Study of Meat Quality of Goats Fed Rice Straw Supplemented with *Moringa* (*Moringa oleifera* Lam.) Foliage

Nasrin Sultana[1,*], Abd Razak Alimon[2], Khan Shahidul Huque[1], Awis Qurni Sazili[2], Halimatun Yaakub[2], S. Mohammad Jahangir Hussain[1] and Nani Gopal Das[1]

Bangladesh Livestock Research Institute, Savar, Dhaka-1341, Bangladesh
[2] Department of Animal Science, Faculty of Agriculture, University Putra Malaysia, Serdang-43400, Selangor, Malaysia

[*]*Corresponding author's email: nassul2003 [AT] yahoo.com*

ABSTRACT—*The study was conducted to investigate the effects of dietary levels of Moringa foliage on the fatty acid profiles and antioxidant activity in the muscles of Black Bengal goats. Thirty buckling of 6 to 8 months of age with an average initial live weight (LW) of 8.07 (±0.87) kg were allocated into five different diets having six in each group for 105 days. Keeping molasses treated rice straw ad libitum as sole diet, 70% of dietary dry matter (DM) requirement was supplied with a conventional concentrate which was replaced with Moringa foliage in treatment diets at 25, 50, 75 and 100%, respectively. Consequently, Moringa foliage intake represented 17.8, 35.6, 52.9 and 67.2% of total diet or 0.85, 1.7, 2.5 and 3.4% of LW in treatment diets keeping the daily gain and dietary intake unchanged (P>0.05). The dietary DM intake and LW gain was 4.6 to 4.8% of average LW and 67.3 to 79.3 g/d. The ratio of polyunsaturated fatty acids (PUFA) n-6 to n-3 was significantly (P<0.01) reduced in diet containing 67.2% Moringa foliage, from 4.2 to 2.4% and 3.8 to 2.6% in Longissimus dorsi (LD) and Semitendinosus (ST) muscles of goats, respectively. The saturated fatty acid was reduced from 47.7 to 39.8% and 45.8 to 39.3%, respectively in both muscles. The lipid oxidation was reduced linearly (y=-0.1x+0.698, r^2=85 for LD; y=-0.073x+0.675, r^2=95 for ST) with increasing supplementation of Moringa foliage. It was concluded that supplementation of Moringa foliage up to 67.2% of diet will produce meat with high PUFA.*

Keywords— Intake of *Moringa* Foliage, Black Bengal Goat, Fatty Acid Profile, Antioxidant Activity

1. INTRODUCTION

The scarcity of quality feed is considered to be the major constraint in rearing small ruminant animals; they are usually raised on crop residues, native pasture, agro-industrial by products and non-conventional feed resources, mainly shrubs and trees that are generally low in protein. In order to alleviate the problems, there is a need to search for alternative quality feeds that can be cultivated by farmers at low costs. It was reported that the intake, digestibility and body weight gain of sheep was improved when a low-quality grass diet was supplemented with *Sesbaia sesban* tree leaves [1]. Moringa (*Moringa oliefera*), a fodder tree native to sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan and distributed widely throughout the tropics, may be a potent protein source for ruminant [2]. The leaves of this tree possess nutritious, therapeutic and prophylactic properties with crude proteins varying from 23 to 40% [3, 4]. They have high antioxidant capacity due to the presence of high quantity of polyphenols [2, 5 and 6]. Moringa leaves exhibit high antioxidant activities due to the presence of carotenoids, vitamins, minerals, amino acids, sterols, glycosides, alkaloids, flavonoids and phenolics [6]. It was reported that both phenolic and flavonoid compounds in *Moringa* leaves not only influence lipid oxidation potential, but may also influence meat quality and fatty acid composition [2]. In addition, phenolic compounds have merits of increasing lenolieic acid concentrations and yielding meat of a lighter color [7, 8].

The proportion of saturated fatty acids (SFA) is often high in ruminant muscle lipids [9] and the poly-unsaturated fatty acids (PUFA) are low, because dietary unsaturated fat is hydrogenated in the rumen [10] by the action of rumen microbes. Excessive consumption of PUFA can increase the formation of oxygen radicals and aldehydes, which is thought to be partly responsible for carcinogenesis and ageing [11]. On the other hand, a low intake of saturated fat and increased PUFA to SFA ratio are associated with a low risk of human coronary heart disease (Hu *et al*., 1999). *Moringa* leaves are rich in n-3 PUFA [13, 14] and the diets of can affect the fatty acid profile of goat meat [15, 16]. Therefore, the work was undertaken to evaluate the effect of replacement of conventional concentrate with *Moringa* foliage on dietary intake, daily gain, meat quality, fatty acid composition and antioxidant activity of *longissimus dorsi* (LD) and *Semitendinosus* (ST) muscles in Black Bengal goats.

2. MATERIALS AND METHODS

2.1 Preparation of Rice Straw and Moringa Foliage

Rice straw (RS), chopping into 2 to 3 cm pieces, was mixed thoroughly with 2.5% molasses on dry matter (DM) basis prior to feeding animals on daily basis. The physical and chemical composition of molasses treated RS is presented in Table 1.

Moringa foliage was collected from the *Moringa* plots of Bangladesh Livestock Research Institute (BLRI), Savar, Dhaka by harvesting the re-growth of stem and leaves of 56 days after trimming, which maintained a leaf and stem ratio of 2:1. During feeding trial, this foliage was mixed with soybean oil, vitamin-mineral premix, DCP and common salt at the rate of 4.5, 0.5, 1 and 1%, respectively on the basis of DM. This harvested biomass was chopped into 1 cm pieces, dried in sun for 36 hours and stored in plastic bags until feeding. It was consisted of leaves, petioles, soft rachis and stems, and the height of trees during harvesting was 120 (±8.5) cm. The physical and chemical composition of this *Moringa* foliage mixture is presented in Table 1.

2.2 Preparation of Concentrate Mixture

A concentrate mixture was prepared by mixing conventional concentrate ingredients (broken maize, soybean meal, kheshari bran, wheat bran, soybean oil, vitamin mineral premix, DCP and salt) in order to supplement the experimental animals. The physical and chemical composition of the conventional mixture on DM basis is presented in Table 1. The concentrate mixture and *Moringa* foliage mixture were iso-caloric and iso-nitrogenous.

Table 1. Physical and chemical composition of dietary components

Ingredients (%DM)	**Molasses treated RS**	***Moringa* foliage mixture**	**Concentrate mixture**
Broken maize	-	-	36
Soybean meal	-	-	42
Kheshari bran	-	-	8
Wheat bran	-	-	7
Soybean oil	-	4.5	4.5
Vitamin mineral premix	-	0.5	0.5
Dicalcium phosphate (DCP)	-	1.0	1.0
Common salt	-	1.0	1.0
Molasses	2.5	-	-
Chemical Composition (% DM)			
DM	90.17	89.67	89.53
OM	83.54	89.42	93.10
CP	5.52	23.91	24.17
EE	2.18	5.13	5.23
ADF	35.78	19.01	12.36
NDF	63.31	32.38	40.66
ME, MJ/kg DM	5.26	11.36	11.31

RS, rice straw; DCP, dicalcium phosphate; DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; ADF, acid detergent fiber; NDF, neutral detergent fiber; ME, metabolizable energy

2.3 Selection of Experimental Animals

A total of thirty Black Bengal buckling of 6 to 8 months of age with an average live weight (LW) of 8.07 (± 0.87) kg were allocated into five different dietary groups having six in each group. All goats were treated with prescribed doses of antihelminthes (Endex, Novartis, India limited) before the commencement of the experiment. The sheep were housed in individual pens measuring 1.25 m^2 (1.25 m × 1.0 m) and provided individual feeders and water buckets. The bucklings were allowed 14 days of adjustment period during which they were gradually accustomed to experimental diets and management.

2.4 Diets of the Experiment

The calculated DM requirements of all animals of all dietary treatments, according to NRC [17], was offered by concentrate and/or *Moringa* foliage mixture by 70%, while molasses treated RS was offered ad-libitum as a basal diet. The diet of control group, thus, was consisted of molasses treated RS (ad *libitum*) and concentrate mixture (70% of DM requirement). In case of treatment groups, the calculated amount of concentrate was replaced with *Moringa* foliage mixture at the rate of 25, 50, 75 and 100%, respectively. Therefore, the supply of *Moringa* foliage mixture to different treatment groups was 17.5, 35, 52.5 and 70% of total DM requirement of animals. The requirements of concentrates and/or *Moringa* foliage mixture of all animals were adjusted by taking fasted LW of every animal by every 7 days interval during the whole trial period. The stipulated amount of molasses treated RS, concentrate mixture and/or *Moringa*

foliage for each lamb were weighed once a day. They are divided in to two equal parts; one part was offered at 08:00 and another part was given at 15:00. In case of concentrate and *Moringa* foliage combination diets, concentrate was offered prior to *Moringa* foliage. The molasses treated RS was offered after concentrate and *Moringa* foliage feeding in separate feeders. The trial was conducted for a period of 105 day during which fresh and clean was supplied ad *libitum* to all animals. The feed offered and refusals were recorded on a daily basis throughout the experimental period in order to determine daily DM intake. The DM content of feed samples and refusals was analyzed on the same day the sample was collected, and representative dry samples were stored for further chemical analysis.

