

Evaluation of *Atriplex nummularia* as a Roughage Source for Growing Lambs: Effects on Performance, Rumen Fermentation and Some Blood Mineral Concentrations

Mahmoud Abdelatife Mohamed Abdullah¹, Ibrahim Mohamed Ibrahim Youssef^{2, *},
Mamdouh Alsayed Eissa³

¹Department of Animal Production, Faculty of Agriculture, Assiut University, Assiut, Egypt

²Department of Nutrition and Clinical Nutrition, Faculty of Veterinary Medicine, Beni-Suef University, Beni-Suef, Egypt

³Department of Soils and Water, Faculty of Agriculture, Assiut University, Assiut, Egypt

Email address:

Ibrahim.Youssef@vet.bsu.edu.eg (I. M. I. Youssef)

*Corresponding author

To cite this article:

Mahmoud Abdelatife Mohamed Abdullah, Ibrahim Mohamed Ibrahim Youssef, Mamdouh Alsayed Eissa. Evaluation of *Atriplex nummularia* as a Roughage Source for Growing Lambs: Effects on Performance, Rumen Fermentation and Some Blood Mineral Concentrations. *International Journal of Animal Science and Technology*. Vol. 2, No. 4, 2018, pp. 55-61. doi: 10.11648/j.ijast.20180204.13

Received: November 16, 2018; **Accepted:** December 8, 2018; **Published:** January 11, 2019

Abstract: This study was conducted to evaluate the feeding of *Atriplex nummularia* as a source of roughages for sheep. Its effects on performance, some blood minerals and ruminal fermentation activities were assessed. Fifteen growing lambs (about 30.5± 1.20 kg B.W.) were randomly allocated into three groups, each with five lambs. The animals in the first group served as a control and were fed on a basal diet consisting of concentrate mixture and wheat straw. The second and third groups were received the same basal diet with substituting the wheat straw by 50% and 100% of *Atriplex nummularia* hay, respectively. The animals fed the *Atriplex* showed a decrease in feed intake and an increase in water intake. However, the body weight was not affected in lambs fed 50% *Atriplex* hay of the roughage amount, but decreased in those fed on that hay alone. Feeding of *Atriplex* increased the total protozoa count and total VFAs in the rumen, but decreased the ammonia N concentration. The increase of VFAs production resulted in a decrease in ruminal pH values. The plasma Na level was increased in both *Atriplex* treatments, but the K and Cl levels were higher in lambs fed on *Atriplex* hay alone. The obtained results indicate that the *Atriplex nummularia* hay can be used as an unconventional roughage source in sheep rations. It can be included at a level reaching the half of roughage amount fed to animals without any adverse effect on body weight. Moreover, it can improve the rumen fermentation and the utilization of degradable protein in the rumen as indicated by the increase in total protozoa count and total VFAs production with reduction of ammonia N concentration in the rumen.

Keywords: *Atriplex nummularia*, Sheep, Rumen Protozoa, Fermentation, Minerals

1. Introduction

Atriplex nummularia (old man saltbush) is a halophyte shrub contains about 10.0 to 26.0% crude protein and 18.0 to 35.0% ash [1]. It contains high concentrations of Ca, P, Mg, Na, K, Cl and S [2]. Sometimes, these constituents can reduce feed intake and produce mineral imbalance, but in some cases it can increase the product quality such as wool production due to sulfur content [3, 4]. *Atriplex* species have high resistance to drought and salt tolerance, so it is

frequently grown as fodder plant in drier areas [5]. Drought resistance allows it to be browsed during the annual dry season when other forage sources are not available [1]. In Egypt, Halophyte plants (salt plants) are commonly spread due to presence of several saline areas. The scarcity of animal feed in arid and semi-arid places triggers the using of non-conventional resources, such as halophytes, as animal feeds [6]. It grows well in deep and metal-contaminated soils

and also adapted to saline ones [7]. The ability of these plants to produce high quality forage under contamination conditions allows using non-traditional resources in agriculture production [8].

