Small Ruminant Research 128 (2015) 1–9

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Growth performance and carcass characteristics of lambs fed halophytes as a partial or whole replacement of berseem hay

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ARTICLE INFO

Article history:
Received 1 November 2014
Received in revised form 3 May 2015
Accepted 6 May 2015
Available online 14 May 2015

Keywords:
Carcass
Growth performance
Halophyte
Lamb

ABSTRACT

The aim of this study was to evaluate partial or whole substitution of berseem hay with *Atriplex nummularia* (AT) and/or *Acacia saligna* (AC) in the diet of Barki lambs. Thirty-six male lambs (body weight 26.5 ± 1.1 kg and age 13 ± 1.1 months) were divided into four groups and fed: (1) the control diet (70% concentrate mixture and 30% berseem hay), (2) AT (AT15 diet) or (3) AC (AC15 diet) replaced 50% of berseem hay in the diet, or (4) AT and AC at a ratio of 1:1 to replace 100% of berseem hay (TC30 diet), respectively. Lamb growth performance, rumen fermentation, blood chemistry, carcass characteristics and intestine histological properties were investigated. Dry matter intake, daily weight gain and feed conversion were measured every two weeks (period) for 10 weeks. Interactions were observed ($P < 0.05$) between period × diet for these measurements and period affected ($P < 0.05$) daily weight gain and feed conversion. Lambs in the AT15 and AC15 groups had increased ($P < 0.05$) dry matter intake (g/lamb/day), water consumption (L/lamb/day), daily weight gain (g/lamb/day) and feed conversion (feed intake/body weight gain) during the last 2, 6, 2 and 8–10 weeks, respectively. The treatments AT15, AC15 and TC30 had decreased concentrations ($P < 0.01$) of ruminal volatile fatty acids, but did not affect ruminal ammonia-N concentrations. Lambs fed the experimental diets had lower ($P < 0.05$) concentrations of blood cholesterol, low density lipoproteins and glucose and higher ($P < 0.05$) concentrations of serum urea. The treatment AT15 had increased ($P < 0.05$) gut fill, pelt and mesentery weights, whereas the treatment AC15 increased ($P < 0.05$) spleen and lung weight as a percentage of carcass weight. In regards to the protein content of the 9–11th ribs, the treatment AT15 was similar to the control, but the AC15 and TC30 were lower ($P < 0.05$) than the control. Lambs in the treatment groups showed a normal histology of ileum, sub-mucosa and Peyer's patches. It could be concluded that AT or AC can replace 50% of berseem in the diet of Barki lambs without compromising lamb growth performance.

1. Introduction

Berseem (*Trifolium alexandrinum*) is the most important leguminous forage crop in the Mediterranean region and the Middle-East. In Egypt, the annually cultivated area is up to 1.3 million hectares (Heuzé et al., 2014). The crop provides green feed to ruminants during growing seasons, but can also be made into hay for animals during other seasons. However, this

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http://dx.doi.org/10.1016/j.smallrumres.2015.05.004

forage crop has the same growing season as wheat (*Triticum aestivum*) and thus competes for arable land, which is scarce in the region with wheat production, which directly provides food to humans. Thus, there is a need to find an alternative to completely, or at least partially, replace berseem.

The Mediterranean region and the Middle-East are in the arid and semi-arid zones and moreover, some arable land is salinised. Such environments limit the number of plant species that could be grown in the region. As a result, options for the replacement of berseem are limited. Recently, people have been aware of the value of halophytic forage shrubs as animal feeds (Shaker, 2014). For example, saltbush *Atriplex* spp. and shrub plants *Acacia* spp. received special attention for their potential to be livestock feeds (Salem et al., 2012, 2015; Shaker, 2014; Alsersy et al., 2015). The plants of these two genera can be grown in a wide range of saline and arid environments (Salem et al., 2012; Shaker, 2014; Alsersy et al., 2015). Hence, there is a great potential for them to be animal feeds.

Atriplex contains a high level of crude protein and plant secondary metabolites (Alsersy et al., 2015; Salem et al., 2015). These secondary metabolites include tannins, oxalates, saponins and alkaloids (Salem et al., 2012). At appropriate concentrations, these compounds have positive effects on nutrient utilisation and animal performance. For example, low concentrations of tannins and saponins in *Atriplex* protect dietary proteins from degradation in the rumen, have a defaunation effect and decrease methane production. As a result, either grazing or stall-fed ruminants fed *Atriplex* had improved animal performance (Ben Salem et al., 2010). *Atriplex nummularia* (AT) has a balanced amino acid composition of methionine and lysine, and the two essential amino acids are higher than those in cereals and are close to the level of the FAO/WHO reference protein score (Khalil et al., 1986).