2.5 Slaughtering and Sampling of Goat Muscles

At the end of the experiment, four goats were randomly selected from each treatment for slaughtering after keeping fasted for about 24 hours. All the animals were slaughtered according to the 'Halal' method by severing the major vessels of the throat by a transverse cut. Approximately 150 g of *Longissimus dorsi* (LD) and *Semitendinosus* (ST) muscles were sampled from the left side of the carcass after chilling at 4°C and stored in -80°C for meat color determination. All visible fat was removed from the meat surface, vacuum packed in polythene packs and stored at -80°C until analysis.

2.6 Carcass Characteristics

Immediately after the animals were dressed, about 10 g of meat was taken from the LD muscle and pH was measured following the procedure of Bendall [18]. The drip loss and cooking loss of meat sample was determined at 17^{th} day postmortem according to a method described by Honikel [19].

Meat tenderness was objectively measured at 17 days postmortem using a Volodkevich bite jaw shear force test by preparing LD and ST muscle samples according to Sazili *et al.*, [20]. The analysis was based on the mechanical force (kg) required to shear the muscle fibers of a cooked meat sample. From each of the cooked samples, at least 3 replicate blocks (1×1×2 cm) were cut parallel to the direction of the muscle fibers as possible. Each block was sheared with the Volodkevich jaw on the texture analyzer (TA.HDplus texture analyzer, Micro System, Surrey, UK) in the centre and perpendicular to the longitudinal direction of the fibers [21]. Shear force values were reported as the average of all block values of each individual sample. The higher shear force value indicates tougher meat, whereas tender meat was indicated by a lower shear force.

The meat color values were determined using a Color Flex spectrophotometer (Hunter Lab Reston, VA, USA) based on the International Commission on Illumination (CIE) Lab-values (also known as L*, a* and b*) with D56 illuminant and 10° standard observer tristimulus values (X,Y,Z) and reflectance at specific wavelengths (400- 700 nm) to express the meat colour data. The three fundamental CIE (Commission on Illumination) Lab outputs: L*, lightness on a scale runs from 0 indicating black (all light absorbed) to 100 indicating white (all light reflected); a*, redness on a scale span from +60 (red) to -60 (green); and b*, yellowness ranging from +60 (yellow) to -60 (blue) were measured. The frozen muscle samples (LD and ST) were transferred from -80 °C freezer into a 4 °C chiller on the 17^{th} day. Samples were allowed to thaw overnight prior to analysis. For each sample, a total of three readings of L*, a* and b* were recorded and then averaged [22]. Hue angle was calculated as $\tan^{-1}(b/a)*180/\pi$, whereas saturation index or chroma (a measure of color vividness) was calculated as $\sqrt{(a2 + b2)}$ [23].

2.7 Chemical Composition

Samples of molasses treated RS, concentrate mixtures, *Moringa* forage, feed refusal and faces in each animal during the collection period were taken separately and thoroughly mixed together according to animal. All mixed samples (Feed and refusal) were ground through 1 mm sieve and sub-sample was taken for subsequent chemical analysis. The proximate composition of both feed and meat samples were done according to AOAC [24]. The Neutral detergent fiber (NDF) and acid detergent fiber (ADF) of feed samples were determined according to the method of Van Soest *et al.*, [25].

2.8 Lipid Extraction and Fatty Acid Analysis

The lipid extraction for fatty acid analyses of the LD and ST muscles were based on procedures described by Folch *et al.*, [26] and modified by Ebrahimi *et al.*,[27, 28]. The data of individual fatty acids were expressed as the percentage of total identified fatty acid. Oxidation of lipid was measured using thiobarbituric acid-reactive substances (TBARS) according to the method of Lynch and Frei [29], modified by Mercier *et al.*, [30]. The TBARS were calculated from a standard curve of 1, 1, 3, 3-tetraethoxypropane and expressed as mg malondialdehyde (MDA) per kg sample. The fatty acid profile of fresh RS, *Moringa* foliage and concentrate mixtures are presented in Table 2.

Table 2. Fatty acid profiles (% of total fatty acid) of RS, *Moringa* foliage and concentrate mixture

Fatty acids	Straw	*Moringa* foliage	Concentrate Mixture
Total fatty acids (g/ 100 DM)	2.44	5.01	5.05
C14:0 (Myristic acid)	0.86	1.68	0.40
C15:0 (Pentadecanoic)	2.06	1.79	1.97
C16:0 (Palmitic acid)	28.81	28.14	27.47
C18:0 (Stearic acid)	13.29	8.00	9.50
C18:1n9 (Oleic acid)	45.45	25.88	52.73
C18:2n6 (linoleic)	2.74	1.97	1.47
C18:3n6(γ-linolenic)	2.31	2.36	1.48
C18:3n3 (α-linolenic)	4.49	30.17	4.96
Total SFA	45.01	39.62	39.36
Total MUFA	45.45	25.89	52.73
Total PUFA n-3	4.49	30.17	4.96
Total PUFA n-6	5.05	4.33	2.95
Total PUFA	9.54	34.50	7.91
Total USFA	54.99	60.38	60.64
n-6 : n-3	1.12	0.14	0.59
USFA: SFA	1.22	1.52	1.54
PUFA: SFA	0.21	0.87	0.20

SFA, sum of C12:0, C14:0, C15:0, C16:0, C17:0 and C18:0; MUFA, sum of C16:1, C17:1 and C18:1n-9[4]; PUFA n-3, sum of C18:3n-3, C20:5n3, C22:5n-3 and C22:6n-3; PUFA n-6, sum of C18:2n-6, C18:3n-6, C20:4n-6; Total USFA, MUFA + PUFA; n-6: n-3 fatty acid ratio, (C18:2n-6+ C18:3n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n3 + C22:5n-3 + C22:6n-3)

2.9 Statistical Analysis

The data were subjected to a one way ANOVA as a completely randomized design using the GLM procedure in SAS [31]. The differences between means were compared using the Duncan's multiple range test [32].

3. RESULTS AND DISCUSSION

3.1 Intake of Diets and LW Gain of Goats

The LW of buckling, LW gain and their daily DM intake from different diets are presented in Table 3. The final LW of the experimental goats and their daily LW gains between the treatments were not significantly different (P>0.05). The average daily gains ranged from 67.3 to 79.3 g/d. Similarly, there were no significant (P>0.05) differences in DM and CP, intakes among dietary groups. The DM intake from RS and concentrate mixtures ranged from 157.4 to 169.5 and 385.6 to 406.1 g/d, respectively, which resulted in total DM intake of 543.3 to 577.1 g/d. Therefore, based on the levels of replacement of concentrate mixtures by *Moringa* foliage (25%, 50%, 75% and 100%, respectively), it can be calculated that the intake of *Moringa* foliage in different treatment diets were 99.1, 203.1, 304.0 and 387.7 g/d, respectively in the diets containing 17.5%, 35%, 52.5% and 70% *Moringa* foliage, and they represented 17.8%, 35.6%, 52.9% and 67.2% of total dietary DM intake.

