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Meat Quality Characteristics of Goat (*Capra hircus*) Artificially Infected with *Haemonchus contortus* and Fed High and Low Protein Diets

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Abstract
A study was conducted to examine the effect of dietary protein supplementation in the presence *Haemonchus contortus* on carcass composition and meat quality of growing goats. Sixteen bucks were divided into two groups (infected; non-infected) of eight animals each, with half of each group randomly assigned to high or low protein diet. Infected goats were dosed with 600 *H. contortus* larvae (stage L_3) thrice per week for 3 weeks. Results showed that diet did not influence temperature, pH, a^* (redness), L^* (lightness); b^* (yellowness) values, water holding capacity (WHC), cooking loss (CL), Warner-Bratzler shear force (WBSF) dressing percentage, carcass proportion and proximate analysis of goat meat. However, infection significantly (P<0.05) affected ash, lipid and C18:3n6-gama fatty acid content of goat meat, while diet and infection significantly affected C20:0 fatty acids of goat meat. Moreover, a significant (P<0.05) interaction between dietary protein and infection was observed for eicosadienoic (C20:2cis11, 14) acid in meat lipid from the goats. Surplus protein in the diet seems not to influence the carcass composition and meat quality of goat. Our results demonstrated that locally available protein sources could be used to feed growing meat goats to minimize production cost.
Keywords Goat, high protein, low protein, meat quality characteristics, *Haemonchus contortus.*

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Introduction

Goat is an important meat animal worldwide. In the United States, goat rearing is one of the developing sectors of livestock production. The total goat population in the US in 2015 was estimated to be 2.68 million head of which 80% were meat goats [1]. There are several reasons for the growing popularity of meat goats in the US, the most important of which are: increasing demand for goat meat among growing populations of different ethnic groups, and health conscious consumers becoming aware of the lower fat content in goat meat compared to mutton, beef, and pork [2, 3]. Goat meat contains essential fatty acids for human health, especially conjugated linoleic acids, which reduce the risk of cardiovascular diseases and cancers [4]. It is also a good source of animal protein.

In spite of the growing demand for goat meat, the growth of the US goat industry has been slow with the major challenge for goat producers being the infection of goat with gastrointestinal nematodes [5]. Gastrointestinal nematodes (GINs) are predominant in goats causing huge losses, including reduced growth and productivity (milk/meat) as well as decreased reproductive performance in mature female goats [6, 7]. Supplementing goats with a high protein source has been shown to alleviate the negative effects of the GINs infection [8, 9]. It has also been reported that dietary protein supplementation improved body weight gain and carcass weight, contributing to improved meat quality [10]. Nevertheless, information on meat quality characteristics of goats infected with GINs is rarely usable. Thus, the goal of this work was to investigate the outcome of dietary protein supplementation in the presence of *Haemonchus contortus* on meat quality characteristics of pen-raised goats sustained only on contract.

Materials and Methods

Study site, animals, diet and experimental design

This experiment was conducted at the Randolph Research and Demonstration Farm, Virginia State University (VSU), United States. Sixteen bucklings aged between 9 and 10 months with an average body weight of 23.69 ± 0.88 kg (Mean ± SE) were used in the study. All animals were administered Levamisole (0.4 mg/kg BW) for endoparasite control and divided into two groups (infected and non-infected) each with eight animals. The animals were then assigned at random to two dietary treatments: high protein (HP) or low protein (LP) diets containing 25% and 16%

crude protein (CP), respectively, with soybean meal as the major source of protein. The experiment was a 2 × 2 (infected/non-infected × HP/LP diets) factorial design. The HP and LP diets contained 7.02 MJ/kg dry matter (DM) and 7.92 MJ/kg DM, respectively, of metabolizable energy. Proximate analysis of the diets and neutral detergent fibers were determined according to the procedures previously described [11, 12]. The metabolizable energy was assessed using the method recommended previously [13]. The Table 1 shows the ingredients and proximate analysis of the diets.

Table 1 Ingredients and nutrient composition of experimental diets.

