C22:6n-3	0.74	0.56	0.66	0.068	0.243
Unidentified FA	2.07	2.00	2.08	0.051	0.114
∑SFA	44.51	41.33	39.00	2.531	0.155
∑MUFA	36.24	38.03	40.07	0.919	0.115
∑PUFA	17.17	18.64	18.87	1.233	0.230
∑n-3	3.20	3.62	3.73	0.292	0.070
∑n-6	13.03	14.01	14.29	0.788	0.110
n-6/n-3	4.07	3.88	3.83	0.191	0.211
PUFA/SFA	0.39	0.45	0.48	0.057	0.120
Total lipid, mg/100 g	3831.20	3879.00	3861.04	36.16	0.110
Cholesterol, mg/100 g	49.21	47.76	44.85	3.110	0.161

a, b, c means having different superscript along the same row are significantly different ($p < 0.05$). ∑SFA = (C14:0 + C15:0 + C16:0 + C18:0), ∑MUFA = (C16:1 + C18:1 + C18:1t10 + C18:1t11), ∑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), ∑PUFA = (CLA c9t11 + CLA c12t10+∑n-3+∑n-6). SEM: standard error of mean.

Table 3. Mean fatty acid (FA) composition (% of total fatty acids) and cholesterol (mg/100 g wet tissue) content of liver in goats fed graded levels of blend of 20% palm oil and 80% canola oil.

	Levels of oil blend (%)				
Parameter	0	4	8	SEM	*p* value
C14:0	1.99	1.81	1.90	0.317	0.191
C15:0	0.96[a]	0.70[b]	0.57[c]	0.155	0.042
C16:0	20.20	19.44	20.01	0.289	0.512
C16:1n-7	2.67	1.67	2.29	0.217	0.080
C18:0	28.43	27.11	25.98	1.055	0.201
C18:1 *trans*-10	0.87[a]	0.40[b]	0.21[c]	0.271	0.015
C18:1 *trans*-11	2.50[c]	3.33[b]	4.07[a]	0.714	0.028
C18:1n-9	18.83	19.81	20.43	1.882	0.260
CLA c9t11	0.98	0.84	0.92	0.117	0.230
CLA t10c12	0.71	0.54	0.57	0.102	0.171
C18:2n-6	10.06	10.81	9.48	0.213	0.240
C18:3n-3	1.69[a]	2.06[b]	2.10[b]	0.176	0.020
C20:4n-6	6.31	8.19	7.14	1.777	0.290
C20:5n-3	0.61[c]	0.78[b]	1.00[a]	0.153	0.011
C22:5n-3	0.76	0.83	0.78	0.049	0.150
C22:6n-3	0.73	0.89	0.83	0.099	0.140
Unidentified FA	1.70	1.68	1.72	0.025	0.110
∑SFA	51.58	49.06	49.46	1.088	0.112
∑MUFA	24.87	25.21	27.00	0.418	0.121
∑PUFA	21.85	24.05	22.82	1.377	0.320
∑n-3	3.78[a]	4.50[b]	4.76[b]	0.596	0.010
∑n-6	16.37	19.00	16.62	0.768	0.450
n-6/n-3	4.33[a]	4.22[a]	3.49[b]	0.333	0.020
PUFA/SFA	0.42	0.49	0.46	0.029	0.060
Total lipid, mg/100 g	3596.12	3623.00	3531.10	53.298	0.111
Cholesterol, mg/100 g	226.33	225.08	220.69	11.057	0.610

a, b, c means having different superscript along the same row are significantly different ($p < 0.05$). ∑SFA = (C14:0 + C15:0 + C16:0 + C18:0), ∑MUFA = (C16:1 + C18:1 + C18:1t10 + C18:1t11), ∑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), ∑PUFA = (CLA c9t11 + CLA c12t10+∑n-3+∑n-6), PUFA/SFA = (∑PUFA/∑SFA). SEM: standard error of mean.

Results and discussion

Fatty acid composition and cholesterol content of tissues

The FA profile and cholesterol content of *infraspinatus* muscle, liver and kidney of goats supplemented with increasing levels of oil blend are presented in Tables 2, 3 and 4, respectively. Regardless of tissue, the C18:0 (17.86–20.70%, 19.22–20.20% and 22.00–22.57% in *infrasprinatus* muscle, liver and kidney, respectively), C18:1n-9 (30.50–34.35%, 18.83–20.43% and 17.92–20.00% in *infrasprinatus* muscle, liver and kidney, respectively) and C16:0 (19.00–23.83%, 19.44–20.43% and 22.27–22.90% in *infrasprinatus* muscle, liver and kidney, respectively) were the major FAs.

The proportion of C14:0 in the kidney and *infraspinatus* muscle decreased ($p < 0.05$) as the level of oil blend increased in the diet. This finding could be due to the preferential incorporation of long chain FA or due to the decrease in the mRNA abundance and activity of lipogenic enzymes required for the synthesis of medium chain FA (Kim et al. 2007). Similar findings were observed when soybean oil (Bessa et al. 2005) and safflower oil (Boles et al. 2005) were supplemented in lambs.

