Effects of palm oil supplementation and fibrolytic enzymes in high forage diets on growth, carcass characteristics and fatty acid profiles of lambs

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Highlights

•Dietary supplementation of palm oil improved carcass and meat quality of lambs.
•Enzyme treatment of forage diets had minimal effects on meat quality traits.
•Palm oil and enzymes can be used in lamb's diets without compromising meat quality.

Abstract

This study investigated the effects of palm oil and fibrolytic enzyme supplementation in high forage diets on growth, carcass characteristics and fatty acid composition of lambs. Forty South African Mutton Merino ram lambs were randomly assigned to four treatment groups (n = 10 lambs/ treatment) and fed a basal total mixed ration (TMR). The treatments were: TMR diet with Megalac as bypass oil (control); TMR diet supplemented with 3% palm oil; TMR diet with cellulase and xylanase enzymes and TMR diet supplemented with 3% palm oil and cellulase and xylanase enzymes. The lambs were slaughtered at a target weight of about 42 kg. Palm oil supplementation resulted in a longer feeding period ($P < 0.05$) and lower dressing percentage ($P < 0.01$), but the carcasses had higher meat yield ($P < 0.01$) and lower fat content ($P < 0.05$) compared to the other treatment groups. Additionally, palm oil supplementation increased the proportion of C18:0 ($P < 0.05$) while decreasing ($P < 0.05$) the proportion of C14:0 ($P < 0.05$) and C16:0 ($P < 0.05$) in fat depots, which may be beneficial for human health. The fibrolytic enzyme treatment had minimal effects on growth, carcass characteristics, meat quality and fatty acid composition of lambs. The interaction effect of palm oil and fibrolytic enzymes had positive effects on the UFA: SFA ratio due to an increase ($P < 0.05$) in C20:3n6 and C20:4n6 and a reduction ($P < 0.05$) in saturated fatty acids. The results suggest that methane mitigation strategies through palm oil and enzyme supplementation can be used in lamb diets without adverse effects on product quality.

Keywords

Methane mitigation
Lamb
Meat quality
Fatty acids
Palm oil
Fibrolytic enzymes

1. Introduction

The livestock sector contributes to greenhouse gas emissions such as carbon dioxide and methane. In South Africa, the annual methane emission from the livestock sector accounts for 65% of total agricultural greenhouse gas (Meissner et al., 2013). Ruminant animals are the main emitters, with beef cattle, sheep, dairy cows and goats responsible for about 71%, 18%, 7% and 3%, respectively, of total livestock methane production (Moeletsi et al., 2017). It is estimated that 95% of livestock methane emission comes from rumen fermentation during the digestion of feed (Meissner et al., 2013). In addition to greenhouse gas emission, the production of rumen methane is associated with a gross energy loss of 2–12% (Johnson and Johnson, 1995). The production of excess rumen methane not only affects the environment but reduces feed conversion efficiency and consequently lowers animal productivity.

The production of methane in the rumen mainly depends on animal characteristics, the level of feed intake, diet composition as well the digestibility and quality of feed (Scholtz et al., 2012). In South Africa, ruminant animals are kept predominantly on grazing pasture and supplementary feed or fattening rations usually consist of hay, cereals and agro-industrial by-products. The problem is that animals on such high fibre diets produce more methane per unit than those consuming high-quality diets (Popova et al., 2011). High quality forages have lower fibre and higher soluble carbohydrates (more digestible) and these include C3 grasses, less mature pastures, grains and forage legumes (Thompson & Rowntree, 2020). It is therefore, a priority to develop cost effective strategies of reducing methane production and improving the productivity of livestock on high forage diets.

Inclusion of plant oils and fibrolytic enzymes in ruminant diets are potential strategies for improving the quality of feed and animal productivity, while reducing rumen methane production (Beauchemin et al., 2008). Supplementing ruminant diets with plant oils decrease methane production through inhibition of methanogens and protozoa, increased production of propionic acid and biohydrogenation of unsaturated fatty acids (Mao et al., 2010). On the other hand, the addition of fibrolytic enzymes to ruminant diets can improve fibre degradability leading to a decrease in acetate to propionate ratio, which is believed to be the mechanism by which methane production is reduced (Beauchemin et al., 2008).