Items	Diets	
	High protein	**Low protein**
Ingredient (%)		
Alfalfa pellet	5.00	17.00
Cracked corn	63.00	73.00
Soybean meal	30.00	8.00
Limestone	1.00	1.00
Ammonium chloride	1.00	1.00
Nutrient composition (%)		
Moisture	11.00	10.90
Crude protein (CP)	24.70	15.80
Lipid	2.79	2.18
Acid detergent fiber (ADF)	14.58	15.90
Total digestible nutrient (TDN)	73.8	79.2
Metabolizable energy (MJ/kg)	11.15	11.96
Nitrogen	3.95	2.52
Organic matter (OM)	96.33	96.39
Ash	3.67	3.61
Phosphorus (P)	0.44	0.32
Potassium (K)	1.25	0.94
Sulfur (S)	0.21	0.14
Calcium (C)	1.28	1.64
Magnesium (Mg)	0.22	0.18

Metabolizable energy (MJ/kg) = TDN (%) × 0.15104, Animal friends rescue project (AFRC, 1998) http://www.animalfriendsrescue.org/.

Culturing of *H. contortus* larvae and infection techniques

H. contortus larvae were obtained from the fecal matter of infected animals and cultured using method previously described [13]. Subsequently, the animals in the infected group were orally trickle infected with a dose of 600 units third stage larvae (L_3) of *H. contortus* (96% pure) on day 0 of the experiment after addition of water to the larvae. Thereafter, the dosage treatment was repeated thrice a week for three consecutive weeks such that each animal in the infected group received a total of 5400 larvae.

Animal management and feeding

Experimental animals were individually housed in pens with concrete floors spread with wood shavings and acclimatized for 14 days before experiment. During the experimental period of 16 weeks, the animals were offered a feed equivalent to 3% of live weight (LW) once a day at 0800h in the morning. Feed offered and refusals were recorded daily for each animal. Clean drinking water and a mineral licking a salt block with 96-98% NaCl, 2000 ppm Mn, 1000 ppm Fe, 1000 ppm Mg, 500 ppm S, 250 ppm Cu, 100 ppm Co, 80 ppm Zn and 70 ppm I per kg block per pen, *ad libitum* were provided throughout the study period.

Harvesting of animals

Twelve goats from all treatments (three from each group) were arbitrarily selected for slaughter 16 weeks later the experimentation began. The animals were deprived of feed, but had access to water for 48 hours, and their body weights were entered prior to harvest. They were humanely harvested by electrical stunning followed by severing of the jugular vein. The carcasses were skinned and heads were removed at the atlantooccipital joint, and the hooves were cut off at the proximal end of the cannon bones, leaving the carpal and tarsal bones on the carcase. The carcass was split into two halves through the medial plane, and the weights of both were recorded as hot carcass weight (HCW). Dressing percentage was defined as the ratio between HCW and slaughter body weight.

Physical measurements

Carcass pH and temperature were measured along the right half side 15-20 min post-mortem at the same spot on the semimembranosus muscle using a portable pH meter. Carcasses were placed at 4 °C for 48 hours and re-weighed to determine the cold carcass weight (CCW) before being frozen at -20 °C. A sample of the longissimus dorsi muscle from the right half of the each carcass was used to evaluate the color of goat meat under controlled lighting conditions in terms of a lightness (L*), redness (a*) and yellowness (b*) scale using a Minolta CR-400/410 chromameter (Minolta Camera Co. Ltd., Osaka, Japan). Water holding capacity (WHC) was measured by weighing out 3 grams (W1) of ground *longissimus dorsi* muscle into test tube containing 20 ml water and centrifuging at 1800g for 10 min. The supernatant was taken out and the sample re-weighed (W2). WHC was assessed by taking off the initial weight of the sample from the final weight according to the method as reported previously [15].

Cooking loss (CL) was evaluated by placing 15 grams (W1) of longissimus dorsi muscle samples in Ziploc plastic bags followed by boiling in a water bath at 71 °C for 50 minute. The boiled samples were cooled on ice for 10 min, dried with paper towels, and reweighed (W2). Cooking loss (%) was computed as

{(W1-W2)/W1} ×100. The samples for determination of cooking loss were used to assess meat Warner-Bratzler shear force (WBSF) as well. Cooked meat samples were cut into 1 × 2 cm cubes parallel to the direction of muscle fiber, then a WBSF instrument equipped with a 5 KN load cell was used to measure the absolute positive force needed to shear through a particular muscle at a crosshead speed of 100 mm/min. The left half of the carcass was dissected into muscle, fat and tone to assess carcass proportion.