Saltbush shrub can be used in the rations of cattle, sheep and goats [1, 2, 9, 10]. Feeding of *Atriplex* species alone to sheep can at best maintain live body weight, but increased their weight when supplemented with hay [2]. Consequently, *Atriplex* can be effectively used not just to rejuvenate saline soils, but also as a source of productive feed [11, 12, 13, 14]. Saltbush shrub is better regarded as a supplement rather than forage to be fed as alone diet. Ruminants grazing old-man saltbush require low salt and high-energy feeds to complement the feeding value of saltbush via achieving the dilution of salts in a balanced diet and enhancing feed consumption and nutrient levels. Saltbush, as a supplement, has high nutritive value as a palatable source of minerals, crude protein and antioxidants. Combining saltbush with other complementary ingredients is a feasible solution to improve the animal performance [15]. However, there is a lack of information about the effect of saltbush on rumen ecology and fermentation. Therefore, the current study was conducted to assess the use of *Atriplex nummularia* as a source of roughages in diets of sheep. Its effects on performance, rumen fermentation and some blood mineral levels were investigated.

2. Materials and Methods

2.1. Preparation of Saltbush Hay

The old man saltbush (*A. nummularia*) was transplanted at 1st of September, and cut at maturity stage on 15th of April. During this period, the climate was hot in summer and cold in winter without rainfall. The collected green plants were sun dried and prepared in the form of hay by distributing them into layers and exposure to sunlight for 7 days. All parts of the plant either leaves (fine or medium-thickness), branches and stems were used in hay making. Then, the saltbush hay was chopped with a 5 cm screening mill and used in the experimental diets.

2.2. Chemical Analyses of Concentrate and Roughages

The concentrate mixture, wheat straw and saltbush hay were analyzed chemically for dry matter (DM), crude protein (CP), crude fiber (CF), and ash contents by using the techniques of AOAC [16]. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al. [17] methods. The elemental composition of the used concentrates and roughages was measured after digestion by H₂SO₄ and H₂O₂ as described by Parkinson and Allen [18]. The mineral elements, especially calcium, phosphorus, magnesium, sodium, chloride and potassium, were measured in the feed samples by means of atomic absorption spectrophotometer (Model 2300, Perkin-Elmer, USA). The chemical analyses of the concentrate mixture, wheat straw and saltbush hay are shown in Table 1.

2.3. Animals, Management and Feeding

Fifteen growing native lambs, of nearly equal body weight (about 28.0 kg), were randomly allocated into three groups, each with five lambs. The animals were housed individually in pens. The trial lasted for 60 days; 15 days pre-experimental or adaptation period and 45 days-feeding period on saltbush. During the pre-experimental period, the lambs were fed on concentrate mixture and wheat straw as basal diets. At the beginning of experiment, the animals were reweighed and their weight were recorded (about 30.5 kg). The lambs in the first group served as a control (CON) and continued in feeding on concentrate mixture plus wheat straw. The animals in other groups were fed on the concentrate mixture with *A. nummularia* hay. The *Atriplex* hay was gradually substituted half the amount of wheat straw in group 2 (ATR50) or replaced the straw totally in group 3 (ATR100). The concentrate mixture contained 53.0% yellow ground corn, 18% soybean meal, 26.3% wheat bran, 2.0% limestone, 0.5% salt and 0.20% trace mineral and vitamin premix. The premix comprised (per kg) 20,000,000 IU vitamin A, 200,000 IU vitamin D₃, 10,000 mg vitamin E, 10,000 mg Fe, 2500 mg Cu, 20,000 mg Mn, 100 mg Mo, 100 mg Co, 800 mg I, 20,000 mg Zn and 100 mg Se. The animals were fed 65% of their requirements as concentrate mixture, while roughage was given *ad lib* with determining its consumed amounts. Consequently, the proportions of concentrate and roughage in the rations were about 65 and 35%, respectively. The rations were formulated to satisfy or exceed the nutrient requirements of lambs according to NRC of sheep [19]. Moreover, the rations were daily offered in almost two equal portions at 8.00 am and 4.00 pm. The feed refusals were collected just before offering the rations of the next day and weighed to determine the daily feed intake. The amount of ration per animal was adjusted biweekly according to the body weight, based on NRC [19] guidelines for sheep. The lambs had a free excess to water, and the total water consumption of each animal was measured daily prior to feeding. Also, the ratio of water intake per feed intake was calculated. The animals were weighed at the onset and end of the experiment as well as at biweekly intervals during the experiment.