Dietary supplementation of plant oils and fibrolytic enzymes are promising strategies for mitigating rumen methane production. However, information on the effect of such technologies including the potential adverse effects on product composition and quality is still limited. This study aimed at investigating the effects of methane mitigating on carcass and meat quality of lambs.

2. Materials and methods

2.1. Animals and treatment

This project was approved by the Animal Ethics Committee of the University of Pretoria (ref no. EC084–14). Forty 3-month old South African Mutton Merino (SAMM) ram lambs were included in this study. The lambs were selected from a farm in the Free State province and they were reared on veld and supplemented with creep feed until they were transported to the Hatfield experimental farm of the University of Pretoria where the trial was conducted. The average body weight at the beginning of the experiment was around 18 kg.

The lambs were blocked according to initial body weight and randomly allocated to four dietary treatment groups. Two lambs from each block were kept in a pen that was randomly allotted to one of the four treatments, with five pens of two lambs per treatment and a total of ten lambs per treatment. A high-forage based total mixed ration (TMR) was formulated to meet the growth and maintenance requirements of the lambs. The formulation and chemical composition of the TMR are presented in Table 1. The TMR was used as a basis to formulate four different treatment groups as follows:

- TMR with bypass oil (Megalac): (Control treatment)
- TMR plus 3% palm oil: (Oil treatment)
- TMR plus 10 µl enzyme per 0.5 g feed (combination of cellulose and xylanase in a ratio of 1:1): (Enzyme treatment)
- TMR plus 3% palm oil and 10 µl enzyme per 0.5 g feed (combination cellulose and xylanase in a ratio of 1:1): (Oil and enzyme treatment)

Table 1. Composition of the total mixed ration.

Material	**Composition (%)**
Maize meal	8
Maize bran	5
Eragrostis curvula hay	30
Soyabean oil cake	13
Feed lime	0.2
Mineral premix	0.2
Lucerne hay	20
Hominy chop	10
Sunflower	12.8
MCP	0.8
Parameter	*Composition*
Dry matter (%)	88.7
Ash (%)	6.9
Crude protein (%)	13.3
Fat (%)	5.8
Starch (g/kg)	236.1
NDF (g/kg)	308.6
ME (MJ/kg DM)	10.1
Ca (%)	0.9
P (%)	0.3

After an adaptation period of 10 days to the experimental conditions, the lambs from all treatment groups were fed *ad libitum*. The quantities offered and refused were recorded. Clean water was available at all times. The lambs were weighed weekly just before feeding.

2.2. Slaughter and sampling procedures

The lambs were slaughtered after a feeding period of approximately 120 days. A day before slaughter, the lambs were weighed to obtain live weight at slaughter and transported over 26 km to the abattoir of the Agricultural Research Council, Irene, South Africa. The lambs were slaughtered and dressed according to standard abattoir procedures. Carcasses were immediately weighed to obtain hot carcass weight and then chilled at 4 °C for 24 h. Carcasses

were re-weighed to obtain cold carcass weight and classified using the South African Carcass Classification System for beef, sheep and goat carcasses.

Carcass temperature and pH were recorded at about 25 mm from the medial line at a point over the 13th rib at 45 min and 24 h post mortem using a portable pH metre (Orion meat probe). Subcutaneous adipose tissue samples of about 5 g were collected from the left side of each carcasses at a point above the 8–9th rib, 25 mm from the midline and stored in polythene bags at − 20 °C for fatty acid analysis (Webb et al., 1994). Carcass composition was determined by dissection the tissues in rib cut-samples from the 8, 9 and 10th Lumbar vertebrae using the method described by (Casey et al., 1988). Briefly, the rib cut-samples (ribs 8–9–10) were cut from the left side of each carcass, the ventral extremity of the sample being on a line draw from the pubic symphysis to the middle of the first rib, to obtain an estimate of total carcass composition (Casey et al., 1988). Meat colour was estimated using coded colour palettes of white and yellow at the level of the 13th dorsal vertebra.

