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Nutritional and Metabolic Responses to Cactus-Atriplex Diets in Pregnant Ewes under semi-Arid conditions

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Abstract

The aim of this study was to identify the most suitable diet based on Opuntia ficus-indica inerme and Atriplex halimus to meet the nutritional requirements of pregnant Barbarine ewes, and to assess its effects on feed intake, digestibility, metabolic profile, and weight variation of the ewes. The experiment was conducted on 36 ewes, allocated into 9 groups using a crossover design. Nine dietary treatments were tested : a control diet (barley straw + barley grain), five combinations of straw with varying proportions of Opuntia and Atriplex (100%, 75/25%, 50/50%, 25/75%, 100%), and three diets composed exclusively of straw, Opuntia, or Atriplex. Dry matter intake of diets D1 to D9 ranged from 43.01 to 71.64 g DM/kg $BW^{0.75}$, corresponding respectively to straw and Opuntia. Organic matter digestibility for diets D3to D6 was 67.47 ± 8.19, 74.27 ± 2.54, 66.34 ± 3.05, and 62.10 ± -65%, respective. Diets D3 to D5 are the most balanced with respect to energy and nitrogen, as shown by their respective energy and nitrogen levels. ANOVA revealed significant ($p < 0.05$) in the digestibility of the diets and in the biochemical parameters. Blood glucose levels remained within the normal physiological range for sheep. Urea and creatinine concentrations in diets 3 to 7 were similar to those in the control group. The Opuntia-Atriplex combination did not alter the metabolism of the ewes. Diet 4 appears to be a promising alternative to conventional diets, by reducing the cost of the diets.

Introduction

Opuntia ficus indica inerme, commonly known as prickly pear, a CAM (Crassulacean Acid Metabolism) plant, and *Atriplex halimus* (chenopodiaceae) is a perennial xerohalophyte native to arid and semi-arid Mediterranean regions. This species tolerates harsh conditions such as salinity), light stress and drought (Martinez et al. 2005), *can* be a sustainable alternative for arid regions, thanks to their adaptation to the climate. These regions suffer from extreme climatic conditions: droughts, irregular rainfall and soil degradation, all of which are exacerbated by climate change, (Garcia-Franco et al. 2018). Arid regions are currently experiencing numerous difficulties for livestock farming, mainly due to insufficient fodder resources, the excessive cost of concentrates, which can even compromise human nutrition, and the often-irreversible degradation of pastoral resources (Bensalem and Smith 2008),(Albuquerque et al. 2020). In Algeria, the number of ewes alone reached 19.3 million in 2020, representing a 4.3% increase compared to 2019 (ONS, 2023). This growth highlights the importance of sheep farming for the production of meat, wool, and milk, as well as the growing challenges of sustaining this sector in the face of chronic fodder shortages and environmental degradation. To address these challenges, it is essential to identify and incorporate sustainable and locally available feed alternatives. Among these, *Opuntia ficus-indica* (cactus) and *Atriplex halimus* have proven to be viable options for supplementing traditional diets in arid and semi-arid regions. It was in this context of aridity that a feeding study was carried out in relation to the end-of-gestation needs of the Barbarine breed of ewe, known for its ability to adapt to the conditions of arid zones. Our experimental approach focused on predicting the nutritional value of the test foods, assessing food intake, evaluating the in vivo digestibility of the various dietary components, determining energy and nitrogen intake, monitoring body weight gain for each diet, and analyzing the metabolic profile. incorporation of the *Opuntia-Atriplex* combination, at 5 levels: 0, 25, 50, 75 and 100% and vice versa. Opuntia cladodes are particularly valuable due to their high-water content and rich composition in energy and minerals, particularly potassium and calcium (Ayadi et al. 2009); Bargougui et al. 2019;), making them a crucial resource during periods of drought. Atriplex halimus is notable for its high crude protein and fibre content, but is also rich in sodium chloride (Ben Salem2010); (Boudaa et al. 2013), oxalates, which reduce calcium availability by creating insoluble calcium oxalate in the rumen and kidneys (Alazzeh et al. 2009). The *Opuntia* cladodes are particularly valuable due to their high water content and their richness in energy and minerals, especially potassium and calcium, making them a crucial resource during periods of drought.*Atriplex halimus* is notable for its high crude protein and fiber content, but it is also rich in sodium chloride (Ben Salem 2008) and oxalates, which reduce calcium availability by forming insoluble calcium oxalate in the rumen and kidneys (Alazzeh et al. 2009). and can contain high levels of tannins (12 to 15 g/kg DM), as observed in Jordan (Abu-Zanat et al. 2003). The interest of this study lies in the possibility of covering the gestation needs of Barbarine ewes and maintaining them physiologically in a satisfactory state of health, with the most appropriate rate of incorporation of Opuntia-Atriplex to replace grain barley in the diet of Barbarine ewes in southern Algeria.