2.4. Ruminal Fermentation Activities

At the end of experiment, 100 ml of rumen fluid was collected from each lamb, by using a stomach tube, post the morning feeding by about 3 - 4 h. About 50 ml of rumen liquor was filtered with one layer of cheese cloth and the filtrate was kept in falcon tubes and transported to the lab in an ice box for measuring the total protozoa count according to Abou El-Naga [20]. Another 50 ml of the sample was filtered with four layers of cheese cloth to separate the solid particles. The filtrate portion was measured immediately for pH, using a pH meter, and ammonia N concentration via using Conway [21] method. Few drops of saturated solution of mercuric chloride were added to the filtrates to stop the microbial activity, and then the samples were stored at -20°C

for total VFAs determination. The total VFAs acids were measured by using the procedures of Warner [22].

2.5. Blood Mineral Concentrations

At the end of experiment, ten ml of blood samples were collected from the jugular vein of each lamb, before morning feeding, in tubes containing potassium ethylene diamine tetra-acetic acid (K-EDTA). Afterwards, the blood samples were immediately centrifuged at 3000 rpm for 15 minutes and the plasma was separated and stored at -20 °C until the chemical analysis. The plasma samples were analyzed for calcium, phosphorus, magnesium, sodium, potassium, and chlorine by atomic absorption spectrophotometry as in the feed samples.

2.6. Statistical Analysis

The results were statistically analyzed by using SAS statistical program [23]. The data were evaluated via using the procedure of General Linear Models (GLM) for analysis of variance. The obtained results were subjected to ANOVA tests accompanied by Duncan's multiple range test to detect the differences among the treatments. The figures are presented as means \pm SE. The data were considered significant at probability values lower than 0.05 ($p < 0.05$).

3. Results

The *A. nummularia* hay was analyzed and found to contain about 18.0% CP as well as high mineral contents (Table 1). Moreover, the ME content of *Atriplex* hay was nearly identical to that of wheat straw (about 1.41 Mcal/kg DM), but its fiber content was lower than wheat straw (12.95 vs. 37.50%). The high ash content of *Atriplex* resulted in a lower organic matter when compared to wheat straw (75.96 vs.

82.50%).

The concentrate intake did not differ among the treatments, whereas the amount of roughage intake decreased ($p < 0.05$) with increasing the proportion of *Atriplex* hay in the diet (Table 2). Thus, lambs fed on *A. nummularia* hay exhibited a lower ($p < 0.05$) total feed intake than the control. However, the water intake was increased ($p < 0.05$) in animals fed on that hay. Consequently, the ratio of water intake/ feed intake was higher ($p < 0.05$) in *Atriplex* fed groups compared to the control. Unexpectedly, the increase in water intake was equal in lambs fed 50% (ATR50) or 100% (ATR100) *Atriplex* hay. Nevertheless, the BW and weight gain of lambs fed 50% saltbush hay of the roughage amount (ATR50) was similar to that of the control, but was decreased in those fed on that hay alone as roughage.

Concerning the rumen fermentation (Table 3), the feeding of *A. nummularia* hay decreased ($p < 0.05$) the ruminal pH compared to the control (6.10 vs. 6.70). However, it increased ($p < 0.05$) the total protozoa count in comparison to the control (5.76×10^6 vs. 1.64×10^6). Moreover, the *Atriplex* improved the total VFAs production in the rumen fluid (13.0 vs. 9.16 mmol/100 ml), but reduced the ammonia N concentration (9.20 vs. 11.3 mg/100 ml).

The effects of *A. nummularia* hay on minerals intake of animals as well as on its concentrations in blood plasma are shown in Table 4. It was found that *Atriplex* hay increased ($p < 0.05$) the minerals intake of lambs in group 2 and 3. The effect on minerals intake was markedly higher in lambs fed on saltbush hay alone as roughage (group 3). However, the *Atriplex* feeding only increased ($p < 0.05$) the plasma Na concentration in both *Atriplex* treatments and the plasma K and Cl in lambs fed the *A. nummularia* hay alone. Nevertheless, there were no significant differences ($p > 0.05$) in plasma Ca, P and Mg levels among the treatments.

Table 1. Chemical composition (% or g/kg DM) of concentrate mixture, wheat straw and *Atriplex nummularia* hay (on dry matter basis).