2.3. Fatty acid analysis

The lipid extraction procedure and determination of fatty acid methyl esters were described by Webb and Casey (1995).

2.4. Statistical analysis

The statistical model included the block effect and treatment effect which was further partitioned into effects of palm oil and enzyme inclusion and interaction between palm oil and enzyme inclusion. Data was analysed as a factorial treatment in a randomised complete block design. Statistical analysis was performed using the General Linear Model (GLM) ANCOVA procedure in SPSS version 23, with total feed intake as a covariate (SPSS, 2015). The results are presented as LS means ± standard error. Differences were considered significant at $P < 0.05$ and a tendency for significance at $0.05 < P < 0.10$.

3. Results

3.1. Growth and carcass characteristics

Results of growth and carcass characteristics of the ram lambs fed the different diets supplemented with palm oil and/or fibrolytic enzymes are presented in Table 2.

Table 2. Effects of palm oil inclusion and fibrolytic enzyme treatment of forage diets on growth and carcass characteristics (LS Means ± SE) of South African Mutton Merino lambs.

	Treatment				*P*-values		
	Control	Oil	Enzyme	Oil + Enzyme	[a]O	[b]E	[c]O*E
Days on Feed	94.2 ± 2.37	101 ± 3.06	93.2 ± 2.31	103 ± 2.78	< 0.01	0.94	0.69
ADG (g)	270 ± 9.49	250 ± 12.7	270 ± 9.49	240 ± 9.49	0.05	0.49	0.40
Slaughter Weight (kg)	42.8 ± 0.64	43.4 ± 2.77	42.7 ± 0.68	41.9 ± 0.69	0.86	0.26	0.23
HCW (kg)	19.8 ± 0.49	19.0 ± 0.51	20.0 ± 0.37	18.3 ± 0.41	< 0.01	0.64	0.27
CCW (kg)	19.2 ± 0.47	18.5 ± 0.51	19.5 ± 0.36	17.9 ± 0.41	< 0.01	0.70	0.28
Dressing %	46.1 ± 0.61	43.7 ± 0.62	46.7 ± 0.44	43.6 ± 0.52	< 0.01	0.57	0.57
Fat%	30.6 ± 0.87	27.6 ± 1.19	30.9 ± 1.84	27.9 ± 1.29	0.03	0.74	0.94
Meat%	47.0 ± 1.55	53.4 ± 0.83	48.1 ± 1.48	51.0 ± 1.39	< 0.01	0.66	0.29
Bone %	22.4 ± 1.45	19.0 ± 0.91	21.0 ± 1.17	21.1 ± 0.94	0.15	0.82	0.12

[a]O= Effect of palm oil supplementation (Oil, Oil + Enzyme *vs.* Control, Enzyme).
[b]E = Effect enzyme inclusion (Enzyme, Oil + Enzyme *vs.* Control, Oil).
[c]O*E = Interaction of palm oil and enzyme (Oil + Enzyme *vs.* Oil; Enzyme).

The lambs were slaughtered at market weight of 42.7 ± 1.20 kg after 98.0 ± 2.63 days of feeding. Lambs fed oil supplemented diets took 8 days longer ($P < 0.05$) to reach the target weight mainly because of a tendency towards lower ($P = 0.05$) average daily gain (ADG) in comparison to lambs kept on diets without oil. The average dressing percentage was 45.0 ± 1.74%. Inclusion of palm oil in lamb diets resulted in lower dressing percentage ($P < 0.01$) and subsequently smaller carcasses ($P < 0.01$) in comparison to diets without oil.

The average proportions of meat, fat and bone in lamb carcasses were 49.9 ± 1.30%, 29.3 ± 1.31% and 20.7 ± 0.91%, respectively. Carcasses of lambs fed diets supplemented with palm oil had a higher ($P < 0.001$) muscle proportion and lower ($P < 0.05$) fat percentage than carcasses of lambs on diets without oil. Bone percentage was not significantly different between dietary treatments. Inclusion of fibrolytic enzymes had no significant effect on growth and carcass characteristics considered in this study.