Regardless of tissue, the proportion of C15:0 decreased ($p < 0.05$) as the level of oil blend increased in diet. The C15:0 is an odd chain FA derived from rumen micro-organisms (Vlaeminck et al. 2006). Therefore, the depression of this FA in the tissue of oil-fed goats could be due to the effect of unprotected fat on rumen microbial ecology and metabolism by reducing either the proportion of odd chain FA in microbial biomass or the flow of microbial biomass to the duodenum. This observation is in tandem with the decrease in the ruminal concentration of C15:0 in the oil-fed goats (Adeyemi et al. 2015c).

The proportion of *trans*-10 C18:1 and *trans*-11 C18:1 in the liver and *infraspinatus* muscle differed ($p < 0.05$) between diets. The liver and *infraspinatus* muscle of the control goats had higher ($p < 0.05$) C18:1 *trans*-10 but lower ($p < 0.05$) C18:1 *trans*-11 compared those fed other diets. Similar trends, but of insignificant effects were observed in the kidney. Both C18:1 *trans*-11 and C18:1 *trans*-10 are intermediate products of biohydrogenation of unsaturated fats in the rumen (Pottier et al. 2006; Bessa et al. 2007; Kim et al. 2007). The increase in the proportion of C18:1 *trans*-11 in the

Table 4. Mean fatty acid (FA) composition (% of total fatty acids) and cholesterol content (mg/100 g wet tissue) of kidney in goats fed graded levels of blend of 20% palm oil and 80% canola oil.

	Levels of oil blend (%)				
Parameter	0	4	8	SEM	*p* value
C14:0	3.80[a]	3.20[b]	2.87[c]	0.400	0.021
C15:0	0.80[a]	0.71[b]	0.57[c]	0.089	0.011
C16:0	22.05	22.57	22.00	1.101	0.162
C16:1n-7	2.98	2.54	2.11	0.463	0.060
C18:0	22.87	22.29	22.80	0.514	0.220
C18:1 *trans*-10	0.70	0.50	0.46	0.130	0.065
C18:1 *trans*-11	1.91	2.36	2.55	0.578	0.090
C18:1n-9	17.92	19.21	20.00	2.674	0.222
CLA c9t11	0.87	0.89	0.87	0.053	0.060
CLA t10c12	0.46	0.47	0.46	0.110	0.073
C18:2n-6	14.16	13.20	12.97	0.738	0.182
C18:3n-3	1.24[a]	1.51[b]	1.79[c]	0.269	0.041
C20:4n-6	6.33	6.89	6.56	0.340	0.100
C20:5n-3	0.84	0.90	0.87	0.046	0.192
C22:5n-3	0.96	0.91	0.90	0.060	0.321
C22:6n-3	0.71	0.71	0.70	0.006	0.101
Unidentified FA	1.60	1.21	1.52	0.192	0.119
Total FA, mg/100 g	3201.11	3178.00	3320.22	30.487	0.100
∑SFA	49.52	48.77	48.24	1.353	0.191
∑MUFA	23.51	24.61	25.12	2.284	0.341
∑PUFA	25.57	25.48	25.13	0.353	0.120
∑n-3	3.04	4.03	4.27	0.580	0.034
∑n-6	20.39	20.12	19.53	0.659	0.192
n-6/n-3	6.71	4.99	4.57	1.164	0.066
PUFA/SFA	0.51	0.52	0.52	0.012	0.100
Total lipid, mg/100 g	3100.56	2987.23	2920.34	32.760	0.112
Cholesterol, mg/100 g	223.61	219.64	212.60	8.155	0.177

a, b, c means having different superscript along the same row are significantly different ($p < 0.05$). ∑SFA = (C14:0 + C15:0 + C16:0 + C17:0 + C18:0), ∑MUFA = (C16:1 + C18:1 + C18:1t10 + C18:1t11), ∑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), ∑PUFA = (CLA c9t11 + CLA c12t10+∑n-3+∑n-6). SEM: standard error of mean.

tissues of oil-fed goats compared with the control goats agrees with the findings of Bessa et al. (2005, 2007). Similarly, dietary canola oil, canolamide or canola oil–canolamide blend (Loor et al. 2002) and 1 kg canola oil/day (Chelikani et al. 2004) increased the levels of C18:1 *trans*-11 in bovine milk.

The decrease in the proportion of C18:1 *trans*-10 following oil supplementation was unexpected. Contrary to the present observation, supplementation of 10% of soybean oil with Lucerne or concentrate-based diet (Bessa et al. 2005) and supplementation of 7.4% of linseed oil, sunflower oil or a blend of sunflower oil and linseed oil (Bessa et al. 2007) increased the proportion of C18:1 *trans*-10 in intramuscular fat of lambs. The observed decrease in the proportion of C18:1 *trans*-10 could be due to the increase in dietary α-tocopherol content as the level of oil blend increased in diet (Table 1). This observation is tandem with the findings of Mapiye et al. (2012) who observed that the supplementation of vitamin E led to a reduction in the proportion of C18:1 *trans*-10 in the subcutaneous fat of steers. Similarly, Pottier et al. (2006) observed that supplementation of vitamin E in high-fat diet reduced the concentration of C18:1 *trans*-10 and increased the concentration of C18:1 *trans*-11 in bovine milk.