Table 3. Effects of inclusion level of *Moringa* foliage on the intake and LW gain of goats

Variables	Inclusion of *Moringa* foliage to diets (% DM)					P-value
	0	17.5	35	52.5	70	
Initial LW (kg)	8.2±0.96	7.9±1.07	8.0±0.73	8.2±0.81	8.1±1.17	0.99
Final LW (kg)	15.2±1.24	15.4±1.18	16.1±0.82	16.3±1.19	14.9±0.84	0.88
LW gain (g/d)	67.3±3.14	71.3±2.82	74.3±3.66	79.3±4.50	67.8±2.83	0.12
DM intake from molasses treated RS (g/d)	157.7±11.11	160.5±10.63	164.1±10.31	169.5±9.44	169.4±13.93	0.78
DM intake from concentrate (g/d)	385.6±22.83	396.4±19.52	406.1±19.19	405.3±22.31	387.7±27.84	0.77
Total DM intake (g/d)	543.3±45.54	556.9±48.3	570.2±28.1	574.8±45.7	577.1±41.33	0.98
Total DM intake (% LW)	4.6±0.14	4.8±0.11	4.7±0.13	4.7±0.12	4.8±0.23	0.30
DM intake from concentrate (%LW)	3.3±0.13	3.4±0.13	3.4±0.13	3.3±0.14	3.4± 0.22	0.21
CP intake (g/d)	98.0±7.10	107.0±9.32	111.0±6.3	111.0±8.8	112.0±9.6	0.74

[a,b,c]Means within rows with different superscripts are significantly different. LW, live weight; CP crude protein; DM, dry matter

The total DM intake represented 4.6%, 4.8%, 4.7%, 4.7% and 4.8% of LW of goats (Table 3) in diets consisted of 0, 17.5, 35, 52.5 and 70% *Moringa* foliage, respectively, which were 3.3%, 3.4%, 3.4%, 3.3% and 3.4% of LW in case of DM intake from concentrate. Based on the replacement levels of conventional concentrate, the intakes of DM from *Moringa* foliage represented 0.85%, 1.7%, 2.5% and 3.4% of LW of goats fed diets containing 17.5%, 35%, 52.5% and 70% *Moringa* foliage, respectively. The intake of CP among treatments varied from 98 to 112 g/d.

The intake of total DM in all dietary groups were higher than that of findings of Moyo *et al*., [5] who reported that intake of DM was 490 g/d in case of crossbred Xhosa lop-eared goat on sole *Moringa* leaves diet. The CP intake was increased with increasing DM intake. Mtenga and Shoo [33] reported a positive correlation between CP and DM intake.

3.2 Physical Characteristics of Meat

The pH of LD muscle, water holding capacity, tenderness and colour parameters of both LD and ST muscles are presented in Table 4. The pH of LD muscle was found similar among dietary groups (P>0.05) which ranged from 6.5 to 6.8. The drip loss of LD muscle was significantly lower (P<0.01) in diets consisted of 52.5 or 70% of *Moringa* foliage compared to other diets, while it did not differ (P>0.05) in case of ST muscle. Although cooking loss in LD muscle was not affected (P>0.01) with the inclusion of *Moringa* foliage in diets, in case of ST muscle it was found significantly higher (P<0.01) in diets containing 0% or 17.5% *Moringa* foliage diets compared to 70% *Moringa* foliage diet. The share force of LD muscle was found significantly higher (P<0.05) in diet containing 70% *Moringa* foliage compared to any other diets. It was found similar in ST muscle of goats fed diets consisted of 35% or 52.5% or 70% of *Moringa* foliage, which differed significantly with diets containing 0% or 17% of *Moringa* foliage. Among the meat colour parameters, the lightness (L*), Redness (a*), yellowness (b*) and chroma (C*) of LD muscle were not affected with the inclusion of *Moringa* foliage to diets. The range of lightness, redness, yellowness and chroma of LD muscle ranged from 42.0 to 46, 12.6 to 14.1, 15.2 to 15.9 and 13.9 to 14.9, respectively. Significantly higher amount of hue angle (44.9) (P<0.01) was found in diet containing 70% *Moringa* foliage, compared to other diets. The lightness and yellowness of ST muscle was also similar (P>0.05) in all dietary groups. However, the redness of ST muscle in diets containing 17.5% or 70% *Moringa* foliage were similar (P>0.05), which differed significantly (P<0.05) with that of other diets. The highest chroma of ST muscle was found in 70% *Moringa* foliage diet which differed significantly (P<0.05) with that of other diets. In general, it was observed that the supplementation of *Moringa* foliage tended to improve meat color characteristics in both LD and ST muscles.

Table 4. Effect of diets on the physical characteristics of LD and ST muscles of goats

Variables	Inclusion of *Moringa* foliage to diets (% DM)					P-Value.
	0	17.5	35	52.5	70	
LD muscle						
pH	6.5±0.07	6.8±0.12	6.8±0.01	6.7±0.12	6.7±0.04	0.41
Drip loss (%)	20.6±0.81^{a}	20.4±0.32^{a}	20.2±0.19^{a}	17.5±1.17^{b}	17.3±0.89^{b}	0.01
Cooking loss (%)	34.5±1.40	35.7±1.40	34.3±0.77	34.8±2.21	32.5±1.64	0.69
Shear force (kg)	1.0±0.03^{b}	1.0±0.04^{b}	1.1±0.04^{b}	1.1±0.03^{b}	1.2 ±0.03^{a}	<0.01
Lightness (L*)	42.5±2.45	42.0±1.30	42.5±0.28	43.2±0.15	46.3±1.25	0.23
Redness (a*)	13.2±0.36	14.1±0.48	13.2±0.68	13.6±0.34	12.6±0.34	0.22
Yellowness (b*)	15.2±0.02	15.3±0.35	15.3±0.68	15.9±0.51	15.7±0.64	0.82
Chroma (C*)	13.9±0.31	14.3±0.48	14.3±0.32	14.2±0.31	14.9±0.25	0.37
Hue angle (H^0)	40.6±1.06^{b}	40.7±0.86^{b}	40.8±0.91^{b}	42.0±0.44^{ab}	44.9±1.46^{a}	0.03
ST muscle						
Drip loss (%)	19.7±0.27	19.8±0.81	19.9±0.47	19.1±0.79	17.3±0.9	0.10
Cooking loss (%)	45.4±2.15^{a}	45.6±1.66^{a}	41.6±2.29^{ab}	40.9±0.86^{ab}	38.9±1.07^{b}	0.05
Shear force (kg)	1.4±0.04^{b}	1.4±0.02^{b}	1.6±0.11^{a}	1.6±0.05^{a}	1.7±0.03^{a}	<0.01
Lightness (L*)	38.8±2.13	38.9±1.28	39.5±0.56	39.8±0.5	41.7±2.05	0.65
Redness (a*)	11.0±0.30^{c}	12.9±0.62^{ab}	12.5±0.71^{bc}	12.6±0.53^{bc}	14.4±0.6^{a}	0.01
Yellowness (b*)	12.0±0.7	13.8±0.20	13.3±1.17	13.1±0.38	14.5±0.83	0.25
Chroma (C*)	10.7±0.27^{c}	12.7±0.32^{b}	12.6±0.66^{b}	12.3±0.41^{b}	14.6±0.15^{a}	<0.01

^{a,b,c}Means within rows with different superscripts are significantly different. L*, measure of darkness to lightness; B*, yellowness-greater value indicates more yellow color; C*, chroma or saturation index ($C^*=\sqrt{a^2b^2}$); H^0, Hue angle ($H^0 = \tan^{-1}(b/a)*180/\pi$); LD, longissimus dorsi; SD, Semitendinosus muscle

The similarity of the pH of warm carcass of different dietary groups suggests that the dietary treatments had no effect on the glycogen content of the meat at slaughter [34]. The mean pH values were within the range for goat [28, 35]. However, the values were higher than those reported by Teixeira *et al*., [36].

Drip loss and cooking loss are important quality criteria for the meat processing industry and the consumer (Offer and Trinick, 1983). The drip loss percentage ranged from 17.3 to 20.6% for LD muscle and 17.3 to 19.9% for ST muscle. The present drip loss values were comparable to the findings of Abdullah *et al*., [38] in Black Bengal goat fed different

energy levels, and was lower than that of Kadim *et al.*, [39] who obtained values between 33.3 to 41.0% in different muscles of Batina, Dhorfari and Jabal Akhdar breed of Omani goats. Conversely, the present drip loss values were much higher than that of the findings of Ebrahimi [27] and Karimi [40]. Variations in the results might be due to post mortem aging, breed differences, and differences in slaughter weight, age of animals, fat content of meat, location of the different muscles and method of measuring the drip loss. In general, supplementation of *Moringa* foliage tended to detract percent of drip loss in LD and ST muscles.

Cooking losses from chevon are of interest as the water that remains in the cooked product is the major contributor to sensation of juiciness [41]. The cooking losses of chevon are often close to or over 35% [41]. The values of cooking loss percentage of LD and ST muscle in the present study were from 32.5 to 35.7 and 38.9 to 45.6% respectively, which is supported by the aforesaid findings, but were, however, higher than those reported by Abdullah *et al.*, [38]. Cooking losses of the meat are possibly exacerbated by its limited fat content [42]. Kannan *et al.*, [43] reported that dietary treatments did not influence cooking loss in goats, while pH, sarcomere length and cooking conditions influence cooking loss of goat muscles.