3.2. Meat quality characteristics

The average ultimate pH was 5.60 ± 0.04. Palm oil supplementation and enzyme treatment were not significantly different, however, there was an interaction effect ($P < 0.05$) between oil and enzyme treatment on ultimate pH. Simultaneous inclusion of oil and enzyme resulted in a higher pHu (5.62 ± 0.06) in comparison to the oil treatment (5.45 ± 0.04) and enzyme treatment (5.56 ± 0.03) groups. Meat colour scores were not significantly different between the dietary treatments.

3.3. Fatty acid composition of the subcutaneous adipose tissue

Summary statistics of the molar proportions of fatty acids in the subcutaneous adipose tissue of lambs are presented in Table 3.

Table 3. Effects of palm oil inclusion and fibrolytic enzyme treatment of forage diets on subcutaneous fatty acid profiles (w/w%; LS Means ± SE) of South African Mutton Merino lambs.

Fatty acids (w/w%)	†Diet treatment				*P*-values		
	Control	Oil	Enzyme	Oil + Enzyme	[a]O	[b]E	[c]O*E
C8:0	0.04 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.04 ± 0.01	0.29	0.47	0.17
C10:0	0.24 ± 0.01	0.24 ± 0.01	0.24 ± 0.01	0.25 ± 0.01	0.66	0.52	0.49
C12:0	0.13 ± 0.01	0.36 ± 0.24	0.12 ± 0.01	0.12 ± 0.02	0.37	0.33	0.38
C14:0	3.28 ± 0.11	3.00 ± 0.09	3.19 ± 0.09	3.06 ± 0.07	0.03	0.89	0.45
C16:0	28.2 ± 0.41	26.5 ± 0.41	28.5 ± 0.32	26.0 ± 0.31	< 0.001	0.78	0.30
C16:1	2.29 ± 0.11	2.40 ± 0.15	2.03 ± 0.09	2.41 ± 0.20	0.15	0.44	0.41
C17:0	1.61 ± 0.11	1.47 ± 0.09	1.76 ± 0.13	1.48 ± 0.06	0.049	0.41	0.49
C18:0	26.2 ± 0.79	29.4 ± 1.03	27.4 ± 0.66	27.8 ± 0.58	0.04	0.79	0.10
C18:1n9c	32.1 ± 0.77	31.6 ± 0.75	31.6 ± 0.48	33.43 ± 0.47	0.29	0.32	0.09
C18:2n6c	4.00 ± 0.19	3.19 ± 0.16	3.83 ± 0.14	3.27 ± 0.14	< 0.001	0.79	0.44
C20:3n6	0.12 ± 0.02	0.11 ± 0.03	0.06 ± 0.02	0.20 ± 0.04	0.05	0.59	0.02
C20:4n6	0.65 ± 0.07	0.55 ± 0.07	0.51 ± 0.06	0.66 ± 0.24	0.66	0.81	0.04
C22:1n9	0.21 ± 0.08	0.30 ± 0.11	0.09 ± 0.03	0.32 ± 0.10	0.08	0.62	0.43
SFA	59.7 ± 0.61	61.0 ± 1.00	61.2 ± 0.60	58.8 ± 0.80	0.49	0.64	0.03
MUFA	34.9 ± 0.74	34.6 ± 0.89	33.9 ± 0.50	36.5 ± 0.62	0.12	0.55	0.06
PUFA	5.35 ± 0.32	4.34 ± 0.25	4.86 ± 0.26	4.64 ± 0.24	0.02	0.72	0.12
UFA:SFA ratio	0.68 ± 0.02	0.64 ± 0.03	0.64 ± 0.02	0.70 ± 0.02	0.44	0.67	0.03

[a]O = Effect of palm oil supplementation (Oil, Oil + Enzyme *vs.* Control, Enzyme).
[b]E = Effect enzyme inclusion (Enzyme, Oil + Enzyme *vs.* Control, Oil).
[c]O*E = Interaction of palm oil and enzyme (Oil + Enzyme *vs.* Oil; Enzyme).