It has been posited that α-tocopherol might exhibits stimulatory and inhibitory effects on the activities and growth of rumen bacteria that synthesize C18:1 *trans*-11 and C18:1 *trans*-10 respectively (Martin & Jenkins 2002; Pottier et al. 2006). Härtig et al. (2005) posited that *trans* FAs are produced in the rumen as a result of ruminal oxidative stress which can be alleviated by α-tocopherol. Nonetheless, the ability of α-tocopherol to alleviate ruminal stress may not be via its normal role as antioxidant due to the greatly reduced rumen environment (Mapiye et al. 2012). An alternative mode of action of α-tocopherol might be related to its structural resemblance to a-deoxy-a-tocopherolquinol and tocopherolquinol which act as endogenous electron donors in the biohydrogenation of conjugated linoleic acids to C18:1 *trans*-11 (Hughes & Tove 1980), thereby enhancing the production of FAs by this pathway.

The proportion of C18:1n-9 in *infraspinatus* muscle was higher in goats fed 4 and 8% oil blend compared with the control goats. However, the proportion of C18:1n-9 in *infraspinatus* muscle did not differ ($p < 0.05$) between goats fed 4 and 8% oil blend. The increase in the proportion of C18:1n-9 could be due to the increased intake of C18:1n-9 as the oil blend increased in diet (Adeyemi et al. 2015c). It could also be due to the desaturation of C18:0 to form C18:1n-9 since the ruminal concentration of C18:0 increased as the level of oil blend increased in diet (Adeyemi et al. 2015c).

Irrespective of tissue, the proportion of C18:2n-6 did not differ between diets. This observation is consistent to that of Karami et al. (2013) who observed that goats fed 3% canola oil had similar C18:2n-6 in the liver and *longissimus lumborum* muscle as those fed 3% palm oil. Similarly, dietary canola oil, canolamide or canola oil-canolamide blend (Loor et al. 2002) and 1 kg canola oil/day (Chelikani et al. 2004) had no effect on the concentration of C18:2n-6 in bovine milk compared with the control diet.

The proportion of C18:3n-3 in the tissues was higher ($p < 0.05$) in goats fed diets supplemented with the oil blend compared with those fed the control diet. However, the proportion of C18:3n-3 in the liver and *infrasprinatus* muscle did not differ between goats fed diets supplemented with 4 and 8% oil blend. The increase in the proportion of C18:3n-3 in the tissues could be due to the increase in the intake and the ruminal concentration of C18:3n-3 as the level of oil blend increased in diet (Adeyemi et al. 2015c). Similarly, dietary C18:3n-3 increased the concentration

of C18:3n-3 in the muscle (Karami et al. 2013; Ebrahimi et al. 2014), liver and kidney of goats (Karami et al. 2013).

Regardless of tissue, the proportion of CLA *cis*-9 *trans*-11 and CLA *trans*-10 *cis*-12 was not influenced by diet. This observation was unexpected. Contrary to the present observation, dietary supplementation of unsaturated fats had significant effects on the concentration of CLA *cis*-9 *trans*-11 and CLA *trans*-10 *cis*-12 in lamb tissue (Bessa et al. 2007) and bovine milk (Loor et al. 2002; Chelikani et al. 2004).

The proportion of the long chain n-3 and n-6 FA in the kidney and *infraspinatus* muscle was similar between diets. In the liver, the proportion of C20:5n-3 increased as the level of oil blend increased in diet. This could be due to the increase in the proportion of C18:3n-3. The C18:3n-3 is the precursor of the long chain n-3 PUFA (Bessa et al. 2007; Kim et al. 2007). Similarly, dietary C18:3n-3 enhanced the proportion of long chain n-3 FA in cattle (Herdmann et al. 2010), lambs (Demirel et al. 2004) and goats (Ebrahimi et al. 2014). Similar findings were observed in lambs fed blend of linseed oil and soybean oil (Bessa et al. 2007) and blend of linseed oil and sunflower oil (Jerónimo et al. 2009).

Regardless of tissue, dietary oil blend had no effect on the total fatty acid, total saturated, monounsaturated and polyunsaturated fatty acids. The similarity in total lipid could be due to the similar metabolizable energy of the diets (Table 1) and the homogenous feed intake and growth performance observed during the feeding trial (Adeyemi et al. 2015c). Intramuscular fats can increase when feed energy are supplied in excess of the basal requirement for muscle deposition (Wood et al. 2008). Glucose has been identified as the major substrate for *de novo* fatty acid synthesis in intramuscular adipocytes and other adipose tissues (Smith & Crouse 1984). Diets capable of enhancing glucose supply to the muscle can increase the deposition of intramuscular fat (Pethick et al. 2004; Smith et al. 2009). Alteration of rumen fermentation to produce propionate (gluconeogenic precursor) could increase the supply of glucose to the muscle (Pethick et al. 2004). The oil blend used in the current study had no effect on the *in vitro* (Adeyemi et al. 2015a) and *in vivo* (Adeyemi et al. 2015c) ruminal concentration of propionate and this could be responsible for the similarity in the intramuscular fat across the treatments. The current finding is similar to the insignificant deposition of intramuscular fat observed when castor oil (Maia et al. 2012) and sunflower oil (Marinova et al. 2001) were supplemented in goats' diets.