Acacia saligna (AC) is the most popular species of *Acacia* owing to its tolerance to drought and salinised soil conditions. It has a high green biomass and high crude protein (CP) content, and, thus, is of high nutritive value (Degan et al., 1997; Salem, 2005). But the plant contains a large amount of condensed tannins and consequently cannot be served as a sole feed for sheep (Degan et al., 1997; Salem et al., 2006). Condensed tannins form precipitates with proteins, resulting in the formation of indigestible tannin-protein complexes (Degan et al., 1997). Tannins also form complexes with soluble carbohydrates, cellulose, hemicelluloses and amino acids, reducing their digestibilities (Barry, 1985). However, if the plant is used as a dietary ingredient accounting for a small proportion of feed intake, condensed tannins would be diluted and beneficial effects appear and negative effects are eliminated.

Therefore, this study aimed to evaluate the viability of partial or complete replacement of berseem hay in the diet of Barki lambs with AT and/or AC. Animal biochemical, physiological and histological parameters, growth performance and carcass characteristics were employed for the evaluation of such replacement.

2. Materials and methods

Experimental animals were cared and handled in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

2.1. A. nummularia and A. saligna preparation

Leaves and stems of fresh nursery plants of saltbush *A. nummularia* and shrub plant *A. saligna* were collected from the North-western desert region of Borg El-Arab, Alexandria, sun-dried, chopped to 3–5 cm in length and stored in a dry environment.

2.2. Animals and treatments

Thirty six growing male Barki lambs, an indigenous breed in Egypt, Libya and Tunisia, with live body weight (BW) of 26.5 ± 1.1 kg and an age of 13 ± 1.1 months, were used. All animals lived under the same hygienic conditions and were managed equally. Prior to the experiment, the animals were treated against internal and external parasites (Albendazole 10 mg/kg BW; Zoetis Inc., Kalamazoo, MI, USA). Lambs were randomly allocated into four treatment groups of nine and individually housed in cages.

Lambs were fed with diets which were formulated to meet their maintenance and growth requirements (NRC, 1985). Before the experiment, lambs were fed on a diet of concentrates and berseem hay at a ratio of 50:50 on a dry matter (DM) basis. The control diet contained concentrates and berseem hay at a ratio of 70:30 on a DM basis. The treatment diets were the same as the control, but half of the berseem hay was replaced with either *A. nummularia* (AT15) or *A. saligna* (AC15), or berseem hay was totally replaced with AT and AC at a 1:1 ratio (TC30). Lambs were adapted to their designated diets for two weeks before measurements. Ingredients and the chemical composition of the diets are presented in Table 1.

2.3. Growth performance

Lambs were weighed every two weeks before morning feeding. Period 1 was defined as from week 0 to week 2, period 2 from week 2 to week 4, and so on. Mean daily body weight gain was calculated by the difference between two consecutive weighings. Feed offered and refused was quantified daily for each lamb to calculate feed consumption. Feed conversion ratio was expressed as feed consumption per unit of body weight gain. A fixed amount of water was available daily and the remaining water was weighed daily for each lamb. A bucket with the same amount of water offered was placed in the animal shed to estimate water evaporation for the calibration of water consumption.

2.4. Blood chemistry

Four lambs per treatment were randomly chosen for blood collection on days 35 and 70 of the experiment. About 10 mL of blood each lamb was collected from the jugular vein immediately before morning feeding. Collected blood was filled into a tube (BD Vacutainer® Tubes, NJ, USA) with heparin for anticoagulant and directly centrifuged at 4000 × g at 4 °C for 20 min. Plasma was separated into a glass vial and frozen at −20 °C until analysis.

2.5. Ruminal fermentation parameters

Rumen samples were collected from the same blood sampled lambs during slaughtering according to the method described in Kholif et al. (2014). Briefly, about 100 mL of rumen contents was sampled and strained through four layers of cheesecloth. Ruminal pH was immediately determined using a digital pH metre (GLP 22, Crison Instruments, Barcelona, Spain). Strained rumen samples were filled into 45-mL glass bottles with a few drops of toluene and paraffin oil added to just cover the surface and stored at −18 °C for later analyses of ammonia-N and volatile fatty acids.

2.6. Slaughter procedure

Lambs were fasted for 18 h and then slaughtered at a commercial slaughterhouse. Body weight was obtained for all lambs immediately before slaughtering. Hot carcass weight including fat tail and kidney fat was determined immediately after dressing. Heads, legs, lungs, hides, hearts, livers and full digestive tract were weighed as well. The 9–11th ribs were separated from the right side of each carcass and physically divided into meat, bone and fat. Meat samples were ground through a 4-mm plate for each animal, mixed and reground. Then, 30–40 g of ground meat from each lamb was placed in a plastic bag and stored at −20 °C for chemical analysis.