On average 60.2 ± 0.75% of the fatty acids in the subcutaneous adipose tissue of the lambs were saturated fatty acid (SFA), while monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) constituted 35.0 ± 0.69% and 4.78 ± 0.20%, respectively. Oleic acid was the most abundant fatty acid in the subcutaneous adipose tissue (av. 32.2 ± 0.62%). Oil supplementation of lamb diets resulted in lower proportions of myristic acid (C14:0; $P < 0.05$), palmitic acid (C16:0; $P < 0.001$), margaric acid (C17:0; $P < 0.05$), linoleic acid (C18:2) and total PUFA in subcutaneous adipose tissue of lambs while the proportion of stearic acid (C18:0) increased ($P < 0.05$) with oil supplementation. Fibrolytic enzyme treatment had no significant effect on the fatty acid profile of the subcutaneous adipose tissue of lambs.

Interaction effects ($P < 0.05$) between oil and enzyme treatment groups were observed on total SFA, components of MUFA and the ratio of unsaturated to saturated fatty acids (UFA: SFA). Total SFA increased with oil supplementation and enzyme treatment, but decreased with simultaneous inclusion of oil and enzyme in the diet. Total MUFA tended to be higher ($P < 0.1$) in oil and enzyme treatment group than in oil supplementation group or enzyme treatment group. This was as a result of an increase in the proportions of γ-linolenic acid (C20:3n6; $P < 0.05$) and arachidonic acid (C20:4n6; $P < 0.05$), observed with simultaneous inclusion of oil and enzyme in lamb diets. Subsequently, the UFA: SFA ratio decreased in both oil treatment and enzyme treatment but increased when oil and enzyme were simultaneously included in the diet.

3.4. Fatty acid composition of the intramuscular adipose tissue

Summary statistics of the molar proportions of fatty acids in the intramuscular fat tissue of lambs are presented in Table 4.

Table 4. Effects of palm oil inclusion and fibrolytic enzyme treatment of forage diets on intramuscular fatty acid composition (w/w%; LS Means ± SE) of South African Mutton Merino lambs.

Fatty acid (w/w%)	Diet treatment				*P*-values		
	Control	**Oil**	**Enzyme**	**Oil + Enzyme**	**[a]O**	**[b]E**	**[c]O*E**
C10.0	0.25 ± 0.05	0.16 ± 0.03	0.21 ± 0.04	0.22 ± 0.03	0.28	0.76	0.20
C12.0	0.32 ± 0.07	0.18 ± 0.04	0.22 ± 0.03	0.60 ± 0.28	0.11	0.22	0.50
C14.0	3.73 ± 0.16	3.11 ± 0.30	3.64 ± 0.20	3.18 ± 0.15	0.01	0.97	0.71
C16.0	31.2 ± 0.41	29.0 ± 0.46	30.4 ± 0.64	28.4 ± 0.48	< 0.001	0.16	0.92
C16.1	2.00 ± 0.28	1.99 ± 0.16	2.11 ± 0.18	2.29 ± 0.13	0.69	0.29	0.60
C17.0	1.40 ± 0.12	1.31 ± 0.12	1.61 ± 0.10	1.54 ± 0.08	0.45	0.045	0.95
C18.0	26.3 ± 1.09	30.2 ± 3.90	26.5 ± 1.24	30.2 ± 0.99	0.002	0.95	0.89
C18.1n9t	3.03 ± 0.30	3.02 ± 1.23	4.12 ± 0.63	2.63 ± 0.25	0.06	0.36	0.06
C18.1n9c	27.6 ± 0.43	27.7 ± 0.68	26.6 ± 0.64	27.64 ± 0.92	0.42	0.45	0.49
C18.2n6c	2.90 ± 0.15	2.14 ± 0.13	2.96 ± 0.15	2.39 ± 0.12	< 0.001	0.27	0.51
C18.3n6	0.17 ± 0.02	0.18 ± 0.02	0.18 ± 0.02	0.18 ± 0.02	0.86	0.91	0.66
C18.3n3	0.25 ± 0.02	0.18 ± 0.02	0.23 ± 0.01	0.20 ± 0.02	0.002	0.94	0.20
C20.0	0.15 ± 0.02	0.17 ± 0.02	0.14 ± 0.02	0.20 ± 0.01	0.006	0.47	0.29
C20.4n6	0.09 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	0.06	0.27	0.37
SFA	63.3 ± 0.75	64.1 ± 0.70	63.1 ± 1.30	63.9 ± 0.93	0.42	0.81	0.97
MUFA	33.2 ± 0.69	33.2 ± 0.69	33.3 ± 1.21	33.1 ± 0.94	0.92	0.95	0.92
PUFA	3.50 ± 0.14	2.57 ± 0.13	3.50 ± 0.15	2.89 ± 0.13	< 0.001	0.26	0.27
UFA:SFA ratio	0.58 ± 0.02	0.56 ± 0.02	0.59 ± 0.03	0.57 ± 0.02	0.37	0.74	0.99