The cholesterol content of *infraspinatus* muscle, liver and kidney was similar across dietary treatments. This finding is consistent with that of Oliveira et al. (2012) who observed that dietary oils had no effect on the cholesterol content of *longissimus dorsi* muscle of young Nellore steers. The muscle cholesterol content in *infraspinatus* muscle is comparable with the values (42.2–71.4 mg/100 g) reported by Beserra et al. (2004) in Moxotó goats and their crosses slaughtered at 8–10 months which coincides with the age at which animals in the current study were slaughtered. Similarly, Park et al. (1991) reported a mean cholesterol content of 57.8, 69.5, 214 and 276 mg/100 g in *longissimus dorsi*, *biceps femoris*, liver and kidney, respectively, in Alpine and Nubian goats.

Antioxidants and lipid oxidation

The effects of dietary oil blend and postmortem storage on lipid oxidation, contents of antioxidant compounds and activity of antioxidant enzymes in *infraspinatus* muscle, liver and kidney of goats are shown in Table 5. Neither diet nor postmortem storage influenced ($p > 0.05$) catalase and superoxide dismutase activities in all tissues. Dietary oil blend did not affect glutathione peroxidase activity and the concentration of γ and δ-tocopherol but increased the concentration of total carotenoids and α-tocopherol in the tissues. Diet did not affect ($p > 0.05$) the thiobarbituric acid reactive substance (TBARS) values of the tissues. The total carotenoids, tocopherol and glutathione peroxidase activity in the tissues decreased ($p < 0.05$) as chill storage continued. The TBARS value of the tissues increased ($p < 0.05$) with increasing postmortem storage. The TBARS values observed on day 7 postmortem were higher ($p < 0.05$) compared with those observed on days 0 and 4 in the tissues. There was no significant difference ($p > 0.05$) between the TBARS values observed on 0 and 4 d postmortem in the tissues.

The antioxidant status of the diet consumed by animals plays a vital role in the postmortem oxidative potential of the muscle (Ponnampalam et al. 2014). The non-significant difference in the TBARS value of *infraspinatus* muscle, kidney and liver across the treatments indicates that in spite of the higher amount of n-3 PUFA in the tissues of oil-fed goats, oxidative stability was not compromised. This could be attributed to the increase ($p < 0.05$) in the concentration of total carotenoids and α-tocopherol in tissues of goats fed diet supplemented with oil blend relative to those fed the control diet. The increase in the concentration of total carotenoids and

Table 5. Effect of diet and postmortem storage on antioxidant status and lipid oxidation in tissues of goats.

		Levels of oil blend (%)				Postmortem storage (d)				*p* value		
Parameter	Tissue	0	4	8	SEM	0	4	7	SEM	Diet (D)	Storage (S)	D × S
Total carotenoids, mg/Kg	*Infraspinatus*	0.13^{b}	0.18^{ab}	0.23^{a}	0.04	0.27^{a}	0.13^{b}	0.12^{b}	0.04	0.024	0.046	0.432
	Liver	0.37^{b}	0.45^{ab}	0.52^{a}	0.05	0.55^{a}	0.51^{a}	0.27^{b}	0.06	0.034	0.001	0.705
	Kidney	0.42^{b}	0.53^{a}	0.57^{a}	0.48	0.59^{a}	0.53^{ab}	0.40^{b}	0.05	0.022	0.020	0.786
α-Tocopherol, mg/kg	*Infraspinatus*	2.98^{b}	3.80^{a}	4.02^{a}	0.36	4.55^{a}	3.92^{ab}	2.83^{b}	0.34	0.022	0.001	0.105
	Liver	29.88^{b}	38.00^{ab}	44.66^{a}	3.47	45.00^{a}	39.22^{ab}	28.33^{b}	3.26	0.021	0.001	0.116
	Kidney	12.92^{c}	15.15^{b}	17.65^{a}	0.93	16.92^{a}	14.55^{b}	14.25^{b}	1.07	0.005	0.061	0.557
γ-Tocopherol, mg/kg	*Infraspinatus*	0.66	0.74	0.78	0.05	0.77^{a}	0.73^{b}	0.68^{c}	0.05	0.329	0.004	0.110
	Liver	6.76	7.53	8.00	0.54	7.87^{a}	7.4^{ab}	7.03^{b}	0.55	0.282	0.032	0.116
	Kidney	1.48	1.66	1.74	0.08	1.68^{a}	1.67^{a}	1.53^{b}	0.08	0.364	0.037	0.580
δ-Tocopherol, mg/kg	*Infraspinatus*	0.06	0.07	0.07	0.007	0.08^{a}	0.07^{a}	0.04^{b}	0.005	0.428	0.001	0.216
	Liver	0.60	0.65	0.72	0.07	0.81^{a}	0.71^{a}	0.45^{b}	0.05	0.470	0.003	0.341
	Kidney	0.12	0.12	0.14	0.01	0.16^{a}	0.13^{a}	0.07^{b}	0.01	0.537	<0.001	0.856
Glutathione peroxidase[1]	*Infraspinatus*	67.52	64.90	60.69	7.22	71.337^{a}	55.878^{b}	45.891^{b}	7.04	0.282	0.012	0.134
	Liver	139.03	134.80	124.63	15.06	145.93^{a}	111.76^{ab}	91.78^{b}	14.52	0.195	0.005	0.074
	Kidney	81.02	74.78	70.88	9.03	87.06^{a}	67.56^{a}	55.07^{b}	8.71	0.165	0.044	0.063
Catalase[2]	*Infraspinatus*	1624.3	1721.2	1623.9	39.50	1733.2	1834.3	1691.3	41.55	0.321	0.101	0.743
	Liver	3261.3	3091.4	3100.2	43.30	3203.2	2956.7	3311.7	52.15	0.242	0.563	0.320
	Kidney	2745.4	2822.4	3001.2	44.79	2951.8	3201.4	2856.2	45.80	0.342	0.876	0.561
Superoxide dismutase[3]	*Infraspinatus*	2.30	2.37	2.34	0.13	2.78	2.59	2.75	0.17	0.231	0.211	0.113
	Liver	4.32	4.11	4.19	0.34	4.76	5.01	5.22	0.40	0.684	0.391	0.971
	Kidney	3.92	3.90	3.88	0.30	3.78	3.87	3.92	0.33	0.361	0.222	0.563
TBARS, mg MDA/kg	*Infraspinatus*	0.32	0.27	0.25	0.06	0.16^{b}	0.28^{b}	0.41^{a}	0.05	0.717	0.010	0.099
	Liver	2.17	1.73	1.02	1.04	0.30^{b}	0.38^{b}	2.23^{a}	0.90	0.7393	0.005	0.801
	Kidney	2.82	2.68	1.51	0.86	0.62^{b}	0.69^{b}	2.71^{a}	0.51	0.5059	<.0001	<.0001

