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Open Access Journal of Veterinary Science & Research
ISSN: 2474-9222

Impact of Supplementation of Different Levels of Rumen Protected Fat on Productive Performance, Lipid Profile and Hot Carcass Characteristics in Fattening Sheep

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Research Article

Volume 8 Issue 1

Received Date: January 12, 2023

Published Date: January 31, 2023

DOI: 10.23880/oajvsr-16000232

Abstract

The present study was aimed at establishing an association between productive performance, lipid profile, and hot carcass quality in fattening sheep supplemented with different levels of rumen protected fat (RPF). Twenty-four adult ewes of 8 - 12 months of age were randomly divided into three groups with eight animals in each; one without supplementation (CSFA0); two supplementation groups (CSFA3 and CSFA5) that were supplemented with 3% and 5% additional RPF in the form of calcium salts of long chain fatty acids (CSFAs), respectively on dry matter intake (DMI). Productive performances and the blood lipid profile were evaluated at fortnightly intervals, and at the end of 60 days, animals were slaughtered and hot carcass characteristics were recorded. Body condition score (BCS) was higher (P<0.05) in CSFA3 and CSFA5 sheep fed with 3% and 5% additional fat by 34.17% and 37.40%, respectively than CSFA0. The average daily gain (ADG) was higher (P<0.05) in sheep fed with CSFAs by 1.51-1.65-fold and enhanced live body weight (LBW) in the CSFA3 and CSFA5 groups by 11.36% and 14.48%, respectively. Plasma HDL and LDL concentrations were higher (P<0.05) in CSFA3 and CSFA5 sheep supplemented with additional RPF. Inclusion of CSFAs in the diet increased (P<0.05) fatness score of hot carcasses in CSFA3 and CSFA5 by 26.19% and 59.52%, respectively. Hot carcass weight (HCW), separable fat, neck, shoulder, flank and breast weights, and carcass compact index (CCI) were higher (P<0.05) in supplementation groups, which increased the dressing percentage (DP) by 3.21% to 3.68%. The BCS, LBW, slaughter weight, separable fat, fore and hind saddle weights were positively (P<0.01) associated with the HCW. Further, HCW, shoulder, and chest circumferences showed a positive (P<0.01) correlation with CCI and DP. The results of the current study concluded that supplementation of 3% and 5% CSFAs improved BCS, ADG, and LBW which enhanced the hot carcass characteristics and quality with an extra DP of 3.21 to 3.68%. However, we were unable to discern a discernible change in productive performance and hot carcass features between 3% and 5% administration of CSFAs. Therefore, inclusion of a 7% (basal diet 4% + 3% supplementation) source of lipids or fat on DMI is preferred for maximizing the desired productive performance and hot carcass quality in fattening sheep.

Keywords: Supplementation; Rumen protected fat; Productive performance; Lipid profile; Hot Carcass Characteristics; Fattening

Introduction

Sheep are an integral part of the rural economy, especially in the arid, semi-arid, and mountainous regions. They play a significant role in the livelihoods of small and marginal farmers and landless labourers engaged in sheep rearing. The dietary supplementation of energy sources is an effective tool to improve the productivity of animals. The vegetable oils and animal fat are sources of energy in animal feed, which also acts as a carrier for fat soluble vitamins and essential fatty acids that enhance the physical nature of the ration [1,2]. Lipids as a source of energy are commonly supplemented up to 6-7% in the diet of high producing dairy animals [3]. However, small ruminants, particularly sheep, are better adapted to a high lipid content in their diet than cattle, and they can consume up to 10% of their dry matter intake in the form of calcium salts [4,5].

Supplementation of calcium salts of long chain fatty acids (CSFAs) as a source of energy is common in the livestock feeding system. CSFAs have been widely used in dairy animals to compensate for negative energy balance during transitional and peak production, as well as in beef cattle to increase fat and dressing percentages [6,7]. CSFAs are a complex of calcium ions with long chain fatty acids primarily from soybean and palm oil, and depending on the producers, they are inactive in the rumen and disperse in the acidic abomasum [8]. CSFAs increase the energy level of the diet without interfering with fibre digestion, allowing for high levels of inclusion in ruminant diets [9]. The inclusion of fat in the diet of ruminants improves energy efficiency due to reduced ruminal methane production and direct utilisation of long-chain fatty acids in fat metabolism [10,11]. Hence, strategic supplementation of energy and protein rich diets may enhance the productive performance of ruminants. Increased productivity in terms of body condition and weight may improve both hot carcass and meat quality. There is more evidence on the impact of CSFAs on carcass and meat quality in large ruminants, particularly in feedlot cattle. However, there is limited information on small ruminants and the level of inclusion of CSFAs in the diet for fattening. As a result, the current study sought to establish a link between productive performance, lipid profile, and the characteristics and quality of the hot carcass in fattening sheep supplemented with varying levels of rumen-protected fat.