Proximate analyses and fatty acid profiles of the meat

Muscle and fat from left half carcasses were cut into small pieces, mixed thoroughly and weighed for proximate analyses according to the standard methods [11]. Subsamples were weighed out, freeze dried and passed through a meat grinder. Moisture and ash content were determined by oven-drying and dry-ashing in a muffle furnace, respectively. Protein content was assessed by dry combustion using a Vario Max CN analyzer (Elementar Americas Inc., Mt. Laurel, NJ, USA) and crude protein (CP) computed as CP (%) = N × 6.25. Total lipid content was determined by Soxhlet extraction using petroleum ether and expressed as a percentage of goat meat.

The total lipids were obtained using Soxhlet extraction. Lipids were saponified into individual fatty acids and converted to volatile methyl ester derivatives by reacting with a boron trifluoride/methanol reagent (2 ml) in a heater for 30 minute. Later added hexane (1 mL) and water (2 mL) in samples and centrifuged to disperse the methyl ester derivatives from fatty acids in hexane. The hexane layer was collected and 1µl was injected into an HP 5890 Series II Gas Chromatograph (Hewlett-Packard Company, Wilmington, DE) equipped with a flame ionization detector. The column used was fused silica capillary column DB-Wax (30 m × 0.25 mm) (Alltech, Deerfield, IL) and helium was used as a carrier gas. The temperatures 250°C, 250°C, and 200°C were set for injector, detector and oven, respectively. The peaks were identified by comparing their retention times with a standard composed of methyl linoleate, methyl oleate, methyl palmitate, and methyl stearate (Sigma-Aldrich Corp, Louis, USA)

Statistical analysis

Two-way analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) were performed using SAS statistical software version 9.4 (SAS Institute, Cary NC) for physical measurement, carcass proportion, proximate chemical and fatty acid profiles data using the General Linear Model (GLM).

Results

Physical measurements

Temperature and pH measured in carcasses 15-20 min post-mortem for goats fed HP and LP diets ranged from 22.0°C to 22.6°C, and 6.5°C to 6.8°C, respectively. No noteworthy differences were observed in carcass temperature and pH values of goats on HP and LP diets (Table 2). There was no interaction between dietary protein and infection for temperature and pH of meat from goats fed HP and LP diets (Table 3). In this study, the Minolta chromameter showed no differences in lightness (L^*), redness (a^*) and yellowness (b^*) values for *longissimus dorsi* muscle of goats fed HP and LP diets (Table 2 and 3). Similarly, no significant interaction was observed between dietary protein and infection on carcass color (Table 3).

The values obtained for WHC in this study ranged between 0.37 g and 0.60 g for both high and low protein groups. There were no substantial differences in WHC of goat meat fed HP and LP diets in the current study (Table 2 and 3). Similarly, there was no interaction between dietary protein and infection on WHC of the meat from goats fed HP and LP diets (Table 3). The results further presented that the percentage for CL in the *longissimus dorsi* muscle of the goats ranged between 22.94 and 26.85. No substantial difference was detected in CL between the two treatments (Table 2 and 3). Although no substantial difference was found in CL among treatments, the trend from goats fed HP diet showed a tendency for high CL. There was no interaction between dietary protein and infection for CL of meat from goats fed high and low protein diets (Table 3).

The WBSF value obtained in the present study ranged between 3.34 and 5.51 kg which are within acceptable values. However, no substantial effects of dietary treatment were detected on shear force values of goat meat in this study. There was also no interaction between dietary protein and infection for WBSF value of meat from goats fed an HP and LP diets (Table 3).