Materials and methods

Animals

Thirty-six Barbarine ewes aged between 4 and 6 years, average weight 57 ± 4.6 kg, parasite-free, body condition 2, placed in digestibility cages divided into 9 batches. The ewes underwent heat synchronisation using vaginal sponges (FGA = 20 mg (Intervet, France), and PMSG = 300 IU).

Foods and diets

The study was conducted in eastern Algeria, using *Opuntia ficus-indica* from Bedjene (Tébessa) and *Atriplex halimus* from Zribet El Oued (Biskra). Samples were collected in March–April 2022 at the early flowering stage. Barley grain and straw were sourced from a local private farm. Nine diets were tested on pregnant ewes over two 29-day periods, including 8 days of data collection per period. Diet substitutions were made (D1 versus D5, D2versus D4, D3versus D6), while diets D7, D8, and D9 were discontinued to prevent potential adverse effects. Rations were formulated based on the nutritional needs of ewes in late gestation, with incorporation rates of Opuntia and Atriplex ranging from 0 to 100%. Diet 1 (control) consisted of 461 g barley and 700 g straw. Other diets included varying combinations of Opuntia and Atriplex, with straw offered in limited amounts. Diets 7, 8, and 9, consisting solely of straw, Opuntia, or Atriplex, were used to assess potential digestive disorders and comparative digestibility (Gebremariam 2006).

Measurements and parameters studied

The quantity distributed in g corresponds to the last third of gestation of the ewes. It took into account the characteristics of the ewe, namely its live weight 57 kg ± 4.7, its UFL = 0.76 of its PDI (g) = 78g, the ingestion capacity – 27 UEM and the bulk of the barley straw 2.33 UEM / Kg of DM (INRA, 1988, 2007). The FULs were predicted from the chemical composition and by using the equations of (INRA, 1988), and (Guerin et al. 1989) specific to each food group. For Opuntia, we did not find any specific equations; however, according to Araba et al. (2009), its energy value is comparable to that of alfalfa. We chose the equations for green alfalfa 1st cycle. As for the PDI values, they were obtained from 4 characteristics: the MAT content; the theoretical degradability of MAT; the content of fermentable organic matter FOM; and the real digestibility (dr) of amino acids of dietary origin. For Atriplex, the DT and dr values are 0.73 and 0.75 respectively. The fresh intake of Opuntia is around 9 to 11 kg (Mulas.2004), given its high palatability and low bulkiness. For Atriplex, UFL values are maximum at the flowering stage values in and 0.80- 0.81UFL / Kg of DM. (Nefzaoui and Chermiti 1991) UFL advanced varying between 0.60 UFL / Kg of DM. Essafı et al, (2007), found values fluctuating between 0.71 and 0.75 UFL / Kg of DM. On the other hand, Le Houerou (1991), mentioned results which are between 0.50 and 0.60UFL /Kg of DM. The PDI have maximum values at the mature grain stage with PDIN of 165.32 g /kg of DM. Kessler (1990), reported that the high levels of proteins and mineral salts allow the use of Atriplex halimus as a fodder reserve in summer and autumn. The intake of the diets was determined by daily weighing of the distributed and the refused. Only the feces were collected each morning, at the same time, weighed and stored at (-18°C). The digestibility was evaluated by the apparent digestive utilization coefficient (ADC usually called by the term digestibility (D….).

Feeding levels (FL) were calculated based on the amount of digestible organic matter intake (DOMI) for energy requirements and the amount of digestible protein in the intestine (PDI) for nitrogen requirements, according to INRA (1988, 2007). Average daily gain or loss was assessed by weekly weighing of the ewes on an empty stomach throughout the trial. Blood samples were collected via jugular venipuncture using heparinised venoject tubes, after fasting, and were centrifuged and stored in microtubes at(− 30°C). Sampling was conducted prior to the introduction of cladodes and at the end of each experimental period. A total of 36 blood samples per biological parameter were collected during period 1, and 24 during period 2. Regarding growth: Lambs were monitored for a period of 21 days. The ewes were allowed a one-week postpartum recovery period before lamb weights began to be measured.

The apparent digestibility coefficient ADC, or D(…), was calculated using the equation: ADC (%) = (I – E). I^{-1} ×100, where I is the amount ingested and E the amount excreted.