2.7. Histological parameters

Immediately after post-mortem examination, tissue specimens from the small intestine were rapidly fixed in 10% neutral buffered formalin solution for at least 24 h. The fixed specimens were dehydrated through ascending grades of ethanol, cleared in chloroform and embedded in paraffin wax at 60 °C. From paraffin blocks, 5-μm thick sections were obtained. These sections were stained using haematoxylin and eosin according to the method of Culling (1983) and examined using bright-field microscopy.

2.8. Chemical analyses

The contents of DM, ash, N, crude fibre (CF) and ether extract (EE) in feed samples were analysed by the method of AOAC (1997), neutral detergent fibre (NDF) and acid detergent fibre (ADF) by the method of Van Soest et al. (1991) using ANKOM200 fibre Analyser unit (ANKOM

Table 1
Diet ingredients and chemical composition (g/kg dry matter).[a]

	Berseem hay	AT	AC	Control	AT15	AC15	TC30
Ingredients							
Berseem (*Trifolium alexandrinum*) hay				300	150	150	0
Atriplex nummularia hay				0	150	0	150
Acacia saligna hay				0	0	150	150
Barley grain				265	265	265	265
Wheat bran				250	250	250	250
Soya bean meal				100	100	100	100
Molasses				55	55	55	55
$NaHCO_3$				20	20	20	20
NaCl				5	5	5	5
Mineral and vitamin mixture[b]				5	5	5	5
Chemical composition							
Organic matter	902	754	863	890	802	887	872
Crude protein	167	189	176	155	161	169	161
Ether extract	20.1	11.1	11.6	17.0	12.5	18.9	17.6
Crude fibre	200	268	228	148	179	168	177
Non-fibre carbohydrates[c]	294	89	236	332	222	299	288
Neutral detergent fibre	421	465	439	386	407	400	405
Acid detergent fibre	281	265	238	191	189	185	183
Secondary compounds							
Total phenolics		113	61				
Saponins		124	24				
Alkaloids		2.3	3.2				
Aqueous fraction[d]		475	68				

[a] Diets contained 70% concentrates and 30% berseem hay (control); 70% concentrates + 15% berseem hay + 15% *Atriplex* (AT15); 70% concentrates + 15% berseem hay + 15% *Acacia* (AC15); or 70% concentrates + 15% *Atriplex* + 15% *Acacia* (TC30). Atriplex (AT); Acacia (AC).
[b] Mineral and vitamin mixture (/kg): Cu, 8 mg; Fe, 35 mg; Mn, 80 mg; Se, 0.6 mg; Zn, 60 mg; vitamin A, 12,000 IU; vitamin D3, 2500 ICU; vitamin E, 20 IU; menadione, 1.3 mg; riboflavin, 5.5 mg; vitamin B12, 10 μg; vitamin B6, 3 mg; thiamine, 3 mg; folic acid, 1.0 mg; D-biotin, 50 μg; Ca-pantothenate, 1 mg; nicotinic acid, 50 mg; choline chloride, 600 mg.
[c] Non-fibre carbohydrates calculated by difference [100 − (%NDF + %CP + %fat + %ash)].
[d] Aqueous fraction (lectins, polypeptides and starch).

Technology Corporation, Macedon, NY, USA). The analysis of NDF was conducted without α-amylase but with sodium sulphite. Both NDF and ADF were expressed without residual ash. Meat samples were analysed for DM, protein, ether extract and ash according to AOAC (1997). The secondary metabolite concentrations in AT and AC were determined as described in Salem et al. (2014). Ruminal ammonia-N concentration was determined according to the method of Gips and Wibbens-Alberts (1968) and ruminal volatile fatty acids by the method of Warner (1964).

2.9. Statistical analysis

Dry matter intake, water consumption, daily weight gain and feed conversion were analysed with diet type, period (as repeated measurement) and their interaction (diet × period) as the experimental factors having fixed effects using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC, 2002) in two-way ANOVA according to the following statistical model:

$$Y_{ijk} = \mu + D_i + T_j + (D \times T)_{ij} + A_k + e_{ijk}$$

where Y_{ijk} is the dry matter intake, water consumption, daily weight gain or feed conversion, respectively, μ is the overall mean, D_i is the fixed effect of diet ($i = 4$), T_j is the fixed effect of period ($j = 5$), $(D \times T)_{ij}$ is the fixed effect of interaction between diet and period, A_k is the random effect of animal ($k = 9$), and e_{ijk} is the random residual error. Significance was declared at a level of $P < 0.05$ and trend at $P \leq 0.10$.

The remaining data obtained were analysed using one-way ANOVA according to the following statistical model:

$$Y_{ij} = \mu + D_i + A_j + e_{ij}$$

where Y_{ij} is the observation, μ is the overall mean, D_i is the fixed effect of diet, A_j is the random effect of animal, and e_{ij} is the random residual error. The comparisons among treatments were performed with Duncan's multiple range test.