Carcass proportion and proximate analysis

Mean dressing percentage for HPN, HPI, LPN and LPI groups were 47.03, 45.03, 46.65 and 46.93, respectively. There was no significant effect of dietary protein on the dressing percentage of goat meat in the present study since the dressing fraction is

Table 2 Temperature, pH, color, WHC, CL and shear force of meat from goats fed a high and low protein diets and infected or not infected with *Haemonchus contortus.*

Parameters	High protein		Low protein	
	Infected	Non-infected	Infected	Non-infected
Temp ^{0}C	22.6 ± 0.06	22.0 ± 0.27	22.5 ± 0.22	22.5 ± 0.15
pH	6.5 ± 0.01	6.7 ± 0.14	6.6 ± 0.19	6.8 ± 0.05
L^*	37.57 ± 1.09	38.04 ± 2.08	35.78 ± 0.14	35.64 ± 1.49
a^*	19.61 ± 0.52	18.93 ± 1.01	18.35 ± 1.62	18.4 ± 1.51
b^*	9.67 ± 0.44	9.73 ± 0.20	8.43 ± 1.65	8.16 ± 1.06
WHC (g)	0.37 ± 0.07	0.59 ± 0.16	0.60 ± 0.05	0.59 ± 0.13
CL (%)	26.85 ± 3.06	26.32 ± 1.93	24.49 ± 2.39	22.94 ± 3.55
Shear force (kg)	5.51 ± 0.00	5.21 ± 0.85	3.34 ± 0.00	4.99 ± 0.10

Temp = Temperature; L = lightness; a*= redness; b*= yellowness; WHC = water holding capacity; CL = cooking loss.
The values are presented as a mean ± standard error of three replicates.

Table 3 Two-way analysis of variance for effect and interaction of protein and infection on temperature, pH, color, WHC, CL and shear force of meat from goats fed high and low protein diets.

Effect	df	Temp	pH	L^*	a^*	b^*	WHC	CL	Shear force
		P-Value (Significant at *P*<0.05)							
Protein (P)	1	0.413	0.356	0.171	0.493	0.201	0.326	0.336	0.342
Infection (I)	1	0.204	0.094	0.909	0.804	0.921	0.367	0.719	0.464
P × I	1	0.159	0.978	0.832	0.778	0.878	0.326	0.860	0.324

Temp = Temperature; L = lightness; a^*= redness; b^*= yellowness; WHC = water holding capacity; CL = cooking loss.
P × I= protein × infection interaction.
The value shows P values of ANOVA and significant level is P <0.05; Degree of freedom = 1

closely related to body weight at slaughter than dietary treatment (Table 4). There was no interaction between dietary protein and infection for dressing percentage of the carcass from goats fed HP and LP diets. There were no significant differences among treatments in the proportion of muscle, bone, and fat. Although fat values numerically increased with protein level, the differences were not statistically significant. No interaction between dietary protein and infection was observed in the proportion of muscle, bone, and fat of the carcass from goats fed HP and LP diets (Table 5).

In this study, the goat meat moisture, ash, lipid and protein contents were 63.1 vs 61.9%, 2.3 vs 2.3%, 46.4 vs 42.6%, and 45.4 vs 42.4% for high and low protein diets, respectively. No significant differences were found in moisture, ash, lipid and protein contents of meat from goats fed high or low protein diets. There was no interaction between dietary protein and infection on moisture and protein content (Table 5). However; ash and lipid content of the goat meat were significantly affected by the infection. Meat from infected goats had significantly lower ash content while lipid contents were higher.

Fatty acid profiles

In the present study, twenty-two fatty acids were identified in lipids extracted from goat meat, which comprised of twelve saturated (C8:0, C10:0, C12:0, C13:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0), six monounsaturated (C14:1, C15:1, C16:1, C17:1, C18:1n9, C20:1cis11) and six polyunsaturated (C18:2n, C18:2n6t, C18:3n6-gama, C18:3n3-alpha, C20:2cis11, 14, C20:3cis11, 14, 17) (Table 6). In this study, meat from HP and LP fed goats contained a similar proportion of saturated (48.01 vs. 48.90%) and monounsaturated (49.82 vs. 48.61%), but a lower concentration of polyunsaturated (3.69 vs. 3.03%) fatty acids. Among the saturated fatty acids, infected goats fed low protein diet had higher (*P*<0.001) percentage of arachidic acid (C20:0) in meat lipid than their counterparts fed high protein diet (Table 6). No significant difference was found in arachidic acid (C20:0) between non-infected goats fed high and low protein diets. No interaction between dietary protein and infection was observed in the saturated fatty acid content of goat meat (Table 7 and Table 8).