Item	Concentrate mixture	Wheat straw	<i>A. nummularia</i> hay
ME, Mcal/kg DM*	2.90	1.51	1.41
Dry matter, %	93.50	92.50	88.85
Organic matter, %	82.50	82.50	75.96
Crude protein, %	17.5	3.40	18.02
Ether extract, %	4.11	1.50	1.20
Crude fiber, %	5.50	37.50	12.95
NDF, %	28.00	72.52	35.20
ADF, %	14.90	45.32	42.32
Minerals, g/kg DM			
Calcium	10.0	0.05	3.50
Phosphorus	8.00	0.04	1.80
Magnesium	5.00	0.05	1.00
Sodium	3.00	0.05	35.00
Potassium	7.00	0.08	17.00
Chloride	6.00	0.03	24.00

*ME value of the concentrate mixture was calculated according to NRC of sheep [19], while that of wheat straw and *A. nummularia* hay were drawn from NRC [19] and Feedipedia website [40], respectively.

Table 2. Effect of *Atriplex nummularia* feeding on performance of lambs throughout the experiment.

Items	Diets ^a		
	CON	ATR50	ATR100
Concentrate intake (kg DM/d)	0.49 ± 0.15 ^a	0.49 ± 0.14 ^a	0.49 ± 0.16 ^a
Roughage intake (kg DM/d)	0.30 ± 0.14 ^a	0.22 ± 0.16 ^b	0.18 ± 0.13 ^c
Total feed intake (kg DM/d)	0.79 ± 0.16 ^a	0.71 ± 0.16 ^b	0.68 ± 0.19 ^c
Water intake (L/d)	2.29 ± 0.14 ^b	3.74 ± 0.27 ^a	3.55 ± 0.24 ^a
Water intake/Feed intake (L/kg DM)	2.88 ± 0.15 ^b	5.22 ± 0.32 ^a	5.20 ± 0.27 ^a
Initial body weight (kg)	30.37 ± 0.62 ^a	30.63 ± 0.62 ^a	30.67 ± 1.54 ^a
Final body weight (kg)	38.66 ± 0.85 ^a	39.62 ± 0.63 ^a	36.88 ± 1.02 ^b
Weight gain (kg)	8.63 ± 0.24 ^a	8.75 ± 0.14 ^a	6.25 ± 0.25 ^b
Average daily gain (g)	191.66 ± 5.32 ^a	194.44 ± 3.21 ^a	138.88 ± 5.55 ^b

^aDiets were CON (its roughage was wheat straw alone, without *A. nummularia*), ATR50 (half of wheat straw was replaced by *A. nummularia*), ATR100 (its roughage was *A. nummularia* alone, without wheat straw).

Table 3. Effect of *Atriplex nummularia* feeding on pH, total protozoa count, ammonia N and total volatile fatty acids concentrations in the rumen of lambs.

Items	Diets ^a		
	CON	ATR50	ATR100
pH value	6.70 ± 0.14 ^a	6.06 ± 0.08 ^b	6.10 ± 0.19 ^b
Total protozoa count (×10 ⁶ /ml)	1.64 ± 0.42 ^c	4.59 ± 0.69 ^b	6.92 ± 0.97 ^a
Ammonia N concentration (mg/100 ml)	11.30 ± 0.52 ^a	9.44 ± 0.35 ^b	8.96 ± 0.46 ^b
Total VFAs concentration (mmol/100 ml)	9.16 ± 0.44 ^c	12.00 ± 0.28 ^b	13.92 ± 0.57 ^a

^aDiets were CON (its roughage was wheat straw alone, without *A. nummularia*), ATR50 (half of wheat straw was replaced by *A. nummularia*), ATR100 (its roughage was *A. nummularia* alone, without wheat straw).

Table 4. Effect of *Atriplex nummularia* feeding on minerals intake and mineral levels of blood plasma in lambs.