3. Results

3.1. Feed intake and growth performance

Interaction effects ($P < 0.01$) occurred between period × diet for DM intake, daily weight gain and feed conversion. Moreover, period affected ($P < 0.01$) both daily weight gain and feed conversion. Replacing berseem hay with AT and AC increased ($P < 0.05$) DM intake (g/lamb/day) during the last two weeks, water consumption (L/lamb/day) during the last six weeks, daily live weight gain (g/lamb/day) through the whole experimental period and feed conversion during the second and last two weeks (Table 2).

Lambs of AC15 had increased DM intake ($P < 0.01$) during the periods of weeks 6–8 and weeks 8–10 compared to other periods. On the contrary, TC30 lambs showed increased DM intake ($P < 0.05$) during the period of weeks 2–4 compared to other periods. Moreover, the daily weight gain and feed conversion were affected by period ($P < 0.05$); the highest daily gain was achieved during the first period (*i.e.*, weeks 0–2) compared to other periods (Table 2).

3.2. Ruminal fermentation and blood parameters

Inclusion of AT or AC in the diets decreased ($P < 0.01$) the total volatile fatty acid concentration compared to the control, but ruminal ammonia-N concentration was not affected.

Table 2
Feed intake and growth performance in growing Barki lambs fed the experimental diets[a] containing *Atriplex* and/or *Acacia* ($n = 9$ per group).

	Control	AT15	AC15	TC30	SEM	*P* value		
						Diet	Period	Period × diet
Initial body weight (kg)	26.2	26.4	25.9	26.9	1.48	NS[b]		
Final body weight (kg)	36.6	39.0	37.3	35.8	1.06	NS		
DM intake (g/lamb/day)								
Week 0–2	952c	1057b	1119ABa	810ABc	47.5	0.015		
Week 2–4	810c	1150a	802Bc	1097Ab	48.3	0.031		
Week 4–6	1136a	882c	851Bc	950ABb	57.1	0.023		
Week 6–8	1176a	1004b	1204Aa	884ABc	56.5	0.042		
Week 8–10	1078c	1172b	1228Aa	710Bd	44.5	0.022		
SEM	133.1	83.5	81.9	85.2		43.8	49.0	98.0
P value	NS	NS	0.008	0.032		0.032	NS	<0.001
Water consumption (L/lamb/day)								
Week 0–2	3.36	3.05	3.80	3.46	0.153	NS		
Week 2–4	3.31	3.11	3.50	3.00	0.147	NS		
Week 4–6	3.41c	3.95a	3.78b	3.90a	0.141	0.040		
Week 6–8	3.45c	4.00a	3.13d	3.79ab	0.156	0.044		
Week 8–10	3.30b	3.92a	3.10c	3.81a	0.150	0.001		
SEM	0.408	0.366	0.348	0.405		0.171	0.191	0.383
P value	NS	NS	NS	NS		NS	NS	NS
Daily weight gain (g/lamb/day)								
Week 0–2	207Ab	246Aa	248Aa	184Ac	11.4	0.041		
Week 2–4	116Bc	176ABab	183ABa	161ABb	10.5	0.011		
Week 4–6	149ABa	118Bb	119Bb	117ABCb	8.0	0.048		
Week 6–8	149ABa	135Bab	121Bb	104BCc	9.4	0.024		
Week 8–10	125Bc	228Aa	147Bb	71Cd	5.8	0.024		
SEM	16.7	22.0	21.6	17.2		8.7	9.7	19.4
P value	0.004	<0.001	<0.001	<0.002		<0.001	<0.001	0.002
Feed conversion (kg feed/kg live weight gain)								
Week 0–2	4.59B	4.30C	4.51C	4.41B	0.918	0.462		
Week 2–4	6.95Aa	6.52ABa	4.38Cb	6.83ABa	0.820	0.026		
Week 4–6	7.61A	7.47A	7.13B	8.11A	0.803	0.265		
Week 6–8	7.91A	7.40A	9.72A	8.47A	0.778	0.092		
Week 8–10	8.62Aa	5.14BCb	8.34ABa	10.04Aa	0.778	0.010		
SEM	0.499	0.564	0.495	0.847		0.276	0.309	0.618
P value	<0.001	<0.001	<0.001	<0.001		0.005	<0.001	<0.001

[a]Diets contained 70% concentrates and 30% berseem hay (control); 70% concentrates + 15% berseem hay + 15% *Atriplex* (AT15); 70% concentrates + 15% berseem hay + 15% Acacia (AC15) or 70% concentrates + 15% *Atriplex* + 15% *Acacia* (TC30).
[b]Not significant ($P > 0.05$).
(A,B,C) means within in the same column with different letters differ significantly among periods ($P < 0.05$).
(a,b,c,d) means within in the same row with different letters differ significantly among treatments ($P < 0.05$).