There was no substantial (*P*<0.05) difference found in monounsaturated and polyunsaturated fatty acids in meat lipids of goats fed HP and LP diets. However, gamma-linolenic (C18:3n6-gama) acid tends to be higher in meat lipid from infected goats fed an HP diet. There was no interaction between dietary protein and infection for monounsaturated fatty acids (Table 9). But, a significant interaction between dietary protein and infection was observed for eicosadienoic (C20:2cis11, 14) acid in meat lipid from goats fed high and low protein diets. Infected groups fed LP diet had a higher proportion of C20:2cis11, 14 acid than their counterparts fed HP diet (Table 10 and Table 11).

Table 4 Carcass proportion and proximate analysis of meat from goats fed high and low protein diets and infected or not infected with *Haemonchus contortus.*

Carcass proportion (%)	High protein		Low protein	
	Infected	Non-infected	Infected	Non-infected
Dressing	47.03 ± 1.08	45.03 ± 1.91	46.65 ± 0.60	46.93 ± 3.00
Muscle	62.90 ± 2.50	58.90 ± 1.45	62.60 ± 1.33	62.70 ± 1.96
Bone	23.80 ± 1.91	24.90 ± 1.43	21.70 ± 1.23	26.20 ± 0.83
Fat	14.30 ± 0.00	14.50 ± 1.75	9.70 ± 0.00	10.80 ± 0.26
Proximate analysis				
Moisture	61.54 ± 2.07	63.09 ± 0.78	60.72 ± 1.28	61.89 ± 0.50
Ash	1.90 ± 0.21 b	2.28 ± 0.16 a	1.76 ± 0.24 b	2.30 ± 0.04 a
Lipid	48.20^{a} ± 3.90	46.40^{b} ± 0.93	46.50^{b} ± 2.80	42.60^{b} ± 1.35
Protein	44.50 ± 0.69	45.40 ± 0.08	45.90 ± 0.73	42.40 ± 0.89

The values are presented as mean ± standard error of three replicates.
Means within treatment in the same row with different letters are significantly (P<0.05) different

Table 5 Two-way analysis of variance for effect and interaction of dietary protein and infection on dressing percentage, proportion of carcass tissues and proximate analysis of meat from goats fed high and low protein diets and infected or uninfected with *Haemonchus contortus.*

Effect	df	Dressing	Muscle	Bone	Fat	Moisture	Ash	Lipid	Protein
		P-Value (Significant at *P*<0.05)							
Protein (P)	1	0.698	0.378	0.748	0.113	0.461	0.741	0.256	0.302
Infection (I)	1	0.658	0.333	0.075	0.702	0.327	0.650	0.095	0.289
P × I	1	0.562	0.302	0.242	0.800	0.891	0.035	0.012	0.686

P × I = protein × infection interaction.
The value shows P values of ANOVA and significant level is P <0.05; Degree of freedom = 1

Table 6 Proportion of saturated fatty acids in meat lipid of goats fed high and low protein diets and infected or not infected with *Haemonchus contortus*.

Fatty acid (%)	High protein		Low protein	
	Infected	Non-infected	Infected	Non-infected
C8:0	0.04 ± 0.01	0.02 ± 0.01	0.03 ±0.00	0.02 ± 0.01
C10:0	0.16 ± 0.02	0.14 ± 0.04	0.15 ± 0.02	0.12 ± 0.04
C12:0	0.48 ± 0.2	0.28 ± 0.05	0.24 ± 0.06	0.22 ± 0.10
C13:0	0.84 ± 0.39	0.40 ± 0.10	0.29 ± 0.11	0.3 ± 0.18
C14:0	3.90 ± 0.73	3.20 ± 0.07	3.19 ± 0.08	2.7 ± 0.60
C15:0	1.50 ± 0.39	1.03 ± 0.15	1.05 ± 0.28	0.89 ± 0.11
C16:0	23.39 ± 1.0	22.9 ± 0.32	24.9 ± 0.72	22.7 ± 0.47
C17:0	1.73 ± 0.15	1.42 ± 0.15	1.59 ± 0.19	1.49 ± 0.05
C18:0	16.90 ± 1.66	17.7 ± 1.49	17.04 ± 1.01	20.75 ± 0.89
C20:0	0.01^{b} ± 0.01	0.03^{b} ± 0.01	0.09^{a} ± 0.01	0.03^{b} ± 0.01