Items	Diets ^a		
	CON	ATR50	ATR100
Minerals intake, g/kg DM			
Calcium	4.90 ± 0.15 ^c	5.25 ± 0.19 ^b	5.59 ± 0.16 ^a
Phosphorus	3.92 ± 0.14 ^b	4.00 ± 0.23 ^b	4.28 ± 0.15 ^a
Magnesium	2.46 ± 0.33 ^b	2.79 ± 0.18 ^a	2.65 ± 0.13 ^a
Sodium	1.48 ± 0.12 ^c	5.29 ± 0.23 ^b	7.98 ± 0.32 ^a
Potassium	3.44 ± 0.14 ^c	5.25 ± 0.29 ^b	6.62 ± 0.24 ^a
Chloride	2.94 ± 0.23 ^c	5.70 ± 0.29 ^b	7.42 ± 0.31 ^a
Plasma mineral levels			
Calcium (mg/dL)	10.93 ± 1.16 ^a	11.65 ± 1.28 ^a	11.73 ± 1.26 ^a
Phosphorus (mg/dL)	6.45 ± 0.68 ^a	7.06 ± 0.83 ^a	6.50 ± 0.58 ^a
Magnesium (mg/dL)	2.99 ± 0.25 ^a	3.18 ± 0.38 ^a	3.24 ± 0.35 ^a
Sodium (mEq/L)	138.45 ± 3.83 ^b	145.33 ± 1.26 ^a	149.66 ± 1.25 ^a
Potassium (mEq/L)	3.97 ± 0.22 ^b	4.33 ± 0.15 ^{ab}	5.11 ± 0.29 ^a
Chloride (mEq/L)	96.82 ± 2.16 ^b	98.07 ± 2.32 ^b	103.45 ± 3.14 ^a

^aDiets were CON (its roughage was wheat straw alone, without *A. nummularia*), ATR50 (half of wheat straw was replaced by *A. nummularia*), ATR100 (its roughage was *A. nummularia* alone, without wheat straw).

4. Discussion

The saltbush hay can be used as a source of protein [18%] and minerals. The *Atriplex* species is characterized by high salt content as well as high levels of calcium, phosphorus, magnesium and other chemical components [2, 4]. However, it is a poor source of energy, like wheat straw, and should be supplemented with high energy feeds. Ben Salem et al. [24] observed a low energy content in *A. nummularia*, which could be a limiting issue to satisfy the animal requirements. The lower feed intake and increasing water intake in animals fed the *Atriplex* hay is attributed to its high mineral content. Norman et al. [3] noticed that the high ash content in *A. nummularia* hay restricted the feed intake. Pearce et al. [25] found reduced feed intake and digestibility rate of animals fed halophyte shrub, resulting in a limited growth rate or

weight loss. In this study, a highly significant decrease in weight of lambs fed on *A. nummularia* alone was observed, which can be attributed to small differences that accumulate over time due to energy restriction, and diminished DM intake. Moreover, the high consumption of ash, Cl and Na can cause mineral imbalances when intake is over a long period of time [4]. However, the weight of lambs fed 50 % *Atriplex* hay of the roughage amount was not affected in spite of reduced feed intake of these animals. It was noticed that the decrease in total feed intake in group 2 (ATR50) was slight in comparison to the control, which can be compensated by the higher rumen fermentation through increased production of VFAs and increased microbial protein synthesis as observed in this study. Consequently, the body weight of these animals was not affected. However, the decrease in feed intake in group 3 (ATR100) was markedly

higher which cannot be compensated by the rumen fermentation.

The water intake increased in animals fed *Atriplex* hay, but it was similar in both *Atriplex* groups although the increased level of this shrub in the roughage. This could be due to a marked decrease in total DM intake of animals in group 3 (ATR100), which restricted the amount of water intake. However, Abu-Zanat [26] reported that the increase in water intake is relative to *Atriplex* addition to the diets. Similarly, Le Houérou [27] and Lefèvre *et al.* [28] found an increase in water consumption when using high levels of *Atriplex* in diets of lambs. Generally, the water intake increases as a result of the salt level increases in the diet. This is due to the fact that salty diet increases the urine excretion by increasing the action of sodium pumps which drives water from cells and to adjust the water level, the brain give signals to drink more water [29].

It was found that the *Atriplex nummularia* increased the total rumen protozoa count, which could be due to the higher mineral contents, especially sulfur. In addition, feeding of *Atriplex* increased the total volatile fatty acids production. This finding could be due to an increase in the total rumen protozoa count in these animals. Moreover, the increase in volatile fatty acid production was indicated by a decrease in ruminal pH values. But, the decrease in ruminal pH was within the range optimum for bacteria (6.0 and 7.0). The reduction in ruminal ammonia N in *Atriplex* fed animals could be attributed to the improvement in microbial protein synthesis, which indicates enhanced utilization of degradable protein in the rumen. Also, it is possible that the energy content of the concentrate mixture had a positive role in the effects of *Atriplex* inside the rumen. The results obtained in the present study are supported with that of Du Toit *et al.* [30]. However, Salem *et al.* [31] found an increase in total VFAs and ammonia N concentrations, without any change in ruminal pH, in sheep fed *Atriplex halimus* ensiled with enzymes.