a, b, c means having different superscript along the same row for each factor are significantly different ($p < 0.05$). [1]Glutathione peroxidase activity is expressed as nmoles NADPH oxidized/min/mg protein. [2]One unit corresponds to the amount of enzyme needed to inhibit 50% dismutation of the superoxide radical. [3]Catalase activity is expressed as nmol.H_2O_2/min/mg protein. D: diet; S: storage; D × S: interaction between diet and storage; SEM: standard error of mean.

α-tocopherol in the tissues mirrored the carotenoid and tocopherol contents of the diets (Table 1). Both carotenoid (precussor of vitamin A) and tocopherol are fat soluble. Thus, the increase in fat content of the diet as dietary oil blend increased could have aided the absorption and deposition of these antioxidants in the tissue of goats. Similar findings were reported by Soler-Velasquez et al. (1998) who observed an increase in the α-tocopherol content in the liver and *gluteus medius* muscle of pig fed 5 and 10% canola oil compared with those fed the control diet.

The similarity in the antioxidant enzyme activities in the tissues across dietary treatments lends support to the similarity in the TBARS values. Increase in the activities of antioxidant enzymes may be related to feedback mechanism in response to lipid oxidation (Venkatraman & Pinnavaia 1998). Earlier studies have reported significant increase in postmortem catalase (Lemaitre et al. 1997; Venkatraman & Pinnavaia 1998), glutathione peroxidase (Luostarinen et al. 1997; Venkatraman & Pinnavaia 1998) and superoxide dismutase (Renerre et al. 1996) activities in response to oxidative stress caused by dietary supplementation of unsaturated fats. Thus, the higher tocopherol and carotenoid contents in the tissues of goats fed oil blend which prevented lipid oxidation in spite of the increase in total n-3 FA might be responsible for the similarity in the antioxidant enzyme activities across the dietary treatments.

The response of antioxidant enzymes to postmortem chill storage of meat has yielded inconsistent results in the literature (Renerre et al. 1996; Renerre et al. 1999; Adeyemi et al. 2015b). In the current study, irrespective of tissue, the superoxide dismutase and catalase activities were stable while the glutathione peroxidase activity decreased ($p < 0.05$) over storage. Renerre et al. (1999) observed a decrease in glutathione peroxidase activity over a 9-d postmortem storage in turkey fed different oils. However, Renerre et al. (1996) observed a non-significant decrease in catalase and glutathione peroxidase activities and a significant decrease in superoxide dismutase activity in different bovine muscles chilled for 8 d. In contrast, catalase, superoxide dismutase and glutathione peroxidase activities were stable during an 8 d ageing of semimembranosus muscle in goats (Adeyemi et al. 2015b).

The increase ($p < 0.05$) in TBARS value and the decrease in tocopherol, carotenoid and glutathione peroxidase activity ($p < 0.05$) as postmortem storage progressed reflect the breakdown of antioxidant defence system in the tissues. The increase in TBARS during refrigerated storage is consistent with the report in broiler meat (Adeyemi & Olorunsanya 2012), chevon (Sabow et al. 2015; Sabow et al. 2016) and beef (Renerre et al. 1996). The decrease in the concentration of tocopherol is in tandem with the report of Irie et al. (1998) who observed a reduction in the concentration of α-tocopherol in Japanese beef as

postmortem storage continued. Similarly, the tocopherol and carotenoid contents decreased over an 8-d chill storage of semimembranosus muscle in goats (Adeyemi et al. 2015b).

Regardless of diet, tissue and postmortem storage, the TBARS value observed on 0 and 4 d postmortem was less than 0.6 mg/kg needed to bring about an objectionable flavour associated with lipid oxidation (Greene & Cumuze 1982). However, there was about five-fold increase in TBARS value of liver and kidney on day 7 postmortem. The implication of this finding is that liver and kidney should not be stored beyond 4 d at 4 °C.