The shear force (WBSF) values, ranging from 1.0 to 1.2 kg and 1.4 to 1.7 kg for LD and ST muscles, respectively, were lower than the findings of Ebrahimi [28] and Karami [40]. The lower WBSF values obtained may be due to the longer refrigeration and higher fat content in the muscles. The shear values depend on factors, such as, diets of the animals prior to slaughter, post mortem methodologies, the muscles sample and the method of sample preparation [41]. Karami, [40] observed that supplementation with antioxidant did not affect ($P>0.05$) the WBSF value of the ST muscle of goats, but did affect ($P<0.05$) the fresh LD muscle. Therefore, shear force values obtained in the present study for both LD and ST muscles of goats are considered within the tender meat range.

Supplementation of *Moringa* foliage was found to improve the color characteristics of goat muscle in the present study. Karami [40] observed that supplementation of *Andographic paniculata* and turmeric in goat diet tended to improve redness, vividness, tenderness, and reduced rate of discoloration in chevon during the post mortem aging period. Row steaks from pasture-fed beef improved meat color quality compared to grain- fed beef [44]. Luciano *et al.*, [45] postulated that diets based on herbage or concentrates did not affect the meat color characteristics, which contradicts the aforementioned findings. Color of meat depends upon many factors and their interaction, but chevon has been reported to have lower lightness and increased redness than lamb, mainly due to the fact that the amount of marbling (intramuscular fat) of goat carcasses is lower than lamb [43]. However, the results of the present study showed that supplementation with *Moringa* foliage to RS based diet improved the color of chevon lightness, redness, and vividness of color (chroma) in both LD and ST muscles of goats.

3.3 Proximate Composition

The proximate composition of LD and ST muscles in goats fed different diets are presented in Table 5. There were no significant differences in terms of moisture and ash content in both LD and ST muscles. Crude protein content of LD muscle was significantly ($P<0.05$) higher in diet consisted of 70% *Moringa* foliage than other treatment groups, while there was no significant ($P>0.05$) difference in protein content in ST muscles among treatments. However, fat content (ether extract) in both LD and ST muscles were significantly ($P<0.01$) lower in goats receiving 52.5 or 70% *Moringa* foliage in diets compared to that consisted of 0, 17.5 or 35% *Moringa* foliage. Increasing levels of *Moringa* foliage in the diets decreased fat content ($P<0.01$) without affecting the crude protein and ash content in both muscles.

Table 5. Proximate composition of LD and ST muscles of goats fed different level of *Moringa* foliage

Variables	Inclusion of *Moringa* foliage to diets (% DM)					P-Value
	0	17.5	35	52.5	70	
LD muscle						
Moisture	74.1±0.2	74.8±0.5	75.0±0.2	75.1±0.5	75.7±0.5	0.14
Crude protein	19.4±0.3^{b}	19.3±0.2^{b}	19.0±0.3^{b}	19.4±0.1^{b}	20.6±0.4^{a}	0.02
Ether extract	4.3±0.4^{a}	3.6±0.1^{a}	3.6±0.2^{a}	2.2±0.2^{b}	1.9±0.03^{b}	<0.01
Ash	1.01±0.02	1.0±0.1	1.2±0.1	1.1±0.03	1.1±0.04	0.46
ST muscle						
Moisture	74.4±0.2	74.8±0.6	74.5±0.5	75.4±0.5	76.1±0.3	0.08
Crude protein	19.4±0.3	19.2±0.2	19.8±0.3	19.4±0.3	19.4±0.1	0.43
Ether extract	3.8±0.2^{a}	3.5±0.2^{a}	3.2±0.3^{a}	2.2±0.3^{b}	1.8±0.3^{b}	<0.01
Ash	1.2±0.004	1.3±0.1	1.4±0.1	1.4±0.1	1.2±0.1	0.21

^{a,b,c} Means within columns with different superscripts are significantly different. LD, *longissimus dorsi*; ST, *semitendinosus* muscle.

3.4 Fatty Acid Profile in Muscles

The fatty acid composition of LD and ST muscles fed different levels of *Moringa* foliage is presented in Tables 6 and 7, respectively. Nineteen fatty acid were identified from both LD and ST muscles, which comprised of six saturated fatty

acids (SFA) (C12:0, C14:0, C15:0, C16:0, C17:0 and C18:0), four mono-unsaturated fatty acids (MUFA) (C16:1, C17:1, C18:1n9 and C18:1t-11), and nine poly-unsaturated fatty acids (PUFA) (C18:2n-6, C18:3n-6, C20:4n-6, C18:3n-3, C20:5n-3, C22:5n-3, C22:6n-3, CLA C9T-11 and CLA C12 T-10). Different levels of *Moringa* foliage in diets did not significantly ($P>0.05$) affect the concentration of most of the SFA in LD and ST muscles, namely lauric acid (C12:0), myristic acid (C14:0), pantadecanoic acid (C15:0), margaric acid (C17:0) and stearic acid (C18:0). However, palmitic acid (C16:0) in both LD and ST muscles of goats (25.2% and 25.9%, respectively) were found significantly ($P<0.05$) high in diet containing no *Moringa* foliage. Significantly higher amount of palmitic acid (C16:0) in both LD and ST muscles resulted in significantly ($P<0.05$) higher amount of total SFA (47.7 and 45.8, respectively) in diet containing no *Moringa* foliage, with no significant difference ($P>0.05$) between *Moringa* foliage supplemented diets at different levels.

Among the MUFA, palmitoleic acid (3.99%) in ST muscle was found significantly higher ($P<0.05$) in dietary group fed with 70% *Moringa* foliage, compared to any other dietary group, although other MUFA and their total proportion in both LD and ST muscles did not vary ($P>0.05$) with the inclusion of different levels of *Moringa* foliage to diets. Oleic acid (C16:1) was the single major contributor to the total MUFA of LD (38.0% to 41.3%) and ST (36.2 to 41.2%) muscle lipids of goats in all dietary groups. The vaccinic acid (C18:1trans-11) in LD muscle lipid was increased ($P>0.05$) with the increase of *Moringa* foliage in diets, while the ST muscle did not follow any trend.

The total PUFA in LD and ST muscle lipids was significantly ($P<0.001$) increased with increasing levels of *Moringa* foliage in diets. Among the identified PUFA in LD muscle, the levels of docosahexaenoic, α-linolenic and eicosopentaenoic acids were statistically similar in *Moringa* foliage supplemented diets, but significantly different from concentrate based diet. The level of linoleic acid in diet containing 70% *Moringa* foliage *was* found similar to diet containing 52.50% *Moringa* foliage, but significantly higher than other diets. The variation in the level of docosahexaenoic acid between control and 70% *Moringa* foliage diet was significant ($P<0.05$), whereas other diets did no differ significantly. The level of CLA C12T10 acid in LD muscle was similar in dietary groups fed 52.5 or 70% *Moringa* foliage, which were significantly higher ($P<0.001$) than other diets. In case of Arachidonic acid, gama-linolenic acid (C18:3n-6) and CLA C9T11, no significant difference was found ($P>0.05$) among dietary groups in LD muscles. The content of PUFA n-6 and n-3 acids of LD muscle in *Moringa* foliage supplemented diets were similar, but significantly higher ($P>0.05$) than control diet.

Among the identified PUFA in ST muscle lipids, the level of linoleic acid between control and 70% *Moringa* foliage diet differed significantly ($P<0.05$), however differences between other diets were not significant. The level of docosapentaenoic, α-linolenic, eicosopentaenoic and Docosahexaenoic acid was found similar ($P>0.05$) in diets containing 52.5% or 70% *Moringa* foliage, but significantly higher ($P<0.05$) than other diets. Similar amount of arachidonic acid in ST muscles of goats ($P>0.05$) were found in all *Moringa* foliage supplemented diets, but significantly higher ($P<0.05$) than that of control diet. The level of CLA C9T11 or CLA C12T10 in different dietary groups did not differ significantly in ST muscle. All the diets containing varying level of *Moringa* foliage had similar level of PUFA n-6 acids which were significantly higher than that in control diet. The level of PUFA n-3 in the diets containing 52.5% or 70% *Moringa* foliage were similar, but significantly higher than that in other diets. The total PUFA n-6 and n-3 contents in ST muscle was significantly increased ($P<0.01$) with increasing supplementation of *Moringa* foliage. Total n-3 PUFA in both LD and ST muscles in *Moringa* foliage and *Moringa*-concentrate diets was significantly higher ($P<0.05$) than the control diet. The total CLA in LD muscle was similar in 52.5% or 70% *Moringa* foliage diets, but significantly higher than control, while the differences among the treatments in ST muscle were not significant ($P>0.05$).