The Ca, P and Mg contents in blood plasma was similar in control and *Atriplex* groups. The highest mineral intake in the *Atriplex* groups led to a slight increase in Na, K and Cl levels in blood plasma. Although minerals were found in concentrations above the sheep requirements by NRC [19] and there was a higher mineral intakes in *Atriplex* groups compared to control, the mineral levels in blood plasma were always within the reference ranges for sheep according to Kahn [32]. The maintenance of mineral levels in blood could be explained by the high water intake [33]; because of the high content of salt in the diet and the requirement for a high water turnover to excrete the surplus salt from the body [19]. In addition, Mayberry *et al.* [34] reported that the high water intake could flush feed particles from the digestive tract before releasing of minerals, and eliminate minerals before they can be absorbed. Consequently, the availability of minerals can be reduced. Also, the absorption of minerals can be decreased by its chemical binding to indigestible molecules or its enclosure in undigested fibers. For example, the Ca and P levels in blood serum might be decreased because *A. nummularia* comprises high levels of secondary metabolites mainly oxalic acid which binds with Ca forming

calcium oxalate, a complex non-digestible compound [35, 36]. In contrast, blood levels of some minerals, such as Ca and P, are hormonally maintained and they are not good indicators of mineral consumption. These findings indicate that the intake levels of *Atriplex* species can fulfill the mineral requirements of maintenance in sheep, and therefore, supplemental salt is not needed in the diet [37]. Nevertheless, Alazzeah and Abu-Zanat [38] found lower levels of Ca and P in blood serum than normal range in lactating ewes fed saltbush, and hence, special attention should be taken when feeding saltbush for long periods. Among the tested minerals, the plasma levels of Na, Cl and K were highly affected with the intake. This is indicated by increasing their levels in the blood plasma due to its high contents in the diets. Moreover, the high plasma levels of Na can affect the palatability and, therefore, reduce the feed intake of the animals [1]. However, the levels of plasma Na and K are considered within the normal reference range of sheep [32], as they can be regulated by aldosterone hormone [39]. Even though, the saltbush requires low salt and high-energy feeds to achieve the dilution of salts in a balanced diet and improving feed intake and nutrient levels.

5. Conclusion

The results showed that increasing the proportion of *Atriplex nummularia* hay in the diets of lambs reduced the feed intake and increased the water intake. However, the body weight was not influenced in animals fed 50% *Atriplex* hay of the roughage amount, but decreased in those fed on that hay alone. Moreover, feeding of *Atriplex* increased the total protozoa count and total VFAs production in the rumen, but decreased the ammonia N level. Including a high level of that hay in the diet raised the Na, K and Cl levels in blood plasma, but the low level increased only the plasma Na. The obtained results indicate that the *Atriplex nummularia* hay can be used as an unconventional roughage source in sheep rations. In the present study, it can be included at a level reaching the half of roughage amount fed to animals without any adverse effect on body weight. Moreover, it can improve the rumen fermentation and the utilization of degradable protein in the rumen as indicated by the increase in total protozoa count and total VFAs production with reduction of ammonia N concentration in the rumen.

References

- [1] Ben Salem H, Norman H, Nefzaoui A, Mayberry D, Pearce K, Revell D (2010). Potential use of oldman saltbush (*Atriplex nummularia* Lindl.) in sheep and goat feeding. *Small Ruminant Research* 91: 13-28.
- [2] Aganga A, Mthetho J, Tshwenyane S (2003). *Atriplex nummularia* (Old Man Saltbush): A potential forage crop for arid regions of Botswana. *Pakistan Journal of Nutrition* 2: 72-75.