Materials and Methods

Experimental Animals and Management

Twenty-four adult ewes of 8-12 months of age with an average body weight of 14.108±0.336 kg were randomly divided into three groups with eight animals in each group (Table 1). All the experimental animals were individually housed, and stall fed with a common basal diet comprising of 60% roughage (finger millet straw) and 40% concentrate (maize-33%, wheat bran-36%, groundnut cake-14%, soybean meal-14%, mineral mixture-2% and common salt-1%) (Table 2) and nutrient requirements were met as per NRC [2]. Group-I (n=8) animals were denoted as CSFA0, which were fed only a basal diet without additional supplementation of rumen protected fat. Whereas, groups II (CSFA3; n=8) and III (CSFA5; n=8) were designated as supplementation groups, and they were supplemented with 3% and 5% additional rumen protected fat in the form of CSFAs (Table 2; Indian Immunologicals Limited, India) in addition to the common basal diet, respectively on dry matter intake. Throughout the 60-day study period, the feed requirements were modified at weekly intervals depending on changes in the animals' body weight. Clean, fresh drinking water was offered around the clock. Sheep were maintained as per standard animal husbandry management practices. The experimental protocol was approved by the Institutional Animal Ethical Committee, and Committee for the Purpose of Control and Supervision of Experiments on Animals, Ministry of Environment, Forest and Climate Change, Government of India (F.No. 25/15/2018-CPCEA).

Feed composition	CSFA0	CSFA3	CSFA5
Number of experimental animals	8 (n=8)	8 (n=8)	8 (n=8)
Basal diet (Finger millet straw - 60% + concentrate mixture - 40%)	3.5% of LBW	3.5% of LBW	3.5% of LBW
Calcium salts of long chain fatty acids	-	3% of DMI	5% of DMI

LBW = Live body weight; DMI = Dry matter intake

Table 1: Grouping of experimental animals based on calcium salts of long chain fatty acids (CSFAs) supplementation levels.

Chemical analysis of Concentrate and Roughage

The crude protein (984.13), ether extract (920.39), crude fibre (978.10) and total ash (942.05) content of the concentrate mixture and finger millet straw were determined by methods of the AOAC [12] in duplicate (Table 2).

Component (%)	Concentrate mixture	Finger millet straw	Calcium salts of long chain fatty acids* (CSFA %)
Dry matter	90.75	90.12	C 12:0 Lauric acid – 0.2
Organic matter	93.46	90.84	C14:0 Myristic acid – 1.2
Total ash	6.54	9.16	C16:0 Palmitic acid – 45.5 – 51.0
Crude protein	20.63	3.64	C18:0 Stearic acid - 3.0 – 7.0
Ether extract	2.84	1.22	C18:1 Oleic acid – 34.0 – 39.0
Crude fibre	6.84	34.11	C18:2 Linoleic acid – 8.0 -11.0
Nitrogen free extract	63.15	51.87	C18:3 Linolenic acid – 2.0
			C20:0 Arachidonic acid – 1.0

* Composition of CSFA is as per manufacturer

Table 2: The chemical composition of the concentrate mixture, finger millet straw, and calcium salts of long chain fatty acids fed to experimental sheep.

Measurement of body weight and body condition score

The body weight gain (kg) was recorded at weekly intervals to calculate the dry matter requirements and the average daily gain. Body condition score (BCS) was subjectively evaluated at fortnightly intervals on a scale of 1-5 with 0.25-point increments, by the same expert to ensure consistency and repeatability [13].

Blood collection and lipid profile

The blood samples were collected in a clean heparinized (20 IU/ml) test tube at fortnightly interval before feeding (08:00 h). The plasma was separated by centrifugation (Centrifuge 5430 R, Eppendorf AG, Germany) at 3000 rpm for 30 min at 4°C and stored at −80°C until estimation of the lipid profile. The high-density lipoproteins (HDL) and low-density lipoproteins (LDL) concentrations were determined by the direct method using commercial kits (ARKRAY Healthcare Pvt. Ltd., Mumbai, India) by enzymatic colorimetric testing, and absorbance was measured in spectrophotometer (BioSpectrometer, Eppendorf AG, Germany) at 600 and 660 nm, respectively [14].