Conclusions

The current study demonstrates that dietary supplementation of blend of 20% palm oil and 80% canola oil beneficially altered the lipid profile and antioxidant status of *infraspinatus* muscle, liver and kidney from goats. The oxidative stability of *infraspinatus* muscle could be maintained for 7 d while that of the liver and kidney could only be maintained for 4 d at chill storage. Further study to determine the effect of dietary blend of 20% palm oil and 80% canola oil on meat quality and fatty acid composition of other muscles is suggested. Also, further research is suggested to establish the mechanism(s) by which dietary α-tocopherol influences biohydrogenation pathways from PUFA to *trans* C18:1 isomers.

Disclosure statement

The authors report that they have no conflicts of interest.

References

Adeyemi KD, Ebrahimi M, Samsudin AA, Alimon AR, Karim R, Karsani SA, Sazili AQ. 2015a. Influence of Carotino oil on *in vitro* rumen fermentation, metabolism and apparent biohydrogenation of fatty acids. Anim Sci J. 86:270–278.

Adeyemi KD, Olorunsanya AO. 2012. Comparative analysis of phenolic composition and antioxidant effect of four Cowpea (*Vignna unguiculata*) varieties on broiler meat. Iranian J Appl Anim Sci. 2:343–349.

Adeyemi KD, Olorunsanya AO, Abe O. 2013. Varietal effect of citrus seed extract on lipid oxidation of broiler meat. Iranian J Appl Anim Sci. 3:195–199.

Adeyemi KD, Sabow AB, Aghwan ZA, Ebrahimi M, Samsudin AA, Alimon AR, Sazili AQ. 2016. Serum fatty acids, biochemical indices and antioxidant status in goats fed canola oil and palm oil blend. J Anim Sci Technol. 58:6.

Adeyemi KD, Sabow AB, Shittu RM, Karim R, Karsani SA, Sazili AQ. 2015b. Impact of chill storage on antioxidant status, lipid and protein oxidation, color, drip loss and fatty acids of semimembranosus muscle in goats. CyTA J Food. [Epub ahead of print]. doi: 10.1080/19476337.2015.1114974.

Adeyemi KD, Sazili AQ, Ebrahimi M, Samsudin AA, Alimon AR, Karim R, Karsani SA, Sabow AB. 2015c. Effects of blend of canola oil and palm oil on nutrient intake and digestibility, growth performance, rumen fermentation and fatty acids in goats. Anim Sci J. [Epub ahead of print]. doi: 10.1111/asj.12549.

AOAC. 1990. Official methods of analysis, 15th ed. Arlington, VA: Association of Official Analytical Chemists. p. 931–932.

Atawodi SE, Yusufu L, Atawodi JC, Asuku O, Yakubu OE. 2011. Phenolic compounds and antioxidant potential of Nigerian red palm oil (*Elaeis guineensis*). Int J Biol. 3:153–161.

Beserra F, Madruga M, Leite A, Da Silva E, Maia E. 2004. Effect of age at slaughter on chemical composition of meat from moxotó goats and their crosses. Small Rum Res. 55:177–181.

Bessa RJ, Alves SP, Jerónimo E, Alfaia CM, Prates JA, Santos-Silva J. 2007. Effect of lipid supplements on ruminal biohydrogenation intermediates and muscle fatty acids in lambs. Eur J Lipid Sci Technol. 109:868–878.

Bessa RJB, Portugal PV, Mendes IA, Santos-Silva J. 2005. Effect of lipid supplementation on growth performance, carcass and meat quality and fatty acid composition of intramuscular lipids of lambs fed dehydrated lucerne or concentrate. Livest Prod Sci. 96:185–194.

Boles JA, Kott RW, Hatfield PG, Bergman JW, Flynn CR. 2005. Supplemental safflower oil affects the fatty acid profile, including conjugated linoleic acid, of lamb. J Anim Sci. 83:2175–2181.

Chelikani PK, Bell JA, Kennelly JJ. 2004. Effects of feeding or abomasal infusion of canola oil in Holstein cows 1. Nutrient digestion and milk composition. J Dairy Res. 71:279–287.

Cross AJ, Leitzmann MF, Gail MH, Hollenbeck AR, Schatzkin A, Sinha RA. 2013. Prospective study of red and processed meat intake in relation to cancer risk. PLoS Med. 4:1973–1984.

Demirel G, Wachira A, Sinclair L, Wilkinson R, Wood J, Enser M. 2004. Effects of dietary n-3 polyunsaturated fatty acids, breed and dietary vitamin E on the fatty acids of lamb muscle, liver and adipose tissue. Br J Nutr. 91:551–565.

Dupont J, White PJ, Johnston KM, Heggtveit HA, McDonald BE, Grundy SM, Bonanome A. 1989. Food safety and health effects of canola oil. J Am Coll Nutr. 8:360–375.

Ebrahimi M, Rajion MA, Goh YM. 2014. Effects of oils rich in linoleic and α-linolenic acids on fatty acid profile and gene expression in goat meat. Nutrients. 6:3913–3928.

Folch, J., Lees, M., Sloane-Stanley, G.A. 1957. Simple method for the isolation and purification of total lipids from animal tissues. J Biol Chem. 226:497–509.

Greene B, Cumuze T. 1982. Relationship between TBA numbers and inexperienced panelists' assessments of oxidized flavor in cooked beef. J Food Sci. 47:52–54.