The PUFA ratios of n-6 and n-3 in LD muscles were similar in ($P>0.05$) *Moringa* foliage diets, but they were significantly higher than control diet. However, that in ST muscle did not show any statistical difference with the inclusion of *Moringa* foliage to diets. The n-6: n-3 PUFA ratios ranged between 2.1 to 4.2 and 2.6 to 3.8% respectively for LD and ST muscles. The PUFA and SFA ratios in both LD and ST muscles were significantly higher ($P<0.01$) in *Moringa* supplemented diets compared to the *Moringa* free diet. The range in the ratio of PUFA to SFA in LD and ST muscles were 0.12 to 0.33 and 0.19 to 0.37, respectively.

Table 10. Fatty acid composition of LD muscles of goats fed different levels of *Moringa* foliage

Fatty acid profile	Inclusion of *Moringa* foliage to diets (%DM)					P-value
	0	17.5	35	52.5	70	
C12:0 (Lauric)	0.48±0.40	0.50±0.22	0.07±0.01	0.49±0.11	0.29±0.05	0.13
C14:0 (Myristic acid)	1.80±0.11	1.51±0.22	1.68±0.19	1.50±0.19	1.57±0.20	0.60
C15:0 ((Pentadecanoic)	0.74±0.21	1.09±0.26	0.64±0.06	1.50±0.25	1.16±0.11	0.14
C16:0 (Palmitic acid)	25.18±0.35^{a}	21.11±0.54^{b}	20.16±0.56^{c}	20.18±0.14^{c}	20.26±0.40^{c}	<0.01
C17:0 (Margaric acid)	0.75 ±0.18	1.36±0.20	1.40±0.11	1.44±0.33	1.18±0.14	0.09
C18:0 (Stearic acid)	18.71±2.20	19.21±1.6	16.34±1.24	16.03±0.91	15.35±0.71	0.07
C16:1 (Palmitoleic acid)	2.74±0.17	2.05±0.10	2.72±0.13	2.42±0.25	2.76 ±0.32	0.13
C17:1(Margaric acid)	1.00±0.13	1.29±0.20	1.09±0.09	1.26±0.3	1.15±0.11	0.06
C18:1n9 (Oleic acid)	39.43±2.06	38.37±1.40	41.30±2.13	38.01±1.36	38.68±1.3	0.34
C18:1t-11(Vaccenic acid)	2.34±0.0.31	2.50±0.15	2.90±0.12	2.97±0.66	3.01±0.45	0.38
C18:2n6 (linoleic)	2.69±0.50^{d}	3.84±0.6^{dc}	4.61±0.41^{bc}	5.70±0.13^{ab}	6.03±0.19^{a}	<0.01
C20:4n6 (Arachidonic acid)	1.28±0.33	2.04±0.4	1.91±0.42	2.63±0.28	2.60±0.30	0.16
C22:5n3 (Docosapentaenoic)	0.24±0.09^{b}	0.94±0.07^{a}	0.69±0.07^{a}	0.83±0.13^{a}	0.88±0.09^{a}	<0.01
C18:3n3 (α-linolenic)	0.27±0.09^{b}	0.63±0.13^{ab}	0.80±0.20^{a}	0.74±0.96^{a}	0.78±0.77^{a}	0.04
C18:3n6 (γ-linoleic)	0.67±0.31	0.60±0.22	0.74±0.20	0.58±0.10	0.81±0.12	0.95
C20:5n3(Eicosapentaenoic)	0.29±0.09^{b}	0.70±0.11^{ab}	0.68±0.05^{ab}	0.89±0.09^{a}	0.81±0.23^{a}	0.04
C22:6n3(Docosahexaenoic)	0.30±0.08^{b}	0.85±0.07^{ab}	0.95±0.2^{ab}	0.96±0.17^{ab}	1.40±0.40^{a}	0.04
CLA C9T11	0.85±0.19	0.89±0.07	0.92±0.09	1.20±0.20	1.05±0.08	0.39
CLA C12T10	0.42±0.07^{b}	0.50±0.02^{b}	0.44±0.01^{b}	0.71±0.04^{a}	0.86±0.12^{a}	<0.01
Total SFA	47.7±0.45^{a}	44.8±0.74^{b}	40.3±1.90^{b}	41.1±1.52^{b}	39.8±1.0^{b}	<0.01
Total MUFA	45.5±1.8	44.2±1.4	48.0±1.9	44.7±2.17	45.0±1.58	0.27
Total PUFA	5.7±1.42^{b}	9.6±1.26^{a}	10.4±0.45^{a}	12.3±0.60^{a}	13.3±0.58^{a}	<0.01
PUFA n-6	4.6±1.12^{b}	6.5±1.13^{a}	7.3±0.28^{a}	8.9±0.23^{a}	9.4±0.31^{a}	<0.01
PUFA n-3	1.1±0.33^{b}	3.1±0.32^{a}	3.1±0.33^{a}	3.4±0.38^{a}	3.8±0.4^{a}	<0.01
Total CLA	1.3±0.22^{b}	1.4±0.08^{ab}	1.4±0.11^{ab}	1.9±0.24^{a}	1.9±0.15^{a}	0.04
n-6 : n-3 ratio	4.2±0.61^{a}	2.1±0.32^{b}	2.3±0.26^{b}	2.6±0.21^{b}	2.4±0.29^{b}	<0.01
PUFA: SFA ratio	0.1±0.03^{c}	0.2±0.03^{b}	0.3±0.02^{ab}	0.3±0.02^{a}	0.3±0.01^{a}	<0.01

LD, *longissimus dorsi*; $^{a, b, c}$ Means within columns with different superscripts are significantly different. SFA, sum of C12:0, C14:0, C15:0, C16:0, C17:0 and C18:0; MUFA, sum of C16:1, C17:1 and C18:1n-9[4]; PUFA n-6, sum of C18:2n-6, C18:3n-6, C20:4n-6; PUFA n-3, sum of C18:3n-3, C20:5n3, C22:5n-3 and C22:6n-3; Total CLA, sum of cis-9 trans-11 CLA and cis-12 trans-10 CLA; PUFA n-6: n-3 fatty acid ratio, (C18:2n-6+ C18:3n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n3 + C22:5n-3 + C22:6n-3).

Table 11. Fatty acid composition of ST muscles of goats fed different levels of *Moringa* foliage