Slaughter and evaluation of hot carcass characteristics

Following the standard procedure, all of the experimental sheep were slaughtered for the evaluation of hot carcass characteristics and quality after 60 days [15]. The sheep were fasted for 12 hours with free access to clean water, and the slaughter body weight (SBW) was recorded before slaughter. Sheep were slaughtered by the traditional halal method by severing the jugular vein and carotid artery, and subsequently, skinning and evisceration were performed. Hot carcass measurements were recorded using a measuring tape and volumetric stick, such as carcass length - from the caudal edge of the last sacral vertebra to the dorso-cranial edge of the atlas; chest depth- greatest depth at the horizontal level of the hanging carcass; carcass width - widest carcass measurement at the ribs using a calliper; buttock circumference - measured using a tape held horizontally around the buttocks at the level of the caudal insertion; and leg length - from the middle of the lump at the proximal end of the tibia to the distal end of the tarsus. The carcass was split into fore and hind saddles (quarters) at the intersection of the 12th and 13th vertebrae, and weight was recorded. The cut surface of the *Longissimus thoracis et lumborum* muscle at the interface of the 12th and 13th ribs on both sides of the carcass was marked on tracing paper and measured as the loin eye area (LEA, cm^2) with a planimeter using standard procedure [16]. Further, hot carcass weight (HCW) and other carcass characteristics were recorded, along with hot carcass dressing percentage (DP% = HCW/SBW × 100) and carcass compactness index (CCI = HCW*100/carcass length). The fatness score (FSC) based on the degree of fat deposit (1 = very lean and 5 = excessively fat) and weight of separable total internal fats (SF) was recorded using a digital table balance [17].

Statistical analysis

All statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS) version 18.00 software for Windows (SPSS Inc., Chicago, IL, USA). The productive performances, lipid profile, hot carcass characteristics, and measurements were analysed by General Linear Model Repeated Measures. The level of statistical significance was set at 0.05. If the effect was found to be significant, a comparison of means was done using Duncan's Multiple Range Test. A paired "t" test was used to test the significance between the initial and final BCS and LBW. Further, the Pearson correlation coefficient (two-tailed) was carried out to establish the association between LBW, BCS, SBW, and hot carcass characteristics and measurements in fattening sheep.

Results

Impact of rumen protected fat on productive performance

Body condition score: The body condition score (BCS) improved (P<0.05) in all the sheep during the experimental period of 60 days (Table 3). The improvement in the BCS was higher (P<0.05) in the CSFA3 and CSFA5 groups by 34.17% and 37.40%, respectively than in CSFA0. However, there was no significant difference between sheep fed with different levels of additional RPF.

Average daily gain (g) and live body weight (kg): The data for the average daily gain (ADG) and live body weight (LBW) of the present study are presented in Table 3. The ADG increased significantly (P<0.05) in sheep fed with CSFAs by 1.51-1.65-fold (26.77 to 34.38g) in comparison to sheep (CSFA0) without supplementation of RPF. LBW increased (P<0.05) in all the experimental sheep during the experimental period, and the increase was higher (P<0.05) in the CSFA3 and CSFA5 groups than the CSFA0 group by 11.36% and 14.48%, respectively. However, we could not find any significant difference among the protected fat supplement groups (CSFA3 and CSFA5).

Parameters	Period	CSFA0	CSFA3	CSFA5
Average daily gain (g)	-	52.50 ± 4.99^{A}	79.27 ± 8.01^{B}	86.88 ± 6.99^{B}
Body weight (kg)	Initial	14.538 ± 0.365^{x}	14.400 ± 0.423^{x}	14.425 ± 0.526^{x}
	Final	17.688 ± 0.334^{Ay}	19.156 ± 0.488^{By}	19.638 ± 0.35^{By}
Body condition score	Initial	2.63 ± 0.13^{x}	2.50 ± 0.16^{x}	2.56 ± 0.20^{x}
	Final	3.50 ± 0.13^{Ay}	4.19 ± 0.19^{By}	4.38 ± 0.16^{By}

Means with superscripts (A, B) differ significantly (A & B = P < 0.05) in the same row.
Means with superscripts (x, y) differ significantly (x & y = P < 0.05) in the same column.
Table 3: Effect of supplementation of calcium salts of long chain fatty acids on average daily body gain, body weight, and body condition score in fattening sheep (Mean±SE).