Härtig C, Loffhagen N, Harms H. 2005. Formation of trans fatty acids is not involved in growth-linked membrane adaptation of *Pseudomonas putida*. Appl Environ Microbiol. 71:1915–1922.

Herdmann A, Martin J, Nuernberg G, Dannenberger D, Nuernberg K. 2010. Effect of dietary n-3 and n-6 PUFA on lipid composition of different tissues of German Holstein

bulls and the fate of bioactive fatty acids during processing. J Agr Food Chem. 58:8314–8321.
Howes NL, Bekhit AEA, Burritt DJ, Campbell AW. 2015. Opportunities and implications of pasture-based lamb fattening to enhance the long-chain fatty acid composition in meat. Comp Rev Food Sci: Food Safety. 14:22–36.
Hughes PE, Tove SB. 1980. Identification of an endogenous electron donor for biohydrogenation as alpha-tocopherolquinol. J Biol Chem. 255:4447–4452.
Irie M, Fujita K, Sudou K. 1998. Changes in α-tocopherol concentrations in plasma and tissues from Japanese Beef cattle fed by two methods of Vitamin E supplementation. Asian-Austral J Anim Sci. 12:810–814.
Jerónimo E, Alves SP, Prates JAM, Santos-Silva J, Bessa RJB. 2009. Effect of dietary replacement of sunflower oil with linseed oil on intramuscular fatty acids of lamb meat. Meat Sci. 83:499–505.
Kamal-Eldin A, Frank J, Razdan A, Tengblad S, Basu S, Vessby B. 2000. Effects of dietary phenolic compounds on tocopherol, cholesterol, and fatty acids in rats. Lipids. 35:427–435.
Kang K, Cherian G, Sim J. 2001. Dietary palm oil alters the lipid stability of polyunsaturated fatty acid-modified poultry products. Poult Sci. 80:228–234.
Karami M, Ponnampalam E, Hopkins D. 2013. The effect of palm oil or canola oil on feedlot performance, plasma and tissue fatty acid profile and meat quality in goats. Meat Sci. 94:165–169.
Kim SC, Adesogan AT, Badinga L, Staples CR. 2007. Effects of dietary n-6:n-3 fatty acid ratio on feed intake, digestibility, and fatty acid profiles of the ruminal contents, liver, and muscle of growing lambs. J Anim Sci. 85:706–716.
Lemaitre D, Véricel E, Polette A, Lagarde M. 1997. Effects of fatty acids on human platelet glutathione peroxidase: possible role of oxidative stress. Biochem Pharm. 53:479–486.
Lin L, Allemekinders H, Dansby A, Campbell L, Durance-Tod S, Berger A, Jones PJH. 2013. Evidence of health benefits of canola oil. Nutr Rev. 71:370–385.
Loor J, Herbein J, Jenkins T. 2002. Nutrient digestion, biohydrogenation, and fatty acid profiles in blood plasma and milk fat from lactating Holstein cows fed canola oil or canolamide. Anim Feed Sci Technol. 97:65–82.
Luostarinen R, Wallin R, Saldeen T. 1997. Dietary (n-3) fatty acids increase superoxide dismutase activity and decrease thromboxane production in the rat heart. Nutr Res. 17:163–175.
Maia MDO, Susin I, Pires AV, Gentil RS, Ferreira EM, Mendes CQ, Alencar SMD. 2012. Growth, carcass characteristics, chemical composition and fatty acid profile of the *longissimus dorsi* muscle in goat kids fed diets with castor oil. R Bras Zootec. 41:2343–2349.
Mapiye C, Dugan MER, Juárez M, Basarab JA, Baron VS, Turner T, Yang X, Aldai N, Aalhus JL. 2012. Influence of α-tocopherol supplementation on trans-18: 1 and conjugated linoleic acid profiles in beef from steers fed a barley-based diet. Animal. 6:1888–1896.
Marinova P, Banskalieva V, Alexandrov S, Tzvetkova V, Stanchev H. 2001. Carcass composition and meat quality of kids fed sunflower oil supplemented diet. Small Rum Res. 42:217–225.
Martin SA, Jenkins TC. 2002. Factors affecting conjugated linoleic acid and trans-C18:1 fatty acid production by mixed ruminal bacteria. J Anim Sci. 80:3347–3352.
Nantapo CW, Muchenje V, Nkukwana TT, Hugo A, Descalzo A, Grigioni G, Hoffman LC. 2015. Socio-economic dynamics and innovative technologies affecting health-related lipid content in diets: implications on global food and nutrition security. Food Res Int. 76:896–905.
Nute G, Richardson R, Wood J, Hughes S, Wilkinson R, Cooper S, Sinclair L. 2007. Effect of dietary oil source on the flavour and the colour and lipid stability of lamb meat. Meat Sci. 77:547–555.
Oguntibeju O, Esterhuyse A, Truter E. 2009. Red palm oil: nutritional, physiological and therapeutic roles in improving human wellbeing and quality of life. Br J Biomed Sci. 66:216–222.
Okonkwo J. 2009. Effects of breed and storage duration on the beta-carotene content of egg yolk. Pakistan J Nutr. 8:1629–1630.
Oliveira E, Sampaio A, Henrique W, Pivaro T, Rosa B, Fernandes A, Andrade A. 2012. Quality traits and lipid composition of meat from Nellore young bulls fed with different oils either protected or unprotected from rumen degradation. Meat Sci. 90:28–35.
Olorunsanya AO, Adeyemi KD, Babatunde IA. 2011. Effect of Bamboo (*Bambusa valgaris*) and Elephant grass (*Pennisetum purpureum*) leaf extracts on oxidative stability of cooked and raw broiler meat. J Agr Res Dev. 10:1–10.
Pan A, Sun Q, Bernstein AM, Schulze MB, Manson JE, Stampfer MJ, Willet WC, Hu FB. 2012. Red meat consumption and mortality: results from 2 prospective cohort studies. Arch Intern Med. 172:555–563.
Park YW, Kouassi MA, Chin KB. 1991. Moisture, total fat and cholesterol in goat organ and muscle meat. J Food Sci. 56:1191–1193.
Pegg RB, Amarowicz R. 2009. Content of tocopherol isomers in oilseed radish cultivars – a short report. Polish J Food Nutr Sci. 59:129–133.
Pethick DW, Harper GS, Oddy VH. 2004. Growth, development and nutritional manipulation of marbling in cattle: a review. Anim Prod Sci. 44:705–715.
Ponnampalam EN, Norng S, Burnett VF, Dunshea FR, Jacobs JL, Hopkins DL. 2014. The synergism of biochemical components controlling lipid oxidation in lamb muscle. Lipids. 49:757–766.
Pottier J, Focant M, Debier C, De Buysser G, Goffe C, Mignolet E, Froidmont E, Larondelle Y. 2006. Effect of dietary vitamin E on rumen biohydrogenation pathways and milk fat depression in dairy cows fed high-fat diets. J Dairy Sci. 89:685–692
Rajion M, McLean J, Cahill RN. 1985. Essential fatty acids in the fetal and newborn lamb. Aust J Biol Sci. 38:33–40.
Renerre M, Dumont F, Gatellier P. 1996. Antioxidant enzyme activities in beef in relation to oxidation of lipid and myoglobin. Meat Sci. 43:111–121.
Renerre M, Poncet K, Mercier Y, Gatellier P, Métro B. 1999. Influence of dietary fat and vitamin E on antioxidant status of muscles of turkey. J Agric Food Chem. 47:237–244.
Rudel L, Morris M. 1973. Determination of cholesterol using o-phthalaldehyde. J Lipid Res. 14:364–366.
Sabow AB, Sazili AQ, Zulkifli I, Goh YM, Ab Kadir MZA, Abdulla NR, Nakyinsige K, Kaka U, Adeyemi KD. 2015. A comparison of bleeding efficiency, microbiological quality and lipid oxidation in goats subjected to conscious halal