The experimental diets containing either AT or AC decreased ($P < 0.05$) the concentrations of cholesterol, low density lipoproteins and glucose in blood. The treatments AT15 and AC15 had greater ($P < 0.05$) serum urea concentration compared to the control. However, this effect disappeared when berseem hay was completely replaced with AT and AC (TC30). Differences in blood total protein, albumin, globulin and high density lipoproteins were not observed ($P > 0.05$) among the diets (Table 3).

3.3. Carcass characteristics

As a percentage of carcass weight, feeding lambs on AT15 diet increased ($P < 0.05$) gut fill, pelt and mesentery. Feeding lambs on AC15 diet increased ($P < 0.05$) the weights of spleen, lung, pelts and mesentery and dressing percentage in comparison with the control diet. Slaughter body weight and carcass weight both did not differ ($P > 0.05$) among the diets (Table 4).

No differences were detected among treatments regarding the physical and chemical composition of the 9–11th ribs with an exception of protein content ($P < 0.05$). Replacement of berseem hay with AT (AT15) did not significantly reduce protein content, but inclusion of AC alone (AC15) or in combination with AT (TC30) greatly reduced the protein content (Table 4).

3.4. Intestinal histopathology

All experimental lambs showed a normal histology of ileum, sub-mucosa and Peyer's patches. Compared to the control diet (Fig. 1), lambs fed AT15 (Fig. 2), AC15 (Fig. 3) and TC30 (Fig. 4) had some reactive alterations in ileum.

4. Discussion

4.1. Feed intake and water consumption

Occurrence of interaction between period and diet for DM intake showed that the DM intake differed with period progress. For the AC15 treatment, the highest

Table 3
Ruminal fermentation and blood parameters of growing Barki lambs fed the experimental diets[a] containing *Atriplex* and/or *Acacia* ($n = 4$ per group).

	Control	AT15	AC15	TC30	SEM	*P* value
Ruminal fermentation parameters						
Volatile fatty acids (mmol/100 mL)	16.2a	14.8ab	15.4a	14.2b	1.36	0.001
Ammonia-N (mg/100 mL)	51.3	46.3	59.0	43.0	7.10	NS[b]
Blood parameters (mg/dL)						
Total protein	6.02	6.77	6.04	5.64	0.382	NS
Albumin	3.81	3.93	3.34	3.33	0.320	NS
Globulin	2.21	2.84	2.71	2.31	0.449	NS
Cholesterol	135a	86d	102c	112b	2.3	0.023
Low density lipoproteins	83.7a	48.7d	60.3c	71.0b	1.98	0.033
High density lipoproteins	28.4	30.5	26.7	28.8	1.37	NS
Urea	32.9c	51.1a	55.2a	39.3b	2.17	0.033
Glucose	101.2a	77.1c	70.1d	93.9b	2.48	0.022

[a] Diets contained 70% concentrates and 30% berseem hay (control); 70% concentrates + 15% berseem hay + 15% *Atriplex* (AT15); 70% concentrates + 15% berseem hay + 15% *Acacia* (AC15) or 70% concentrates + 15% *Atriplex* + 15% *Acacia* (TC30).
[b] Not significant ($P > 0.05$).
(a,b,c,d) means within the same row with different letters differ significantly among treatments ($P < 0.05$).

feed consumption occurred during the last two periods from week 6 to week 10, which may be related to adaptability to the AC15 diet. However, for the TC30 treatment, feed consumption increased during the period from week 2 to week 4 and decreased gradually with period. Previous studies illustrated that the increased level of salt in the diet from AT and AC can limit feed intake and result in a poor efficiency of digestible energy (Masters et al., 2005). The presence of plant secondary metabolites may also restrict nutrient utilisation causing reduced feed intake (Alsersy et al., 2015; Salem et al., 2015). The results obtained in the present study showed that feed intake during the first six weeks was improved by about 6.6, 11.3 and 8.1% for AC15, AT15 and TC30, respectively *versus* the control diet. However, during the last four weeks the intake decreased. Moujahed et al. (2005) reported a decrease in intake with increasing level of AC in the diet of sheep and goats. This decrease in intake was explained by the palatability and increased tannin intake, which along with period increased rumen retention time, decreased intestine motility and

Table 4
Carcass characteristics, physical and chemical composition of the 9–11th ribs of growing Barki lambs fed the experimental diets[a] containing *Atriplex* and/or *Acacia* ($n = 9$ per group).