Lipid Profile

HDL and LDL cholesterol: The supplementation of CSFAs increased (P<0.05) the plasma levels of HDL and LDL cholesterol in the CSFA3 and CSFA5 groups in comparison to CSFA0 from 15th day onwards (Figure 1). The dose dependent increase (P<0.05) was noticed in HDL concentration in sheep (CSFA3 and CSFA5) supplemented with protected fat from 30th day onwards. Whereas, the increment was higher (P<0.05) in CSFA3 and CSFA5 sheep by 30.83% and 47.10%, respectively than CSFA0. Furthermore, sheep (CSFA5) supplemented with 5% CSFAs had 12.43% higher (P<0.05) HDL concentration than CSFA3 animals fed with 3% RPF. Similarly, we found dose-dependent variation (P<0.05) in LDL concentration starting on the 45th day in sheep supplemented with CSFAs.

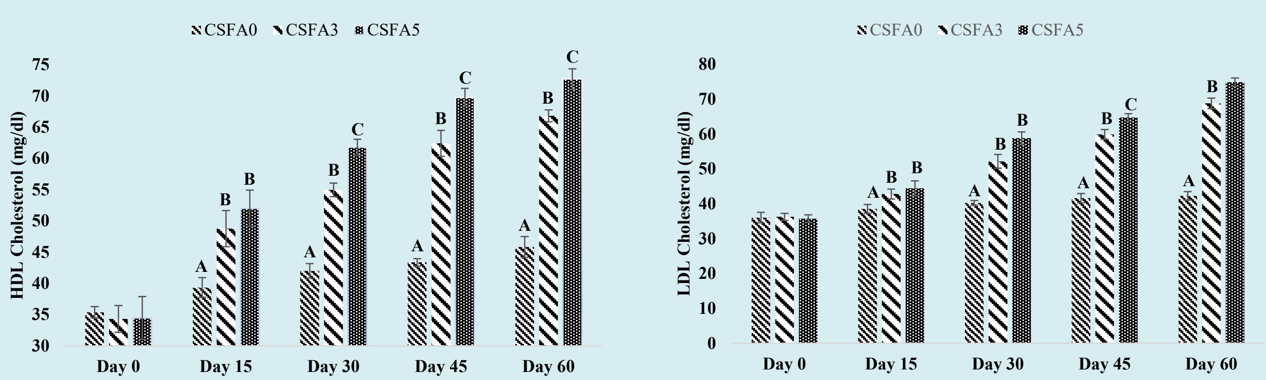

Figure 1: Impact of supplementation of different levels of calcium salts of long chain fatty acids on plasma concentrations of HDL and LDL cholesterol (mg/dl) in fattening sheep.
Bars with different superscripts (A, B, C) differ significantly (A, B, C = P < 0.05) in the graph (means±SE).

Impact on hot carcass quality: The supplementation of calcium salts of long chain fatty acids improved the hot carcass characteristics in sheep (CSFA3 and CSFA5) in contrast to sheep (CSFA0), which were not fed with an additional source of fat during the experimental period.

Hot carcass characteristics and measurements: The slaughter body weight (SBW) was significantly higher (P<0.05) in sheep (CSFA3 and CSFA5) fed with additional CSFAs in contrast to CSFA0 (Table 4). The same trend was also reflected in the hot carcass weight (HCW), which was higher (P<0.05) in the CSFA3 and CSFA5 by 17.14% and 23.09%, respectively than CSFA0. The inclusion of RPF in the diet increased (P<0.05) the fatness score of hot carcasses in the CSFA3 and CSFA5 groups by 26.19% and 59.52%, respectively than CSFA0. Further, separable fat, neck, shoulder, flank and breast weights, and CCI were higher (P<0.05) in sheep (CSFA3 and CSFA5) fed with additional RPF than CSFA0 animals. Interestingly, supplementation also enhanced (P<0.05) the dreeing percentage in CSFA3 and CSFA5 by 3.21% and 3.68%, respectively. In addition, some of the carcass measurements, such as the loin eye area, chest, and shoulder circumferences, and leg width were higher (P<0.05) in sheep (CSFA3 and CSFA5) supplemented with RPF (Table 5).