slaughter and slaughter following minimal anesthesia. Meat Sci. 104:78–84.

Sabow AB, Sazili AQ, Zulkifli I, Goh YM, Ab Kadir MZA, Aghwan AA, Nakyinsige K, Kaka U, Adeyemi KD. 2016. Changes of microbial spoilage, lipid-protein oxidation and physicochemical properties during postmortem refrigerated storage of goat meat. Anim Sci J. [Epub ahead of print]. doi: 10.1111/asj.12496.

SAS. 2003. Statistical analytical system. SAS version 9.1.

Shahidi F, Zhong Y. 2010. Novel antioxidants in food quality preservation and health promotion. Eur J Lipid Sci Technol. 112:930–940.

Siew W, Ng W. 2000. Differential scanning thermograms of palm oil triglycerides in the presence of diglycerides. J Oil Palm Res. 12:1–7.

Smith SB, Crouse J. 1984. Relative contributions of acetate, lactate, and glucose to lipogenesis in bovine intramuscular and subcutaneous adipose tissue. J Nutr. 114:792–800.

Smith S, Kawachi H, Choi C, Choi C, Wu G, Sawyer J. 2009. Cellular regulation of bovine intramuscular adipose tissue development and composition. J Anim Sci. 87:72–82.

Sola-Ojo FE, Adeyemi KD, Toye AA, Bolu SA, Fayeye TR, Annongu AA, Garba SO, Karim OR. 2013. Performance, carcass profile and oxidative stability of broiler chickens fed processed baobab seed meal. Bull Environ Pharmacol Life Sci. 2:94–99.

Soler-Velasquez MP, Brendemuhl JH, McDowell LR, Sheppard KA, Johnson DD, Williams SN. 1998. Effects of supplemental vitamin E and canola oil on tissue tocopherol and liver fatty acid profile of finishing swine. J Anim Sci. 76:110–117.

Van Soest PJ, Robertson J, Lewis B. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J Dairy Sci. 74:3583–3597.

Venkatraman JT, Pinnavaia L. 1998. Effects of saturated, n-6 and n-3 lipids on activities of enzymes involved in antioxidant defense in normal rats. Nutr Res. 18:341–350.

Vlaeminck B, Fievez V, Cabrita A, Fonseca A, Dewhurst R. 2006. Factors affecting odd-and branched-chain fatty acids in milk: a review. Anim Feed Sci Technol. 131:389–417

Wood J, Enser M, Fisher A, Nute G, Sheard P, Richardson R, Whittington F. 2008. Fat deposition, fatty acid composition and meat quality: a review. Meat Sci. 78:343–358.