	Control	AT15	AC15	TC30	SEM	*P* value
Carcass characteristics						
Slaughter body weight (kg)	36.7	39.0	37.3	35.8	3.09	NS[b]
Carcass weight (kg)	15.9	16.1	15.0	15.8	1.84	NS
Dressing (g/kg)	433b	413c	402d	440a	2.7	0.022
Organs weight (g/kg carcass)						
Full gut	171.3c	217.0a	177.3c	194.5b	5.96	0.032
Empty gut	64.1	60.8	64.3	64.8	2.37	NS
Pelt	91.1b	138.0a	93.5b	136.6a	3.60	0.001
Liver	14.7	16.2	14.7	14.8	2.10	NS
Heat	3.5	3.6	3.5	3.7	0.12	NS
Heart fat	1.7	1.5	1.4	2.1	0.72	NS
Spleen	3.1a	1.9b	3.1a	2.1b	0.03	0.033
Lung	11.5b	11.3b	12.1a	9.8c	0.18	0.041
Mesentery	18.2b	20.4a	14.0c	19.9a	1.14	0.011
Characteristics of the 9–11th ribs (g)						
Weight of the 9–11th ribs	370	420	380	360	38.5	NS
Meat weight	213	240	203	180	24.3	NS
Subcutaneous weight	55.5	69.0	70.0	68.0	10.01	NS
Weight of fat between mussels	29.7	30.9	35.0	29.4	1.06	NS
Total fat weight	85.2	99.9	105.0	107.4	13.02	NS
Bone weight	71.9	79.7	72.2	72.6	6.03	NS
Chemical composition of the 9–11th ribs (g/kg)						
Dry matter	516	466	484	512	24.9	NS
Protein	194a	189a	175b	173b	6.2	0.011
Ether extract	282	337	334	307	22.6	NS
Ash	7.8	7.9	7.6	8.2	0.25	NS

[a] Diets contained 70% concentrates and 30% berseem hay (control); 70% concentrates + 15% berseem hay + 15% *Atriplex* (AT15); 70% concentrates + 15% berseem hay + 15% *Acacia* (AC15) or 70% concentrates + 15% *Atriplex* + 15% *Acacia* (TC30).
[b] Not significant ($P > 0.05$).
(a,b,c,d) means within the same row with different letters differ significantly among treatments ($P < 0.05$).

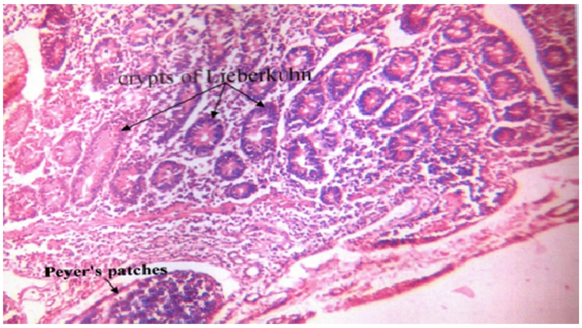

Fig. 1. Photomicrograph of ileum of control lambs stained with haematoxylin and eosin (160×): normal histology.

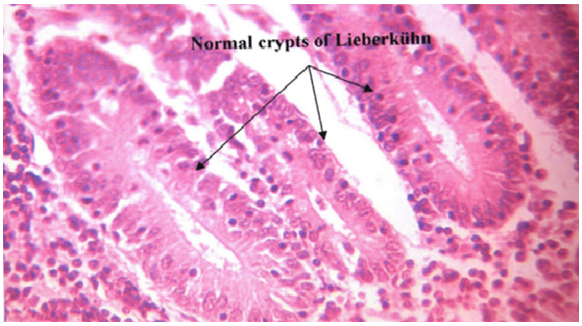

Fig. 2. Photomicrograph of ileum of AT15 lambs stained with haematoxylin and eosin (160×): normal histology.

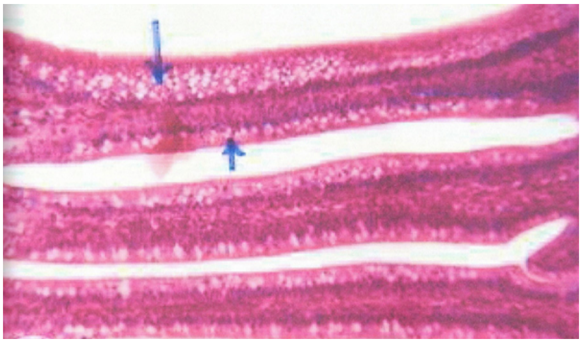

Fig. 3. Photomicrograph of ileum of AC15 lambs stained with haematoxylin and eosin (160×): normal elongated villi with normal excess of goblet cell formation (arrows).