- [3] Norman HC, Freind C, Masters DG, Rintoul AJ, Dynes RA, Williams IH (2004). Variation within and between two saltbush species in plant composition and subsequent selection by sheep. *Australian Journal of Agricultural Research* 55: 999-1007.
- [4] Norman H, Masters D, Wilmot M, Rintoul A (2008). Effect of supplementation with grain, hay or straw on the performance of weaner Merino sheep grazing old man (*Atriplex nummularia*) or river (*Atriplex amnicola*) saltbush. *Grass and forage science* 63: 179-192.
- [5] El Nasr HA, Kandil H, El Kerdawy A, Khamis H, El-Shaer H (1997). Value of processed saltbush and acacia shrubs as sheep fodders under the arid conditions of Egypt. *Small Ruminant Research* 1: 15-20.
- [6] Attia-Ismail S, Elsayed H, Asker A, Zaki E (2009). Effect of different buffers on rumen kinetics of sheep fed halophyte plants. *Journal of Environmental Science* 19: 89-106.
- [7] Eissa MA, Ahmed EM (2016). Nitrogen and phosphorus fertilization for some *Atriplex* plants grown on metal-contaminated soils. *Soil and Sediment Contamination: An International Journal* 25: 431-442.
- [8] Eissa M, Ahmed E, Reichman S (2016). Production of the forage halophyte *Atriplex amnicola* in metal - contaminated soils. *Soil Use and Management* 32: 350-356.
- [9] Ahmed M, Elghandour M, Salem A, Zeweil H, Kholif A, Klieve A, Abdelrassol A (2015). Influence of *Trichoderma reesei* or *Saccharomyces cerevisiae* on performance, ruminal fermentation, carcass characteristics and blood biochemistry of lambs fed *Atriplex nummularia* and *Acacia saligna* mixture. *Livestock Science* 180: 90-97.
- [10] Meneses, R., Varela, G., Flores, H (2012). Evaluating the use of *Atriplex nummularia* hay on feed intake, growth, and carcass characteristics of creole kids. *Chilean Journal of Agricultural Research* 72: 74.
- [11] Hopkins D, Nicholson A (1999). Meat quality of wether lambs grazed on either saltbush (*Atriplex nummularia*) plus supplements or lucerne (*Medicago sativa*). *Meat Science* 51: 91-95.
- [12] Moreno GMB, Borba H, de Araújo GGL, Sanudo C, da Silva Sobrinho AG, Buzanskas ME, de Lima Júnior DM, de Almeida VVS, Neto OB (2015). Meat quality of lambs fed different saltbush hay (*Atriplex nummularia*) levels. *Italian Journal of Animal Science* 14: 251-259.
- [13] Obeidat BS, Mahmoud KZ, Maswadeh JA, Bsoul EY (2016). Effects of feeding *Atriplex halimus* L. on growth performance and carcass characteristics of fattening Awassi lambs. *Small Ruminant Research* 137: 65-70.
- [14] Moreno GMB, Borba H, de Araújo GGL, Voltolini TV, de Moraes SA, da Silva Sobrinho AG, Neto OB, de Lima Júnior DM, Cirne LGA, Buzanskas ME (2017). Digestibility and performance of lambs fed diets containing old man saltbush hay. *Semina: Ciências Agrárias* 38: 455-466.
- [15] Hintsa K, Berhe A, Balehegn M, Berhe K (2018). Effect of replacing concentrate feed with leaves of Oldman saltbush (*Atriplex nummularia*) on feed intake, weight gain, and carcass parameters of highland sheep fed on wheat straw in northern Ethiopia. *Tropical Animal Health and Production* 50: 1435-1440.
- [16] AOAC (2005). *Official Methods of Analysis of AOAC International*, 18th ed. Association of Official Analytical Chemists, Gaithersburg, MD.
- [17] Van Soest PV, Robertson J, Lewis B (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74: 3583-3597.
- [18] Parkinson J, Allen S (1975). A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. *Communications in Soil Science and Plant Analysis* 6: 1-11.
- [19] NRC (1985). *Nutrient Requirements of Sheep*. National Research Council. Washington, DC, USA.
- [20] Abou El-Naga M (1967). Some metabolic studies on rumen microorganisms. Thesis, Faculty of Agric., Unive. Alex.
- [21] Conway EF (1962). *Ammonia, General Method. Microdiffusion Analysis and Volumetric Error*. Crosby Lockwood and Son Ltd., London, UK, p. 98-100.
- [22] Warner ACI (1964). Production of volatile fatty acids in the rumen: methods of measurement. *Nutrition Abstract Review* 34: 339.
- [23] SAS (2002). *Institute SAS User's Guide*. Release 6.12 Edition: SAS institute Inc., Cary, NC.
- [24] Ben Salem H, Nefzaoui A, Salem LB (2002). Supplementing spineless cactus (*Opuntia ficus-indica* f. *inermis*) based diets with urea-treated straw or oldman saltbush (*Atriplex nummularia*). Effects on intake, digestion and sheep growth. *The Journal of Agricultural Science* 138: 85-92.
- [25] Pearce K, Masters D, Smith G, Jacob R, Pethick D (2005). Plasma and tissue α -tocopherol concentrations and meat colour stability in sheep grazing saltbush (*Atriplex* spp.). *Australian Journal of Agricultural Research* 56: 663-672.
- [26] Abu-Zanat MMW (2005). Voluntary intake and digestibility of saltbush by sheep. *Asian-Aust. Journal of Animal Science* 118: 214-220.
- [27] Le Houérou H (1992). The role of saltbushes (*Atriplex* spp.) in arid land rehabilitation in the Mediterranean Basin: a review. *Agroforestry Systems* 18: 107-148.
- [28] Lefèvre I, Marchal G, Ghanem ME, Correal E, Lutts S (2010). Cadmium has contrasting effects on polyethylene glycol-Sensitive and resistant cell lines in the Mediterranean halophyte species *Atriplex halimus* L. *Journal of Plant Physiology* 167: 365-374.
- [29] Harper ME, Willis JS, Patrick J (1997). Sodium and chloride in nutrition. *Handbook of Nutritionally Essential Mineral Elements* 8217: 93-116.
- [30] Du Toit CJL, Van Niekerk WA, Hassan A, Rethman NFG, Coertze RJ (2006). Fermentation in the rumen of sheep fed *Atriplex nummularia* cv. De Kock supplemented with incremental levels of barley and maize grain. *South African Journal of Animal Science* 36 (5): 74-77.
- [31] Salem AZM, Alsersy H, Camacho LM, El-Adawy MM, Elghandour MMY, Kholif AE, Rivero N, Alonso MU, Zaragoza A (2015). Feed intake, nutrient digestibility, nitrogen utilization, and ruminal fermentation activities in sheep fed *Atriplex halimus* ensiled with three developed enzyme cocktails. *Czech Journal of Animal Science* 60 (4): 185-194.