Fatty acid profile	Inclusion of *Moringa* foliage to diets (%DM)					P-value
	0	17.5	35	52.5	70	
C12:0 (Laruic)	0.69±0.23	0.52±0.28	0.25±0.05	0.52±0.14	0.13±0.02	0.20
C14:0 (Myristic acid)	2.30±0.34	1.73±0.22	1.24±0.09	1.88±0.24	1.97±0.37	0.14
C15:0 (Pentadecanoic)	1.30±0.23	1.51±0.15	1.70±0.29	2.06±0.16	1.40±0.05	0.10
C16:0 (Palmitic acid)	25.86±0.19^{a}	20.0±1.29^{b}	18.77±0.47^{b}	19.12±0.73^{b}	19.94±0.85^{b}	<0.01
C17:0 (Margaric acid)	1.22±0.08	1.55±0.19	1.69±0.16	2.14±0.40	1.54±0.10	0.10
C18:0 (Stearic acid)	14.46±0.80	14.06±0.54	15.55±0.55	14.08±0.61	14.33±0.92	0.08
C16:1 (Palmitoleic)	2.30±0.26^{b}	2.51±0.03^{b}	2.36±0.23^{b}	2.85±0.09^{b}	3.99±0.39^{a}	<0.01
C17:1 (Margaroleic)	1.41±0.19	1.27±0.03	1.32±0.13	1.48±0.06	1.38±0.19	0.85
C18:1n9 (Oleic acid)	37.86±1.39	40.71±2.5	41.16±1.28	36.22±1.3	36.52±1.94	0.22
C18:1t-11 (Vaccenic)	2.44±0.57	3.32 ± 0.38	2.67±0.15	3.41±0.13	2.78±0.20	0.33
C18:2n6 (linoleic)	4.27±0.10^{b}	5.29±0.29^{ab}	5.59±0.78^{ab}	6.22±0.9^{ab}	7.14±0.71^{a}	0.05
C22:5n3(Docosapentaenoic)	0.42±0.11^{b}	0.49±0.16^{b}	0.63±0.05^{b}	1.07±0.10^{a}	1.04±0.15^{a}	<0.01
C20:4n6 (Arachidonic acid)	1.95±0.18b	2.59±0.22ab	3.12±0.56a	3.61±0.28a	2.78±0.23^{ab}	0.03
C18:3n3 (α-linolenic)	0.60±0.02^{c}	0.75±0.1^{bc}	0.68±0.01^{b}	0.90±0.07^{a}	0.87 ±0.07^{a}	0.02
C18:3n6(γ-linoleic)	0.65±0.11^{abc}	0.76±0.08^{ab}	0.55±0.03^{c}	0.80±0.06^{a}	0.44±0.08^{c}	0.03
C20:5n3 (Eicosapentaenoic)	0.34±0.08^{b}	0.55±0.17^{b}	0.61±0.06^{b}	0.95±0.16^{a}	1.11±0.36^{a}	0.03
C22:6n3 (Docosahexaenoic)	0.45±0.06^{b}	0.71±0.09^{b}	0.69±0.10^{b}	1.07±0.12^{a}	1.00±0.02^{a}	<0.01
CLA C9T11	0.93±0.20	0.92±0.10	0.94±0.07	1.02±0.08	1.04±0.13	0.94
CLA C12T10	0.58±0.13	0.60±0.009	0.55±0.07	0.61±0.06	0.60±0.08	0.97
Total SFA	45.8±1.32^{a}	39.5±1.93^{b}	39.2±0.66^{b}	39.8±1.03^{b}	39.3±1.68^{b}	<0.01
Total MUFA	44.0±1.84	47.8±2.13	47.5±1.37	43.9±1.37	44.7±2.18	0.17
Total PUFA	8.7±0.42^{d}	11.1±0.62^{c}	11.9±1.39^{bc}	14.6±0.73^{a}	14.4±0.41^{ab}	<0.01
PUFA n-6	6.9±0.23^{b}	8.6±1.31^{a}	9.3±1.34^{a}	10.6±0.81^{a}	10.4±0.52^{a}	0.02
PUFA n-3	1.8±0.18^{c}	2.5±0.51^{b}	2.6±0.05^{b}	3.9±0.36^{a}	4.0±0.34^{a}	<0.01
Total CLA	1.5±0.33	1.5±0.10	1.5±0.14	1.6±0.08	1.6±0.14	0.96
n-6 : n-3 ratio	3.8±0.74	3.5±0.66	3.6±0.42	2.7±0.36	2.6±0.33	0.30
PUFA:SFA ratio	0.2^{c} ±0.01	0.3±0.20^{bc}	0.3±0.04^{ab}	0.4±0.20^{ab}	0.4±0.01^{a}	<0.01

ST, *semitendinosus* muscles; $^{a, b, c}$ Means within columns with different superscripts are significantly different. SFA, sum of C12:0, C14:0, C15:0, C16:0, C17:0 and C18:0; MUFA, sum of C16:1, C17:1 and C18:1n-9^{4}; PUFA n-6, sum of C18:2n-6, C18:3n-6, C20:4n-6; PUFA n-3, sum of C18:3n-3, C20:5n3, C22:5n-3 and C22:6n-3; Total CLA, sum of cis-9 trans-11 CLA and cis-12 trans-10 CLA; PUFA n-6: n-3 fatty acid ratio, (C18:2n-6+ C18:3n-6 + C20:4n-6) ÷ (C18:3n-3 + C20:5n3 + C22:5n-3 + C22:6n-3).

The composition of fatty acids and ratio of unsaturated fatty acids to SFA, especially PUFA to SFA, and also the ratio of PUFA n-6 to PUFA n-3 are important risk indicators of coronary heart disease in human [46, 47]. The fatty acid profiles reported in this study are within the range reported by Mushi *et al*., [48]. The proportion of PUFA to SFA and PUFA n-6 to PUFA n-3 from samples of LD and ST muscles were decreased with higher levels of *Moringa* foliage to diets. The range of ratio of PUFA to SFA values in the study were found to be similar to those reported by Qwele *et al*., [49] in goats, but were lower than those reported by Peňa *et al*., [50]. Both muscles tended to reduce the ratio of PUFA n-6 to n-3 with increasing supplementation of *Moringa* foliage. The lower ratio between PUFA n-6 to PUFA n-3 in meat reduces the risk of coronary heart disease in human [51]. Therefore, this study recognized the benefits of *Moringa* foliage feeding relative to concentrates, in increasing the amount of omega-3 fatty acids in goat meat lipid. The ratio of PUFA n-6 to PUFA n-3 found in the control diet in LD muscles was higher (4.2%) compared to the recommended level, while the ST muscles were within the range of recommended values of between 1 and 4 [52]. This ratio is often 2 or less for ruminants finished on pasture, whereas it is often between 6 and 10 for ruminants finished with concentrate based diets [53].

Higher level of palmitic acid (C16:0) in concentrate mixture than *Moringa* foliage (Table 2) resulted in increased palmatic acid intake as reflected in the higher level of total SFA in all muscles of goats fed diet supplemented with only 70% concentrate mixture. The long chain fatty acids composition in LD and ST muscles in the present study comprised

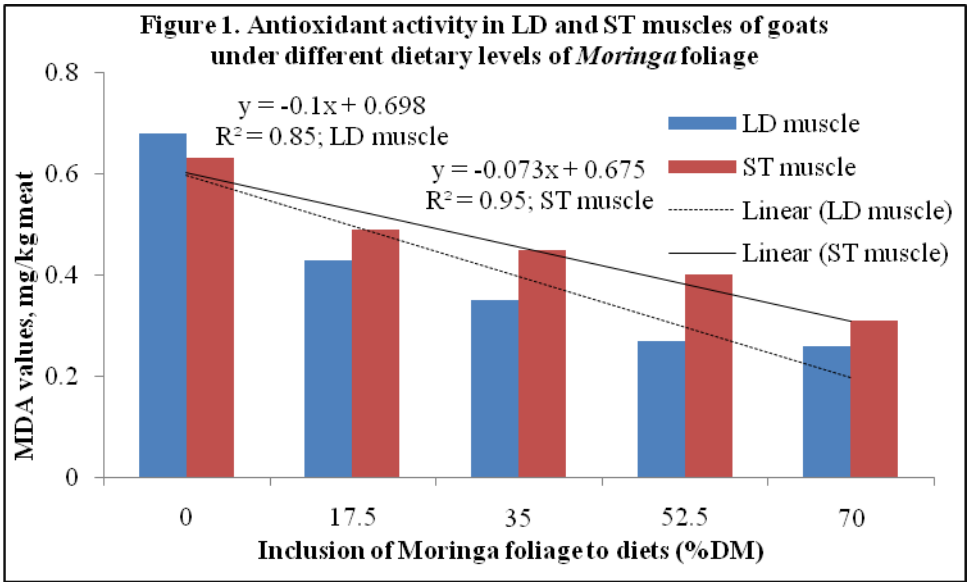
of oleic acid (C18:1) to be the most abundant followed by palmitic (C16:0) and stearic (C18:0) acids which were similar to those reported by Qwele *et al*., [49] and Ebrahimi *et al*., [27, 28]. Peňa *et al*., [50] suggested that palmitic acid increased the blood cholesterol; stearic acid had no detrimental effects to human health, and oleic acid decreased the blood cholesterol. The proportion of desirable fatty acids (DFA) had no adverse implications on human health (C18:0 and all MUFA+ all PUFA) [54]. The ranges of DFA were between 69.9 to 74.7% and 67.2 to 74.9% for LD and ST muscles in the current study. These findings are in agreement with that of Qwele *et al*., [49] (74.81 to 76.38%) in goat muscles fed with *Moringa* leaf.

The level of total SFA was decreased and total PUFA was increased with increasing *Moringa* foliage in the diet. Similar results were observed by Ebrahimi *et al*., [28] in goats fed oil palm frond. The higher percentage of n-3 fatty acids in LD and ST muscles of the *Moringa* foliage supplemented goats could be due to the higher levels of n-3 fatty acids present in the *Moringa* foliage (Table 2). The increasing level of *Moringa* foliage to diets resulting in increased levels of total PUFA n-3 and PUFA n-6 in both LD and ST muscles suggests incomplete or reduced bio-hydrogenation of C18:3n-3 and C18:2n-6 fatty acids in the rumen. The trend in the increase of linoleic acid (C18:2n-6) in the muscles of goats fed *Moringa* foliage supplemented diets also supports this statement. It is possible that the high inclusion levels of *Moringa* foliage to diet, which contain a series of secondary compounds such as phenols, tannins, flavonoids, terpenoids, and steroids [2], could alter the rumen environment making it unfavorable for complete bio-hydrogenation [55]. Apparently, certain phenols exhibit toxicity on microbial species that are implicated at different steps of fatty acid bio-hydrogenation [56]. These observation are consistent with those finding of Kălber *et al*., [57] who reported high content of total extractable phenols (TEP) in fresh buckwheat forage that was associated with an increased transfer rate of α-linlenic acid (C18:3n-3) from feed to dairy cow. The large quantities of α-linolenic (C18:3n-3) and linoleic acids (C18:2n-6) obtained in LD and ST muscles of goats fed diets with 70% *Moringa* foliage, which is high in them (Table 2), was due to incomplete bio-hydrogenation in the rumen leading to increased absorption and deposition in the muscles.