Carcass characteristics	CSFA0	CSFA3	CSFA5
Slaughter body weight (kg)	16.554±0.443^{A}	18.220±0.457^{B}	18.931±0.306^{B}
Hot carcass weight (kg)	8.020±0.290^{A}	9.394±0.366^{B}	9.872±0.221^{B}
Dressing percentage (%)	48.40±0.04^{A}	51.61±0.03^{B}	52.08±0.04^{B}
Carcass compact index	31.45±1.35^{A}	37.51±1.02^{B}	39.95±1.19^{B}
Fatness score (1-5)	2.63±0.09^{A}	3.31±0.09^{B}	4.19±0.13^{C}
Separable fat (kg)	0.656±0.090^{A}	1.170±0.082^{B}	1.188±0.145^{B}
Fore saddle (kg)	3.667±0.146	3.900±0.126	4.179±0.257
Hind saddle (kg)	3.914±0.184	4.160±0.164	4.174±0.208
Neck (kg)	0.372±0.271^{A}	0.442±0.085^{B}	0.442±0.118^{B}
Shoulder (kg)	1.800±0.058^{A}	2.122±0.129^{B}	2.172±0.107^{B}
Rack rib (kg)	0.767±0.096	0.925±0.066	0.865±.093
Loin (kg)	0.551±0.069	0.573±0.038	0.588±0.038
Leg (kg)	2.730±0.124	3.124±0.299	2.988±0.261
Flank (kg)	0.321±0.015^{A}	0.369±0.020^{B}	0.397±0.021^{B}
Breast (kg)	0.281±0.017^{A}	0.349±0.01^{B}	0.403±0.024^{B}

Means with superscripts (A, B) differ significantly (P<0.05) in the same row.

Table 4: The impact of supplementation with calcium salts of long chain fatty acids on the hot carcass characteristics in fattening sheep (Mean±SE).

Carcass measurements	CSFA0	CSFA3	CSFA5
Carcass length (cm)	64.95±1.19	63.68±0.81	62.76±0.91
Buttock circumference (cm)	44.45±1.96	47.17±0.51	47.52±0.91
Chest width (cm)	5.61±0.25	5.99±0.23	5.61±0.25
Chest circumference (cm)	56.24±0.81^{A}	60.78±0.97$^{\mathbf{B}}$	61.32±1.60^{B}
Chest depth (cm)	16.15±0.61	17.42±0.36	16.87±0.46
Shoulder circumference (cm)	30.30±0.58^{A}	32.11±0.46^{B}	35.20±1.50^{B}
Leg length (cm)	30.12±0.76	29.57±1.07	30.84±1.02
Leg width (cm)	11.79±1.14^{A}	15.24±1.12^{B}	16.51±0.56^{B}
Loin eye area (cm^2)	12.98±0.29^{A}	15.75±0.28^{B}	16.36±0.21^{B}

Means with different superscripts (A, B) differ significantly (P < 0.05) in the same row.

Table 5: The impact of supplementing calcium salts of long chain fatty acids on carcass measurements in fattening sheep (Mean±SE)

The correlation between productive performance and hot carcass characteristics

The slaughter body weight (SBW) showed a positive correlation (P<0.05) with LBW and BCS in sheep (Table 6). The HCW was highly (P<0.01) influenced by the BCS, LBW, and SBW, along with the fatness score of hot carcasses. The separable fat was also positively (P<0.01) integrated with the HCW. In addition, the fore and hind saddle weights were highly (P<0.01) associated with HCW in sheep. The shoulder and chest circumferences of the carcass showed a positive correlation (P<0.05) with HCW. Therefore, hot carcass characteristics such as HCW, fatness score, separable fat, saddle weights, and carcass measurements (circumference of shoulder and chest) exhibited a positive (P<0.01) correlation with carcass compact index and dressing percentage. In addition, productive performance (BCS, LBW) and SBW also positively (P<0.05) consolidated the hot carcass DP in sheep.