The values are presented as a mean ± standard error of three replicates.
Means within treatment in the same row with different letters are significantly different (P<0.05).

Discussion

The body temperature of animals ranges from 37 °C to 39 °C. After slaughtering, the temperature drops as heat is lost to the atmosphere. The rate of loss depends on carcass size and subcutaneous fat covering [16]. The similarity in carcass temperature in the present study might be due to a lack of variation in carcass size and fat covering. Glycogen present in the goat muscle at slaughter is metabolized through an anaerobic process leading to the formation of lactic acid and consequently a lowering of meat pH. The ultimate pH value of goat meat would be around 5.5-5.6 [4]. Slightly high muscle pH in the present study could be the result of stressful condition of transportation that depleted muscle glycogen prior to slaughter resulting in low residual levels of glucose and consequently increasing the pH of the meat. Our results are in accord with previous reports [17, 18], that diets did not affect muscle temperature and pH values of the goat carcass.

The color is one of the principle meat quality characteristics that determine consumer purchasing decision. The meat color changes are closely associated with fat, pigment, microbial load, pH and age/growth rate of animals [2, 19]. The lack of variation in meat color in the present study could be ascribed to the similarity in the age of the goats. These results are in accord with the findings of Obeidat et al. [20], who reported no differences in L*, a*, and b* values of goats fed a diet containing 16% CP. Contrary, Arsenos et al. [21] reported a significant difference in the color attributes of goat meat kept in pasture supplemented with protein. The discrepancy could be attributed to differences in feeding regimen in the two studies. The WHC is another important meat quality characteristic which influences meat product yield, which in turn has

Table 7 Two-way analysis of variance for effect and interaction of dietary protein and infection of proportion of saturated fatty acids in meat lipid from goats fed high and low protein diets infected or not infected with *Haemonchus contortus.*

Effect	df	C8:0	C10:0	C12:0	C13:0	C14:0	C15:0	C16:0	C:17:0	C18:0	C20:0
		P-Value (Significant at *P*<0.05)									
Protein (P)	1	0.815	0.593	0.238	0.193	0.245	0.280	0.361	0.840	0.252	0.002
Infection (I)	1	0.128	0.428	0.364	0.383	0.224	0.252	0.076	0.188	0.125	0.006
P x I	1	0.488	0.788	0.451	0.355	0.767	0.562	0.237	0.479	0.286	0.091

P × I= protein × infection interaction.
The value shows P values of ANOVA and significant level is P <0.05; Degree of freedom = 1

Table 8 Proportion of monounsaturated fatty acid in meat lipid from goats fed high and low protein diets and infected or not infected with *Haemonchus contortus.*

	High protein		Low protein	
Fatty acid (%)	Infected	Non-infected	Infected	Non-infected
C14:1	1.97 ± 0.88	1.11 ± 0.25	0.90 ± 0.05	0.87 ± 0.40
C15:1	0.53 ± 0.23	0.24 ± 0.11	0.17 ± 0.07	0.20 ± 0.12
C16:1	4.36 ± 0.82	4.18 ± 0.20	3.98 ± 0.21	3.25 ± 0.38
C17:1	1.89 ± 0.44	1.41 ± 0.15	1.46 ± 0.12	1.19 ± 0.12
C18:1n9c	40.0 ± 1.70	43.8 ± 0.51	41.96 ± 1.61	43.1± 1.56
C20:1 cis 11	0.04 ± 0.01	0.09 ± 0.04	0.07 ± 0.02	0.06 ± 0.02

The values are presented as a mean ± standard error of three replicates.