The ratio of PUFA to SFA of LD and ST muscles of the study ranged from 0.1 to 0.3 and 0.2 to 0.4, respectively which were within the recommended level of 0.45 [41]. From a human health perspective, the decreased SFA in the muscles from the *Moringa* foliage diet group would help to improve the image of chevon, which is generally regarded as redt meat with high SFA content. Thus, the supplementation of diet of goat with *Moringa* foliage can be used to manipulate the fatty acid composition of muscles with the challenge to increase the ratio of PUFA to SFA values and reduce the ratio of PUFA n-6 to PUFA n-3 values.

3.5 Lipid Oxidation in LD and ST Muscles

Effect of supplementation of *Moringa* foliage on the TBARS values for LD and ST muscle lipids of goat is presented in Figure 1. The MDA value was significantly higher (P<0.01) in both LD and ST muscles of goats fed no *Moringa* foliage compared to any other *Moringa* foliage supplemented diets. The rate of lipid oxidation was reduced linearly (r^2=85 for LD muscle and r^2=95 for ST muscle) with increasing supplementation of *Moringa* foliage.



It shows that supplementation with *Moringa* foliage had a significant effect (P<0.01) on TBARS values in both LD and ST muscles. The inhibition of lipid oxidation in *Moringa* foliage supplemented muscles in goats indicated that *Moringa* folage may have prevented the formation of excessive free radicals in the defense mechanism in the animal system. Lipid peroxidation is a complex process taking place in aerobic cells and reacts between molecular oxygen and polyunsaturated fatty acids which leads to the oxidation of meat pigments and generation of rancid odors and flavors [6].

The different active components of *Moringa* foliage such as the phenolic compounds, flavonoids, carotenoids, vitamins, minerals, amino acids, sterols, glycosides, and alkaloids have been proven to contain significant antioxidant potential [6]. Polyphenols can protect meat from lipid oxidation by acting as a chain-breaking peroxy-radical scavenger [2]. Malondialdehyde is the major lipid oxidation substrate in the TBARS test [58]. Recent studies by Moyo *et al*., [13] and Qwele *et al*., [49] provided more evidence to support that *Moringa* leaves exert a strong and efficient antioxidant activity in the liver and muscle of goats, respectively.

4. CONCLUSION

It may be concluded that the inclusion of *Moringa* foliage to the diet of goats at 67.2% or 3.4% of LW increased the ratio of PUFA to SFA, and decreased the ratio of PUFA n-6 to n-3 significantly ($P<0.01$) in both LD (*longissimus dorsi*) and ST (*semitendinosus*) muscles without affecting the dietary intake and daily gain. The significant antioxidant potential of *Moringa* foliage was indicated by the linearly reduction of lipid oxidation ($r^2=85$ for LD muscle and $r^2=95$ for ST muscle) with increasing supplementation of *Moringa* foliage up to that levels. Therefore, supplementation of the diet of goats with *Moringa* foliage up to that level may help to increase antioxidant activity in muscles of goat and to produce meat with more desirable PUFA and less SFA.

4. REFERENCES

[1] Manaye, T., Tolera, A., and Zewdu, T., (2009). Feed intake, digestibility and body weight gain of sheep fed Napier grass mixed with different level of *Sesbania Sesban*. Livestock Science 122: 24-29.

[2] Sreelatha, S., and Padma. P.R., (2009). Antioxidant activity and total phenolic content of *Moringa oliefera* leaves in two stages of maturity. *Plant Foods and Human Nutrition* 64:303-311.

[3] Marcu, M.G., and Pharma, D., (2005). Miracle Tree.KOS Health Publicationa, 466 Foothill Blvd number 251, La Canada, CA. 91011.

[4] Mendieta-Aracia, B., Spörndly, R., Sànchez, R.N., Salmerón-Miranda, F., and Halling, M., (2013). Biomass production and chemical composition of *Moringa oleifera* under different planting densities and levels of nitrogen fertilization.*Agroforestry System* 87:81-92.

[5] Moyo, B., Oyedemi, S., Masika, P.J., and Muchenje, V., (2012). Polyphenolic content and antioxidant properties of *Moringa oleifera* leaf extracts and enzymatic activity of liver from goats supplemented with *Moringa oleifera* leaves/ sunflower seed cake. *Meat Science* 91: *4*41-447.

[6] Verma, A.R., Vijayakumar, M., Mathela, C.S., and Rao, C.V., (2009). *In vitro* and *in vivo* antioxidant properties of different fractions of *Moringa oleifera* leaves.*Food and Chemical Toxicology* 47: 2196-2201.

[7] Mapiye, C., Chimonyo, M., Dzama, K., Hugo, A., Strydom, P.E., and Muchenje, V., (2011). Fatty acid composition of beef from Nguni steers supplemented with Acacia Karroo leaf-meal. *Journal of Food Composition and Analysis*. 24. 523-528.

[8] Patra, A.K., and Saxena, J., (2011). Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition.*Journal of the Science of Food and Agriculture* 91: 24-37.

[9] Bas, P., and Morand-Fehr, P., (2000). Effect of nutritional factors on fatty acid composition of lamb fat deposits.*Livestock Production Science* 64: 61-79.

[10] Jenkins, T.C., Wallace, R.J., Moate, P.J., and Mosley, E.E., (2008). Board-invited review: Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. *Journal of Animal Science* 86: 397-412.

[11] Russo. C., Preziuso, G., Casarosa, L., Campodoni, G., and Cianci, D., (1999). Effect of diet energy source on the chemical-physical characteristics of meat and depot fat lambs carcasses. *Small Ruminant Research* 33: 77-85.

[12] Hu, F.B., Stampfer, M.J., Manson, J.E., Aschiero, A., Colditz, G.A., Speizer, F.E., Hennekens, C.H., and Willet, W.C., (1999). Dietary saturated fats and their food sources in relation to the risk of coronary heart disease in women.*American Journal of Clinical Nutrition* 70: 1001-1008.

[13] Moyo, B., Masika, P.J., Hugo, A. and Muchenje, V., (2011). Nutritional characterization of moringa (*Moringa oleifera* Lam.) leaves. *African Journal of Biotechnology*10 : 12925-12933.

[14] Amaglo, N.K., Bennett, R.N., Curto, R.B.L., Rosa, E.A.S., Turco, V.L., Giuffrida, A., Curto, A.L., Crea, F., and Timpo, G.M., (2010). Profiling selected phytochemicals and nutrients in different tissues of the multipurpose tree *Moringa oleifera* L., grown in Ghana. *Food Chemistry* 122: 1047-1054.

[15] Coltro, W.K.T., Ferreira, M.M.C., Macedo, F.A.F., Oliveira, C.C., Visentainer, J.V., Souza, N.E., and Matsushita, M., (2005). Correlation of animal diet and fatty acid content in young goat meat by gas chromatography and chemometrics.*Meat Science* 71: 358-363.

[16] Talpur, F.N., Bhanger, M.I. and Sherazi, S.T.H., (2008). Intramuscular fatty acid profile of longissimus dorsi and semitendinosus muscle from Pateri goats fed under traditional feeding system of Sindh, Pakistan. *Meat Science* 80: 819-822.