[a]O= Effect of palm oil supplementation (Oil, Oil + Enzyme *vs.* Control, Enzyme).
[b]E = Effect enzyme inclusion (Enzyme, Oil + Enzyme *vs.* Control, Oil).
[c]O*E = Interaction of palm oil and enzyme (Oil + Enzyme *vs.* Oil; Enzyme).

Palmitic acid (C16:0) was the most abundant fatty acid in the intramuscular adipose tissue of lambs with an average proportion of 29.8 ± 0.50%. The proportions of SFA in the intramuscular adipose tissue were primarily influenced by oil treatment. This effect decreased the proportion of myristic acid (C14:0; $P < 0.05$), palmitic acid (C16:0; $P < 0.001$) while increasing the proportion of stearic acid (C18:0; $P < 0.01$) and eicosanoic acid (C20:0; $P < 0.01$).

Desirable fatty acids in the intramuscular adipose of lambs were also influenced by oil supplementation. This effect resulted in a decrease in the proportion of linoleic acid (C18:2; $P < 0.001$), γ-linolenic acid (C18:3n3; $P < 0.01$) and total PUFA ($P < 0.001$) in comparison to diets without oil.

The effect of enzyme inclusion was limited to margaric acid. A higher ($P < 0.05$) proportion of margaric acid was deposited in the intramuscular adipose tissue of lambs fed diets treated with enzymes compared to diets without enzymes. Overall, there were no significant

interaction effects between palm oil and fibrolytic enzyme treatments on fatty acid composition of intramuscular adipose tissue.

4. Discussion

4.1. Growth and carcass characteristics

The ADG obtained in this study, compares well with values previously reported for Merino lambs fed similar diets (Bessa et al., 2005, Manso et al., 2009, Francisco et al., 2015). Our results on growth performance agree with those of Dutta et al. (2008) who reported non-significant differences in ADG when lambs received 2.5% of supplemented palm oil. In the present study, lambs on palm oil supplemented diets took longer to reach market weight, perhaps due to decreased feed intake or lower NDF digestibility when forages are supplemented with oils (Santos-Silva et al., 2004, Bessa et al., 2005, Francisco et al., 2015). The lambs were slaughtered at live weights close to 43 kg, which is the target slaughter weight for lambs in South African feedlots (Sheridan et al.,2003).

The average dressing percentage obtained in this study was within the normal range of 44–49%, previously reported for SAMM lambs in feedlot conditions (Webb et al., 2018, Brand et al., 2017). Dressing percentage was significantly lower for oil supplemented groups, possibly due to differences in the level of fatness and mass of non-carcass components (Lough et al., 1994). However, this effect was not observed by Manso et al. (2009) when lamb diets were supplemented with 4% hydrogenated palm oil or 4% soya bean oil.