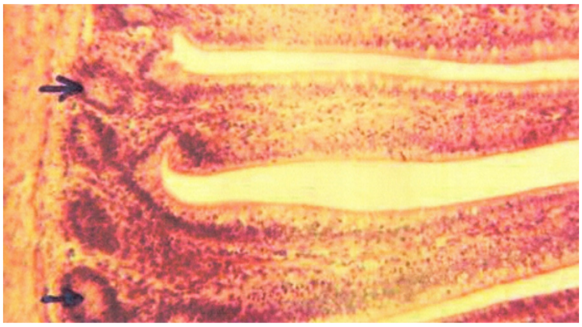

Fig. 4. Photomicrograph of ileum of TC30 lambs stained with haematoxylin and eosin (160×): normal histology.

increased retention time for the digesta in the gut (Garcia et al., 1999). Moreover, the highest intake was recorded with AT and this might be related to high energy content in the AT diet (Du Toit et al., 2006). However, Abu-Zanat (2005) reported that the inclusion of AT in the diet to substitute 50% of alfalfa hay had no effects on feed intake.

Increased water consumption was observed with lambs fed the experimental diets specially after feeding the diets for four weeks. This result is consistent with Bhatti (2009) who found that Kajli lambs drank more water when *Atriplex amnicola* hay was supplemented in the diet. Increased water consumption may result from the high contents of ash and salt in AT and AC. The greater salt consumed would force animals to consume more water to excrete excess salt and an increase in water recycling consequently influences rumen physiology and metabolism (Abu-Zanat and Tabbaa, 2006). To relieve the effect, feeding animals with a mixture of shrub species to dilute the high salt content may be recommended as a farming practice.

4.2. Rumen fermentation

A substantial amount of N in AT and AC is present in non-protein compounds which are degraded by rumen microflora to produce ammonia-N. Adequate quantity of energy from molasses and barley would enhance feed degradation and utilisation by microorganisms and the host animal (Le Houérou, 1992). This hypothesis explains the unchanged values of ruminal ammonia-N in the rumen of lambs fed diets with higher protein content. Newbold et al. (1996) concluded that decreased ruminal ammonia-N concentration is mainly due to reduced proteolysis, reduced degradation of peptides and deamination of amino acids in the rumen. Decreased volatile fatty acids with the experimental diets may be due to the diluted ruminal contents as a result of increased water consumption for animals fed both AC and AT.

4.3. Blood chemistry

No differences in blood total protein and globulin were observed among treatments. These results were in agreement with those reported by Shaker (2014) who found no differences in these parameters when sheep were fed AT. The slight increase in total proteins with AT15 and AC15 could be attributed to the increased CP. Kumar et al. (1980) reported a positive correlation between dietary protein and plasma protein concentrations.

Shaker (2014) noted that feeding sheep salt tolerant plants decreased ($P < 0.01$) plasma glucose concentration by 17.9%, which might be attributed to the tannin content in these plants. High salt in these salt tolerant forages might reduce glucose concentration.

Decreased cholesterol concentrations were observed with the experimental diets. This may be due to the presence of tannins which interfere with lipid digestion through forming complexes with fatty acids (Romero et al., 2000), decreasing cholesterol absorption and increasing fat excretion (Bravo et al., 1993). However, saponins may cause the same effects (Fayed et al., 2010) through inhibiting cholesterol absorption, causing reductions in plasma high-density lipoprotein and in cholesterol fraction (Morehouse et al., 1999). The same trend was observed with other reports with Barki rams (Shaker, 2014).

Urea and creatinine are the two main nitrogenous compounds excreted from the kidneys. Accordingly, any change in their concentrations would reflect impaired glomerular filtration and/or insufficiency of renal tubules (Kaneko, 1989). Furthermore, urea is the major N containing metabolic product of protein catabolism, accounting for more than 75% of the non-protein N excreted. In addition, urea production is also dependent on several variables such as diet and hepatic synthesis. The present results revealed that an increase in mean concentration of urea was observed in animals fed the experimental diets. The increased urea concentration could be due to the presence of higher contents of protein and non-protein. Cenci et al. (2006) showed that the values of total protein, urea, phosphorus and calcium concentrations in the serum were within the normal range when animals were fed AC. Moreover, Arieli et al. (1989) reported that urea concentration in plasma was higher by about 30% when sheep consumed saltbush *versus* a control diet.