- [32] Kahn CM (2005). The Merck Veterinary Manual, 9th ed. Whitehouse Station, N. J.; [Great Britain]: Merck & Co.
- [33] Millsom D (2002). Direct seeding Oldman saltbush (*Atriplex* sp.) and associated chenopod species in saline clay. *Branching Out* 21: 4-6.
- [34] Mayberry D, Masters D, Vercoe P (2010). Mineral metabolism of sheep fed saltbush or a formulated high-salt diet. *Small Ruminant Research* 91: 81-86.
- [35] Blaney B, Gartner R, Head T (1982). The effects of oxalate in tropical grasses on calcium, phosphorus and magnesium availability to cattle. *The Journal of Agricultural Science* 99: 533-539.
- [36] Cheeke P (1995). Endogenous toxins and mycotoxins in forage grasses and their effects on livestock. p. 909-918. En: *Journal of Animal Science*. Vol. 73, no. 3 (Mar 1995).
- [37] Otal J, Orengo J, Quiles A, Hevia ML, Fuentes F (2010). Characterization of edible biomass of *Atriplex halimus* L. and its effect on feed and water intakes, and on blood mineral profile in non-pregnant Manchega-breed sheep. *Small Ruminant Research* 91: 208–214.
- [38] Alazzeah A, Abu-Zanat M (2004). Impact of feeding saltbush (*Atriplex* sp.) on some mineral concentrations in the blood serum of lactating Awassi ewes. *Small Ruminant Research* 54: 81-88.
- [39] . Safwate A, Davicco M, Dalle M, Barlet JP (1984). Electrolyte balance, mode of delivery and plasma aldosterone levels in newborn lambs. *Reproduction Nutrition Développement* 24 (4): 351-360.
- [40] Feedipedia - Animal Feed Resources Information System - INRA CIRAD AFZ and FAO. <https://www.feedipedia.org/node/184>.