In our study, palm oil supplementation of diet resulted in lambs with lower carcass weight. However, considering the results on carcass composition, lambs fed diets supplemented with palm oil performed better, with higher meat percentage and lower fat proportion than lambs on diets without oil. These results contrast previous studies which have reported that oil supplementation of lamb diets results in greater fat deposition and decreased muscle proportion (Solomon et al., 1992, Santos-Silva et al., 2004, Bessa et al., 2005;). Factors such as forage type, nature and level of oil inclusion as well as animal characteristics may explain variation between our results and previous studies. Nevertheless, 95% of the lamb carcasses in our study were classified as A2, that is, no permanent incisors with a fat score of 2. Current market trends show that lambs in the A2 class have a better market value. Therefore, differences in carcass characteristics between dietary treatments observed in the present study might not have major economic implications.

4.2. Meat quality characteristics

Muscle pHu is known to affect key meat quality attributes such as colour, tenderness and water holding capacity (Scheffler and Gerrard, 2007). The pHu values observed in this study compare well with values previously reported for SAMM lambs and its crosses (Webb et al., 1994, Hoffman et al., 2003, Cloete et al., 2012). The differences observed in pHu are not of major concern since all pH values were within the normal range of 5.4–5.8 for acceptable meat quality (Tarrant and Sherington, 1980). This is reflected by meat colour scores which were not different across all dietary treatments. Meat colour is an important factor and it influences the acceptability of meat by consumers (Khliji et al., 2010). Our results suggest that methane mitigating strategies through supplementing lamb diets with palm oil and/or fibrolytic enzymes can be used without negative effects on the physical quality and subsequent consumer acceptability of meat.

4.3. Fatty acid composition

Fat and long chain fatty acids contribute to important aspects of meat quality and are key to the nutritional and sensory value of the meat (Webb and O'Neill, 2008). The present study investigated the effect of rumen methane mitigating strategies through palm oil supplementation and/or inclusion of fibrolytic enzymes on fatty acid composition of the subcutaneous and intramuscular adipose tissue of lambs.

Both fat depots were comprised mostly of long-chained fatty acids (twelve or more carbon atoms) which is typical of fats from animal origin (Webb et al., 1994). In accordance to data published in literature (Webb et al., 1994, Castro et al., 2005, Radunz et al., 2009), oleic acid (C18:1n9c), stearic acid (C18:0) and palmitic acid (C16:0) were the most abundant fatty acids, accounting for more than 85% of the total fatty acids. A greater proportion (more than 60%) of SFA, was deposited in both subcutaneous and intramuscular adipose tissue. These results agree with previous studies which showed higher proportions of SFA than unsaturated fatty acids (UFA) in lambs kept on high forage diets (Webb and Casey, 1995, Rowe et al., 1999; Díaz et al., 2005). According to Choi et al. (2005) forages stimulate ruminal activity and biohydrogenation of fatty acids thus increasing the proportion of SFA.55

There is public concern about overall saturated fatty acids in meat, however, stearic acid (C18:0) does not appear to affect cholesterol concentrations in human blood (Valsta et al., 2005). Only myristic acid (C14:0) and palmitic acid (C16:0) have hypercholesterolemia properties (Howes et al., 2015). In this study, palm oil supplementation increased the proportion of stearic acid while reducing the proportion of myristic acid (C14:0) and palmitic acid (C16:0) in both adipose tissue depots. A similar effect was reported by Manso et.al. (2009) with 10% soya bean oil supplementation. The increase in the proportion of stearic acid and a concomitant decrease in the proportion of myristic acid (C14:0) and palmitic acid (C16:0) suggest that supplementing diets with oil may have a positive impact on fatty acid profile of lambs in terms of human health.

Another saturated fatty acid affected by dietary treatment was margaric acid (C17:0). Oil supplementation resulted in lower proportion of margaric acid in the subcutaneous adipose tissue. On the other hand, the proportion of margaric acid increased with simultaneous inclusion of palm oil and fibrolytic enzymes in the intramuscular muscle. Margaric acid does not have a high impact on blood cholesterol levels as palmitic acid and myristic acid (Valsta et al., 2005), therefore, change in the proportion of margaric acid in meat does not cause risk to human health.