4.4. Growth performance

Period affected lambs daily weight gain, where the highest gain was achieved during the first two weeks. This might be related to the lack of gut fill due to the weak impact of the forages during the first period of consumption. Compensatory growth during the first period cannot be ignored as the lambs were fed on diets containing concentrates and hay at a ratio of 70:30 on a DM basis during the experiment, which had higher nutritive values than the diet containing concentrates and hay at a ratio of 50:50 before the experiment. Lambs fed either AC15 or AT15 had an improved daily body weight gain compared with other treatment lambs. These results underlined the potential of salt tolerant plants as a dietary component to fulfil animal requirements for growth. The improved body weight gain may be due to increased feed intake and digestibility (Alsersy et al., 2015; Salem et al., 2015). In addition, complementary effects may occur between the presence of non-protein N in both AT and AC and metabolisable energy of barley grains and molasses in the diet (Pearce et al., 2010). Moreover, the low content of tannins in the diets can improve N utilisation through the protection of dietary proteins from rumen degradation (Salem et al., 2006). However, Shaker (2014) found that body weight was not affected by feeding a salt tolerant fodder crop mixture containing AT. Also, Abu-Zanat (2005) reported that animals eating a diet having lucerne hay partially replaced with *A. nummularia* or *Atriplex halimus* had lower growth rate than those consuming a diet where alfalfa hay was not replaced. In our study, the diet with berseem hay completely replaced with AT and AC (TC30) reduced body weight gain. These negative results in the previous and present studies may be attributed to decreased DM intake and blood albumin, which might result from too high contents of salt and tannin in the diet, causing reduced N digestibility (Kumar et al., 1980; Alsersy et al., 2015).

4.5. Carcass traits

Improved carcass weights were observed with the experimental diets of AC15 and AT15. This response can be attributed to increased CP content and improved voluntary feed intake. For both diets, barley and molasses were the main energy sources. The presence of readily available energy sources can improve the utilisation of a high content of N present in the form of non-protein compounds. Feeding a high-energy supplement can improve the feeding value of saltbush pastures by providing ruminal microbes with energy to produce microbial protein, to stimulate carbohydrate digestion and to detoxify secondary metabolites (Norman et al., 2008). On the contrary, when the two plants were mixed together, the concentration of the secondary metabolites increased over the ability of ruminal microflora to tolerate, causing the observed negative effects.

The dressing percentage was almost the same for TC30 and the control. However, AT15 and AC15 lowered the dressing percentage compared to the control. Al-Owaimer et al. (2008) noted that dressing percentage was greater in lambs fed a diet without AT than those fed a diet with AT. However, Abdul Aziz et al. (2001) found that dressing percentage increased in lambs fed AC compared to those fed the control diet. No differences were observed in the physical characteristics of the 9–11th ribs. However, lambs fed AT15 had an increased weight over the other lambs.

With the exception of CP content, the chemical composition of the 9–11th ribs was not affected. The total fat contents of the carcass increased with the experimental diets *versus* the control. However, a number of studies have concluded that consuming saltbush or a diet high in salt may decrease carcass fat content and increase the lean proportion compared to animals grazing either a grain–hay-based diet or a pasture-stubble paddock (Kraidees et al., 1998; Pearce et al., 2010). Al-Owaimer et al. (2008) found that lambs fed a complete diet containing AT had a lower fat content than those fed the control diet. The increase in carcass fat contents in our study might be due to the synergism of the two plants supplemented and/or some kind of complementary effects between the high content of grains and molasses in the diet.

4.6. Intestinal histopathology

The microscopic examination showed that the ileum of lambs fed either AT or AC was not degenerative and had less or no inflammatory reactions. This observation indicated that the ileum had an active absorptive function (Tufarelli et al., 2010). Excess goblet cells formed in these lambs suggested an active mucus secretory function.

The main and common alterations observed under microscopic examination with the experimental diets were the shortness in the height of the ileal villi. The shorter villi were somewhat thickened owing to congestion and dilatation of the lacteal vessels while the epithelium was active and contained excess goblet cells with less or no vacuolation or microvesicular formation. In this respect, Robins and Brooker (2005) stated a marked increase in villous height and crypt depth were recorded for abomasal and intestinal samples of sheep fed *Acacia aneura* compared with polyethylene glycol as a control. Long and thin gastric pits adjacent to the surface were a feature of *A. aneura*-fed sheep, contrasting with deep and wide gastric pits open to the luminal surface in sheep fed hay chaff. Abomasal epithelia of sheep fed with *A. aneura* and *A. aneura* plus polyethylene glycol showed discrete areas of tissue fragility compared with sheep fed hay chaff.

Generally, it is clear that feeding diets containing AT and AC led to negative effects on the intestinal morphological properties in ileum which could reduce the absorptive surface in digestive tract and consequently decrease lamb growth performance.

5. Conclusion

It could be concluded that *A. nummularia* and *A. saligna* could replace berseem hay up to 50% in the diet of Barki lambs without compromise of lamb growth performance, although feeding *A. nummularia* and *A. saligna* led to some changes in intestinal morphological properties. Thus, the use of these plants as a feed supplement for livestock may be considered as a partial solution to the problem of feed shortage. More studies are required to evaluate effects of inclusion of these halophytic forage shrubs at different levels on small ruminant production, especially on a large scale.

Conflicts of interest

None declared.

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