	LBW	BCS	SBW	HCW	FSC	SF	FS	HS	SC	CC	BC	CCI
BCS	0.384											
SBW	0.770**	0.464*										
HCW	0.817**	0.545**	0.879**									
FSC	0.489*	0.453*	0.507*	0.686**								
SF	0.745**	0.433*	0.776**	0.806**	0.524*							
FS	0.531**	0.440*	0.475*	0.695**	0.466*	0.291						
HS	0.723**	0.371	0.602*	0.721**	0.298	0.509*	0.717**					
SC	0.574*	0.298	0.525*	0.686*	0.675*	0.521*	0.543*	0.457*				
CC	0.656*	0.358	0.517*	0.613*	0.417*	0.419*	0.402	0.38	0.332			
BC	0.423*	0.454*	0.29	0.328	0.199	0.393	0.156	0.118	0.396	0.432*		
CCI	0.825**	0.496*	0.831**	0.935**	0.716**	0.799**	0.539**	0.535**	0.592**	0.721**	0.412*	
DP	0.628**	0.471*	0.472*	0.835**	0.680**	0.601**	0.734**	0.642**	0.641**	0.552**	0.262	0.776**

*Correlation is significant at the 0.05 level (two-tailed)
**Correlation is significant at the 0.01 level (two-tailed)
LBW = Live body weight; BCS = Body condition score; SBW = Slaughter body weight; HCW = Hot carcass weight; FSC = Fatness score; SF = Separatable fat; FS = Fore saddle; HS = Hind saddle; SC = Shoulder circumference; CC = Chest circumference; BC = Buttock circumference; CCI = Carcass compact index; DP = Dressing percentage

Table 6: Pearson correlation between live body weight, body condition score, slaughter weight, and hot carcass characteristics in fattening sheep.

Discussion

Impact of rumen protected fat on productive performance

Body condition score: In routine animal management practices, the body condition score is used to represent weight gain and health status [18,19]. Supplementation of CSFAs improved BCS in the present study, which is in line with the reports of Vahora, et al. [20] and Nguyen, et al. [21] in buffalo and sheep. Nguyen, et al. [21] reported a positive impact on BCS, productive and reproductive performance of sheep fed with rumen protected oils containing eicosapentaenoic and docosahexaenoic acids. Supplementation of bypass fat enhances BCS and blood biochemical parameters that are associated with productive performance in ruminants [22]. Feeding of a high lipogenic diet improves body condition scores with higher ADG in goats [23]. Further, Vahora, et al. [20] also observed an improved BCS along with increased average daily weight gain in buffaloes fed with rumen bypass fat.

Average daily gain and live body weight: The productive performance is mechanism of synthesis, degradation and deposition of body proteins which requires high energy that could be met by high energy diets in animals [17]. In the present study, ADG and LBW were higher in sheep (CSFA3 and CSFA5) supplemented with CSFAs, which are similar to the earlier findings of Awawdeh, et al. [24] and Bhatt and Sahoo [25] in sheep, goats [26], and cattle [27]. The supplementation of bypass fat increased the LBW in cattle and goats in accordance with the levels of fat in the diet [27,26]. Ghoorchi, et al. [28] reported an increased ADG and feed conversion ratio in Atabay ewes by the inclusion of

3 - 5% CSFAs in the diet. Further, Awawdeh, et al. [24] also confirmed that feeding yellow grease or soyabean oil as a source of energy to Awassi ewes improved ADG as a result of greater utilization efficiency or enhanced efficiency in the reformation of dietary fat into body fat. However, there was no difference in ADG and LBW among the supplementation groups, which could be due to the decreased DMI in CSFA5 sheep fed with 5% CSFA. Whereas, Haddad and Younis [29] and Behan, et al. [30] observed similar body weight gain in sheep supplemented with rumen protected fat, in contrast to the present findings which could be due to level of inclusion and source of CSFAs. The dietary energy levels are more essential for the regulation of feed efficiency than the protein levels, particularly in finishing lambs [31,25]. The increase in LBW and ADG, increases linearly with the level of CSFAs in the diet of post-weaning lambs [32]. In addition, the level of tissue deposition is strongly correlated with the optimal level of protein intake and the amount of energy available for retention in the muscle [33]. Therefore, dietary energy levels are critical for improved feed efficiency and productive performance in sheep [31].