Table 9 Two-way analysis of variance for effect and interaction of dietary protein and infection on the proportion of monounsaturated fatty acids in meat lipid of goats fed high and low protein diets and infected or not infected with *Haemonchus contortus.*

Effect	df	C14:1	C15:1	C16:1	C17:1	C18:1n9c	C20:1 cis 11
		P-Value (Significant at *P*<0.05)					
Protein (P)	1	0.222	0.202	0.206	0.228	0.662	0.863
Infection (I)	1	0.401	0.393	0.367	0.171	0.120	0.531
P × I	1	0.425	0.298	0.570	0.684	0.391	0.291

P × I= protein × infection interaction.
The value shows P values of ANOVA and significant level is P <0.05; Degree of freedom = 1

Table 10 Proportion of polyunsaturated fatty acid in meat lipid of goats fed a high and low protein diets and infected or not infected with *Haemonchus contortus.*

	High protein		Low protein	
Fatty acid (%)	Infected	Non-infected	Infected	Non-infected
C18:2nc	3.05 ± 0.76	2.27 ± 0.12	2.14 ± 0.32	2.21± 0.13
C18:2n6t	0.22 ± 0.12	0.25 ± 0.03	0.15 ± 0.06	0.2 ± 0.07
C18:3n6-gama	0.25 ± 0.01 a	0.12 ± 0.07 b	0.15 ± 0.07 b	0.01± 0.00 c
C18:3n3-alpha	0.37 ± 0.06	0.41 ± 0.06	0.41 ± 0.03	0.43 ± 0.30
C20:2 cis 11,14	0.04 ± 0.02 ab	0.1 ± 0.02 b	0.08 ± 0.01 a	0.04 ± 0.01 ab
C20:3 cis 11, 14, 17	0.12 ± 0.03	0.17 ± 0.04	0.12 ± 0.03	0.11 ± 0.01

The values are presented as a mean ± standard error of three replicates.
Means within treatment in the same row with different letters are significantly different (*P*<0.05).

Table 11 Two-way analysis of variance for effect and interaction of dietary protein and infection on the proportion of polyunsaturated fatty acids in meat lipid of goats fed high and low protein diets and infected or not infected with *Haemonchus contortus*.

Effect	df	C18:2nc	C18:2n6t	C18:3n6-gama	C18:3n3-alpha	C20:2 cis 11, 14	C20:3 cis 11, 14, 17
		P-Values (Significant at *P*<0.05)					
Protein	1	0.279	0.463	0.067	0.574	0.484	0.257
Infection	1	0.427	0.568	0.026	0.533	0.484	0.485
P × I	1	0.341	0.848	0.894	0.850	0.016	0.257

P × I = protein × infection interaction.
The value shows P values of ANOVA and significant level is P <0.05; Degree of freedom = 1

economic implications as well as the effect on eating quality [22]. The values obtained for WHC in the present study are similar to those reported earlier [15], whose values for WHC of Majorera kids fed different diets ranged between 0.31 g and 0.72 g. Our results are in accord with the previous findings [15, 22], who reported no substantial effect of diet on WHC of goat meat. Additionally, cooking loss (CL) is another important meat quality characteristic that results from a reduction in meat weight after cooking. The CL of meat is determined by various factors such as cooking method, time and temperature [22]. The CL percentages obtained in this study were 26 vs 23 for goats fed HP and LP diets, respectively. The diet did not have any effect on CL of goat meat in this study. These results are in agreement with the findings of Adam et al. [22] and Hwangbo et al. [23], who observed that dietary treatments did not affect CL of goat meat. Meat tenderness is considered to be the most important meat quality characteristic that determines consumer satisfaction. Assessment of factors affecting goat meat tenderness is especially important because of its lower tenderness compared to lamb and beef [2]. Goat meat tenderness value is often in acceptable range because of higher collagen content, lower collagen solubility, and less intramuscular fat [4]. The tenderness values reported in this study were 5.21 vs 4.99 kg of goats fed an HP and LP diets, respectively. Similar results have been reported previously in goats, where it was found that diet did not affect the shear force value of chevon [24, 20]. The lack of differences in tenderness values in this study could be the result of similarity in the age of the goats.