Our results on desirable fatty acids (C18:0, C18:1, C 18:2, C18:3, C20:5, C22:6) are within the range of 63–71% stated by Banskalieva, et al. (2000) for lamb and mutton. Inclusion of palm oil increased the proportion of stearic acid (C18:0), but decreased the proportion of linoleic acid (C18:2n6c) in both fat depots. Plant oils are rich in oleic acid and linoleic acid which are hydrogenated by ruminal microorganisms to stearic acid (Doreau and Ferlay, 1994). This would probably explain the increase in the proportion of stearic acid and a corresponding decrease in the proportion of linoleic acid in fat depots of lambs fed diets supplemented with palm oil.

Conjugated linoleic acid (C18:2n6c) was the main PUFA while oleic acid was the most prominent MUFA, as previously reported (Bessa et al., 2005). The proportion of oleic acid was not affected by dietary treatment, but the proportion of linoleic acid (C18:2n6c)

decreased in adipose tissue of lambs fed oil supplemented diets with subsequent effect on the proportion of PUFA. Previous studies have shown a similar effect on the proportion of linoleic acid with oil supplementation (Castro et al., 2005). This is probably because plant oils contain lower levels of linoleic acid, which cannot be synthesised *de novo* (Webb and O' Neill, 2008). This is also supported by a tendency towards lower levels of arachidonic acid (C20:4 n-6) which is formed by desaturation and elongation of linoleic acid (Webb and O' Neill, 2008). The results obtained in this study suggest that inclusion of palm oil in lamb diets may decrease the proportion of linoleic acid (C18:2n6c), which is generally regarded as beneficial for human health (Scollan et al., 2006). However, differences in the proportion of linoleic acid (C18:2n6c) and arachidonic acid (C20:4 n-6) observed between dietary treatments were so small and could be negligible.

The UFA: SFA ratio is commonly used to assess the nutritional value of fats. Nutritionists recommend UFA: SFA ratio higher than 0.4 (Scollan et al., 2006). In the present study, the UFA: SFA ratios for both fat depots were above the recommended minimum value, possibly because the lambs were slaughtered at a young age, before accumulation of fat (Cifuni et al., 1999). Palm oil supplementation and treatment of forages with fibrolytic enzymes had no influence on the UFA: SFA ratio in both the subcutaneous and intramuscular adipose tissue of lambs. However, a combination of palm oil and fibrolytic enzymes increased the UFA: SFA ratio mainly as a result of an increase in the components of UFA which included γ-linolenic acid (C20:3n6) and arachidonic acid (C20:4n6) and a decrease in total SFA. It can only be speculated that the combination oil and enzyme promote deposition of UFA at the expense of SFA. Nonetheless, all the UFA: SFA values were above the recommended minimum value, hence the differences in fatty acid profiles of lambs are presumably of minor importance.

Higher proportions of UFA are desirable from a health perspective, but they have negative effects on quality aspects such as fat firmness, shelf life and meat flavour (Webb et al., 1999, Wood et al., 2004; Francisco et al., 2015). In the present study lower proportions of PUFA were deposited in lambs fed oil supplemented diets as opposed to diets without oil. However, the differences between dietary treatments in the proportions of PUFA deposited in both subcutaneous and intramuscular adipose tissue were minor (less than 1%) and will presumably not have effects on the technological quality of meat.

5. Conclusion

Lambs on palm oil supplemented diets took on average 8 days longer to reach the target slaughter weight and they had lower dressing percentage and subsequently smaller carcasses in comparison to lambs on control and enzyme treatment diets. This implies that palm oil supplementation of lamb diets may decrease production. Feedlots should consider this factor when implementing such methane mitigating strategies.

Both palm oil supplementation and inclusion of fibrolytic enzymes in high forage diets showed significant effects on meat quality parameters and fatty acid profiles of lambs, but the differences were in most cases numerically small and probably negligible. Overall, the methane mitigating strategies investigated in this study had no adverse effects on meat quality of lambs. Therefore, palm oil supplementation and/or inclusion of fibrolytic enzymes in high forage lamb diets can be cost effective strategies for mitigating methane emission without compromising meat quality. Consumer resistance to such dietary interventions is therefore not expected.

Conflict of Interest

The authors has no conflict of interest.

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