Lipid profile: The feeding of CSFAs increased the concentrations of plasma HDL and LDL in the present study in parallel to the findings of Obeidat, et al. [34] in sheep and cattle [35]. Supplementation of 50 and 100 g CSFAs per day increased the blood cholesterol, triglycerides, and HDL in ewes [34]. The inclusion of CSFAs in the feed of ruminants has increased the plasma concentration of LDL and HDL. The increased secretion of lipoproteins with greater triglycerides from the digestive tract may be the cause of the elevated levels of lipid metabolites in plasma [3]. Furthermore, feeding rumen-protected fat activates the intestine's lipoprotein cholesterol export system, which increases the circulating levels of LDL and HDL in goats and ewes [36,37]. Lee, et al. [38] and Kang, et al. [35] observed an increased level of HDL in cattle when fed with rumen-protected oleic acid that derives from absorbed rumen protected fat in the small intestine.

Impact on hot carcass quality

Hot carcass characteristics and measurements: Ruminant productivity and meat quality were improved by supplementing rumen-protected fat [17]. Our results of the present study also evidenced the increase in hot carcass weight, loin eye area, fatness score, separatable fat, carcass compact index, and dressing percentage in sheep fed with additional CSFAs (CSFA3 and CSFA5). The increase in carcass yields could be due to the efficient utilization of dry matter for growth and development [17]. Further, supplementation of medium- and long-chain fatty acids gives rise to a higher level of ATP than volatile fatty acids in ruminants [39]. Therefore, the extra availability of high energy is spared for muscle formation and growth in the animals [17]. The inclusion of lipid sources, especially polyunsaturated fatty acids, in ruminants enhances the meat quality and nutritional value of meat fat [40,41]. Cleef, et al. [5] reported that feeding yellow grease as a source of energy had improved the DP in crossbred lambs. The fatty acid content of the feed influences the meat's fatty acid profile, and these FA are preferably integrated into muscle, which is an important metabolic trait in fattening sheep [42]. Therefore, feeding a high energy diet or CSFAs significantly increases the hot carcass weight and DP in ewes and lambs [43,32,44].

The increased fatness score and separable fat level in the present investigation referred to the carcass adiposity, which is superior in sheep fed with a high energy diet in comparison to a low energy [45]. Clinquart, et al. [10] and Bhatt, et al. [32] reported an increment in carcass yield as a result of enhanced carcass fat from the inclusion of fat in the diet of lambs. The increase in carcass fat deposit with a high energy diet eventually materializes in the later stages of growth [46]. CSFAs prevent ruminal acidosis and promote the absorption of lipid soluble nutrients that enhance meat quality [47]. Further, Savell and Cross [48], Veiseth, et al. [49] and Pannier, et al. [50] reported that an increase in the intermuscular fat content enhances the palatability of meat, reduces the shear force value that specifies tenderness, and improves the meat quality.

The correlation between productive performance and hot carcass characteristics

The body weight directly influences the productive performance and profitability of any livestock species [51]. SBW showed a positive correlation with HCW, and the increase in SBW improved the hot carcass yield in sheep [25]. The level of tissue deposition is majorly correlated with the optimum level of protein intake and the extent of available energy for retention in the muscle [33]. The trend of improvement in HCW and simultaneous increment in CCI and DP in sheep fed with CSFAs is similar to previous studies by Cleef, et al. [5] and Slimene, et al. [52]. It has been reported that an increase in the SBW of lambs upscaled the hot carcass measurements and dressing percentage in sheep [53]. The enhancement in the FSC and total fat content positively enhanced HCW, CCI, and DP in sheep, particularly the subcutaneous fat deposit that enhances the mass [45]. Dressing percentage is a major factor that arbitrates meat production and carcass quality, where it has a positive correlation with body weight and increases with increasing body weight [54,55]. Carlos, et al. [56] and Slimene, et al. [52] also observed a positive correlation between dressing percentage and fatness score in steers.

Conclusion

The results of the current study revealed that supplementation of 3 and 5% of rumen protected fat improved the body condition score with higher average daily gain and live body weight in fattening sheep. The increase in body condition score, average daily gain and live body weight enhanced the hot carcass characteristics and quality with an extra dressing percentage of 3.21 - 3.68%. However, we could not appreciate significant differences in productive performance and hot carcass characteristics between 3% and 5% supplementation of calcium salts of long chain fatty acids. Therefore, inclusion of 7% (basal diet 4% + 3% supplementation) lipids or sources of fat in the diet is preferred for maximizing the desired productive performance, hot carcass characteristics and meat quality in fattening sheep. Further studies are necessary in large herds to establish the optimum levels of fatty acid supplementation required to maximise productivity in sheep.

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