[17] NRC, (2007). National Research Council, Nutrient requirements of small ruminant. Sixth edition, National academy Press, Washington, DC., USA.pp.384.
[18] Bendall, J.R., (1975). Cold-contracture and ATP-turnover in the red and white musculature of the pig, post mortem.*Journal of the Science of Food and Agriculture* 26: 55-71.
[19] Honikel, K.O., (1998). Reference methods for the assessment of physical characteristics of meat.*Meat Science* 49: 447-457.
[20] Sazili, A.Q., Parr, J., Sensky, D.L., Jones, S.W., Barddey, R.G. and Buttery, P.J., (2005). The relationship between slow and fast myosin heavy chain content, calpastatin and meat tenderness in different ovine skeletal muscles.*Meat Science* 69: 17-25.
[21] Brown, R.A., Prajapati, R., Mc Grouther, D.A., Yannas, I.V., and Eastwood, M., (1998). Tensional homeostasis in dermal fibroblasts: Mechanical responses to mechanical loading in three-dimensional substrates. *Journal of cellular Physiology* 175: 323-332.
[22] Hunt, M.C., (1980). Meat color measurements.*Meat Conference of the American Meat Science Assoc*. Purdue University, Lafayette, Ind. 41-46.
[23] Hunter, R.S., and Harold, R.W., (1987). Uniform color scales. In: The Measurement of Appearance, 2nd ed. Hunter Associates Laboratory, VA, pp. 135-148.
[24] AOAC, (2000). *Official Methods of Analysis.17th edn. Association of Official Analytical Chemist.*Washington, DC., USA.
[25] Van Soest, P.J., Robertson, J.D., and Lewis, B.A., (1991). Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharide in relation to animal nutrition. J. Dairy Sci. 74;3583-3597.
[26] Folch, J., Lees, M., and Sloane Stanley, G.H., (1957). A simple method for the isolation and purification of total lipids from animal tissues.*The Journal of Biological Chemistry* 226: 497-509.
[27] Ebrahimi, M., (2012a). Production of omega-3 polyunsaturated fatty acid-enriched chevon using treated oil palm (Elaeis Guineensis) fronds. PhD Thesis, Universiti Putra Malaysia . Malaysia.
[28] Ebrahimi, M., Rajion, M.A., Goh, Y.M., and Sazili, A.Q., (2012b). Impact of different inclusion levels of oil palm ((*Elaeis guineensis*, Jacq.) fronds on fatty acid profiles of goat muscles.*Journal of Animal Physiology and Animal Nutrition* 96: 962-969.
[29] Lynch, S.M., and Frei, B., (1993). Mechanisms of copper- and iron dependent oxidative modification of human low-density lipoprotein.*Journal of lipid Research* 34: 1745-1751
[30] Mercier, Y., Gatellier, P., Viau, M., Remignon, H., and Renerre, M., (1998). Effect of dietary fat vitamin E on color stability and on lipid and protein oxidation in turkey meat during storage.*Meat Science* 48: *301-318.*
[31] SAS, (2007). User's Guide. 9.2 ed. In SAS Inst. Inc, Cary, NC, USA.
[32] Steel, R.G.D., and Torrie, J.H., (1980). *Principles and Procedures of Statistics: A biometric Approach*. 2nd*ed*. New York; McGraw-Hill Kogakusha.
[33] Mtenga, L.A., and Shoo, R.A., (1990). Growth rate, feed intake and feed utilization of Small East African goats supplemented with *Leucaena leucochephala*.*Small Ruminant Research* 3: 9-18.
[34] Priolo, A., Micol, D., and Agabriel, J., (2001). Effect of grass feeding systems on ruminant meat color and flavor.A review.*Animal Research* 50: 185-200.
[35] Cetin, O., Bingol, E.B., Colak, H., and Hampikyan, H., (2012). Effect of electrical stimulation on meat quality of lamb and goat meat.*The Scientific World Journal* ID 574202:1- 9.
[36] Teixeira, A., Pereira, E., and Rodrigues, E.S., (2011). Goat meat quality. Effect of salting, air drying and ageing processes.*Small Ruminant Research* 98: 55-58.
[37] Offer, G., and Trinick, J., (1983). On the mechanism of water holding in meat: The swelling and shrinking of myofibrils. Meat Science 8: 245-281.
[38] Abdullah, A.Y., and Musallam, H.S., (2007). Effect of different level of energy on carcass composition and meat quality of male black goats kids. *Livestock Science* 107: 70-80.
[39] Kadim, I.T., Mahgoub, O., Al-Ajmi, D.S., Al-Maqbaly, R.S., Al-Saqri, N.M. and Ritchite, A., (2003). An evaluation of growth, carcass and meat quality characteristics of Omani goat breeds. *Meat Science* 66: 203-210.
[40] Karami, M., (2010). Effect of dietary supplementation of vitamin E, *Andrographis paniculata* nees and *curcuma longa* L. on growth, carcass and meat quality of goats. PhD Thesis, Universiti Putra Malaysia, Malaysia.
[41] Webb, E.C., Casey, N.H., and Simela, L., (2005). Goat meat quality.*Small Ruminant Research* 60: *153-166.*
[42] Huff-Lonergan, E., and Lonergan, S.M., (2005). Mechanism of water holding capacity of meat: the role of post mortem biochemical and structural changes. *Meat Science* 71: 194-204.
[43] Kannan, G., Gadiyaram, K.M., Galipalli, S., Carmichael, A., Kouakou, B., Pringle, T.D., McMillin, K.W., and Gelaye, S., (2006). Meat quality in goats as influenced by dietary protein and energy levels, and postmortem aging.*Small Ruminant Research* 61: 45-52.
[44] Tansawat, R., (2012). "Chemical Characterization of Meat Related to Animal Diet" All Graduate Theses and Dissertations. Paper 1339. http://digitalcommons.usu.edu/etd/1339.
[45] Luciano, G., Monahan, F.J., Vasta, V., Pennisi, P., Bella, M. and Priolo, A., (2009). Lipid and color stability of meat from lambs fed fresh herbage or concentrate. *Meat Science* 82: 193-199.

[46] Williams, C.M., and Burdge, G., (2006). Long-chain n-3 PUFA: plant v. marine sources. *Proceedings of the Nutrition Society* 65: 42-50.
[47] Wood, J.D., Richardson, R.I., Nute, G.R., Fisher, A.V., Campo, M.M., Kasapidou, E., Sheared, P.R., and Enser, M., (2003). Effect of fatty acids on meat quality: a review. *Meat Science* 66: 21-32.
[48] Mushi, D.E., Thomassen, M.S., Kifaro, G.C. and Eik, L.O., (2010). Fatty acid composition of minced meat, longissimus muscle and omental fat from Small East African goats finished on different levels of concentrate supplementation. *Meat Science* 86: 337-342.
[49] Qwele, K., Hugo, A., Oyedemi, S.O., Moyo, B., Masika, P.J., and Muchenje, V., (2013). Chemical composition, fatty acid content and antioxidant potential of meat from goats supplemented with moringa (*Moringa oleifera)* leaves, sunflower cake and grass hay. *Meat Science* 93: 455-462.
[50] Peňa, F., Bonvillani, A., Freire, B., Juarez, M., Perea, J., and Gomez, G., (2009). Effects of genotype slaughter weight on the meat quality of Criollo Cordobes and Anglonubian kids produced under extensive feeding conditions. *Meat Science* 83: 417-422.
[51] American Heart Association, (2011). Fish and omega-3 fatty acids. Available from: http://www.amhrt.org/HEARTORG/Getting Health/ Nutrition Center/Health Diet Goals/ Fish-and-Omega-3-Fatty Acid_UCM_303248_Article.jsp.Accessed September 1, 2011.
[52] Simopoulos, A.P., (2008). The importance of omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases.*Experimental Biology and Medicine* 233: 674-688.
[53] Raes, K., DeSmet, S., and Demeyer, D., (2004). Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: a review. *Animal Feed Science and Technology* 113: 199-221.
[54] Banskalieva, V., Sahlu, T., and Goetsch, A.L., (2000). Fatty acid composition of goat muscles and fat depots: a review. *Small Ruminant Research* 37: 255-268.
[55] Jayanegara, A., Kreuzer, M., Wina, E., and Leiber, F., (2011). Significance of phenolic compounds in tropical forages for the ruminal bypass of polyunsaturated fatty acids and appearance of biohydrogenation intermediates as examined *in vitro.Animal Production Science*. 51: 1127- 1136.
[56] Vasta, V., Yanez-Ruiz, D.R., Mele, M., Serra, A., Luciano, G., Lanza, M., Biondi, L., and Priolo, A., (2010). Bacterial and protozoal communities and fatty acid profile in the rumen of sheep fed a diet containing added tannins. *Applied and Environmental Microbiology.* 76**:** 2549-2555.
[57] Kälber, T., Meier, J.S., Kreuzer, M., and Leiber, F., (2011). Flowering catch crops used as forage plants for dairy cows: influence on fatty acids and tocopherols in milk. *Journal of dairy Science* 94: 1477- 1489.
[58] David, R.J., (1990). Malondialdehyde and thiobarbituric acid-reactivity as diagnostic indices of lipid peroxidation and peroxidative tissue injury.*Free Radical Biology and Medicine* 9: 515-540.