The dressing percentage is a measure of carcass weight relative to the live weight of the animal at slaughter. The values for dressing percentage of goat meat in this study are in accord of previous studies [25, 19]. Our results agreed with Atti et al. [26], who reported no substantial alteration in dressing percentage of goats fed diets containing 108 and 158 g CP/kg DM. Dietary treatment is well-known to affect the proportion of carcass composition of farm animals, especially fat when there is dissimilarity in energy content of the diet [17]. The lack of significant differences in carcass proportion of goats fed HP or LP diets may be attributed to the similarity in dressing percentage of the carcass. These results are in agreement with other findings [23] where goats fed 18% and 20% CP did not differ in the proportion of carcass tissue composition. Other related studies reported that the proportion of muscle, bone, and adipose tissue appeared not to be depended on the increase of CP in the ration [25, 26].

The results of the proximate analysis of the goat meat showed that principal chemical constituents, particularly protein that significantly contributes to the nutritive value of meat remained the same in all treatments. The lack of substantial difference in protein content between the two treatments suggests that 16% CP in LP diet was sufficient for growing meat goat. These observations are similar to those reported by Atti et al. [26], who found no significant differences in the chemical characteristics of *supra spinatus* muscle of male goat kids fed 108 g/kg CP/DM and 128 g/kg CP/DM. Similar results were also reported by Obeidat et al. [20], who found no change in chemical analysis of the goat meat of indigenous Greek goat kids supplemented with 192 g/kg CP/DM. However, infection with *H. contortus* affected ash and lipid proportions in goat meat. The observed lower ash value of the infected goat meat suggests that the absorption of minerals was negatively affected by the GINs infection. Additionally, the observed higher lipid value of the infected goat meat suggests that gastrointestinal parasitism with the nematode greatly affects lipid metabolism of the host animal under certain feeding regimen.

The most abundant fatty acids in the meat lipid were palmitic (C16:0), stearic (C18:0) and oleic (C18:1n9) acids, which accounted for a total of 82.33% and 85.25% of total fatty acids in goats fed HP and LP diets, respectively. These effects are alike to those of Lee et al. [2], who reported that palmitic, stearic and oleic acids constituted 73.1%, 75.3%, and 71.4%, respectively, of total fatty acid composition in *longissimus dorsi* muscle and subcutaneous fat from goats fed hay, concentrate, and hay plus concentrate. Nevertheless, the values reported in the current study are somewhat higher than those mentioned by Lee et al. [2]. The fluctuation in results of the two studies could partly be ascribed to differences in feed composition and partly to the age of goats used in the study. The observed variation in arachidic (C20:0) acid between infected goats fed HP and LP diets suggests that nematode infection might cause an effect on host metabolism of certain fatty acids, an observation that merits further investigation. Saturated fatty acids such as lauric (C12:0), myristic (C14:0) and palmitic (C16:0) acid increase the level of cholesterol in the blood, thus higher risk of cardiovascular diseases [2]. In the current study, the proportion of three saturated fatty acids was found to be 0.7 vs 0.47%, 7.29 vs 6.03% and 48.22 vs 48.67% in meat lipids from goats fed high and low protein diets, respectively. The high gamma-linolenic (C18:3n6-gama) acid in meat lipid from infected goats fed HP diet suggests that some polyunsaturated fatty acids play immunomodulation roles in the host animal under gastrointestinal nematode parasitism.

In conclusion, our results demonstrated that feeding goats a higher level of crude protein (25% CP) did not influence temperature, pH, color, WHC, CL, WBSF, dressing percentage, carcass proportion and proximate analysis of goat meat. However, infection influenced ash, lipid and gamma-linolenic acid of the goat meat. It was also observed that diet and *H. contortus* infection in goat appeared to influence arachidic acid in the meat. The interaction between dietary protein and infection increased the proportion of cis11, 14 eicosadienoic acids in goat meat. It can be concluded that surplus protein supplementation did not affect the carcass composition and meat quality characteristics of goats. Therefore, locally available protein sources can be used to supplement growing goats to minimize production cost. The effect of infection on some chemical parameters such as ash, lipid and gamma-linolenic acid that tends to influence meat quality requires further investigation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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