Energy feeding level (FL_energy) was defined as: FL_energy = DOMI (g.kg / $BW^{0.75}$)/ 23, with 23 g DOMI representing the maintenance requirement (equivalent to 95 kcal ME kg / $BW^{0.75}$).DOMI was calculated as: DOMI = OM ingested × OM digestibility. Nitrogen feeding level (FL_nitrogen)was defined as:FL_nitrogen = PDI(g $BWP^{0.75}$) / 2.5,where 2.5 g PDI / kg $BW^{0.75}$ corresponds to nitrogen maintenance needs. Maintenance feeding units for lactation (FUL) were estimated as: FUL_maintenance = $BW^{0.75}$× 0.033. Total FUL intake: FUL_total = $BW^{0.75}$ × 0.033 × FL. FUL available for gestation: FUL_gestation = FUL_total – FUL_maintenance. PDI requirements for maintenance: PDI_maintenance = $BW^{0.75}$ × 2.5. Total PDI intake: PDI_total = $BW^{0.75}$ × 2.5 × FL. PDI available for gestation: PDI_gestation = PDI_total – PDI_maintenance. All equations used are from (INRA, 1988, 2007*) and (Guérin et a.l 1989).*

Test procedure.

The experiment was conducted in a sheepfold in El-Oued (Algeria) over two periods of 29 days: 21 days of diet adaptation and 8 days of data collection. The 100% diets (straw, Opuntia, Atriplex) were discontinued due to physiological issues observed in 12 ewes. The remaining 24 ewes continued the trial with cross-over diets. The constituents of each feed and feces were analyzed using conventional methods: water content was determined by steaming at 103°C ± 2°C, crude fiber content by the Weende method, total nitrogen by Kjeldhal, and fat by hexane extraction using a Soxhlet apparatus. For the diets that received straw, the contents were determined on representative samples of the offered and refused diets. NDF and ADF were determined using the method described by Van Soest et al. (1991). The biochemical analysis was carried out using a COBAS C111 autoanalyzer, produced by ROCHE diagnostics in Rotkreuz (Switzerland).

Statistical analysis.

The results of the various chemical analyses were processed using Excel to calculate means and standard deviations, and with Statistica software version 6 for analysis of variance (ANOVA), followed by the Newman-Keuls test to rank the different treatments at significance levels of $p < 0.05$ and $p < 0.0$- The comparison of means between treatments showed no significant differences between D1 and D4. However, highly significant differences ($p < 0.01$) were observed between (D1 and D9), (D1 and D8), (D1 and D7), (D1 and D6), (D1 and D5), as well as between (D1 and D2).

Results

Chemical composition, intake and digestibility

The results of the chemical composition of each feed and their nutritional values are shown in Table - The results of the chemical composition of the experimental feeds show that Opuntia cladodes have a UFL value / Kg DM of 0.63, (FAO 1989) indicating a value between 0.6 and 0.7. The PDI in g/ Kg DM are of the order of 38 ± 7.5 for PDIN and 64 ± 2 for PDIE. FUL values for Atriplex are highest at the flowering stage, at 0.81 FUL (Arbouche et al. 2013). (Essafı et al.2007), found values fluctuating between 0.71 and 0.75 FUL/ kg DM. (Nefzaoui and Chermiti 1991) put forward FUL values of between 0.6 and 0.8 FUL/kg DM. Le houerou (1991), on the other hand, reported results of between 0.50 and 0.60 FUL/Kg DM. Our results for Atriplex are 0.83 ± 0.03 UFL/kg DM and 120 ± 17g PDIN and 98 ± 9 PDIE g. The FUL values for straw and grain barley are close to the standards of (INRA 1988) The composition of the diets fed is shown in Table 2. The diets were isoenergetic but not iso nitrogenous and we deliberately avoided balancing the diets with commercial nitrogen. The FUL and PDI contents of the diets were calculated from the chemical composition of each feed and by the prediction equations of (INRA, 1988, 2007). The intake of diets D1to D6 were practically equal and appeared to be independent of their digestibility. The straw intake of diets D2, to D6 is on average around 148 ± 36 g, showing that the straw is intended solely for the salivation of the diets. Only on diet 1, the straw intake was 617g because the addition of concentrate (grain barley) to the ration increased the straw intake and even improved the digestibility of the diet (Jarrige 1989).

Table 2
Quantity of DM distributed and ingested (g/animal/day), chemical composition by diet and ration cost.

Distributed	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
Grain barley	461	-	-	-	-	-	-	-	-
Opuntia	-	1140 (100%)	855 (75%)	570 (50%)	285 (25%)	-	-	1210	-
Atriplex			215 (25%)	430 (50%)	645 (75%)	860 (100%)	-	-	960
Straw	700	200	200	200	200	200	1680		
Total FUL	0.80	0,80	0,80	0,80	0,80	0,80	0,76	0,76	0,79
Total PDIg	46,1	48,7	59	69,2	79,4	89,7	45,3	46	90
DM distributed	1161	1340	1270	1200	1130	1060	1700	1210	960
Ingestible	D1	D2	D3	D4	D5	D6	D7	D8	D9
Grain barley	461	-							
Opuntia		960	790	566	285	-			
Atriplex			180	400	644	810		-	-
Straw	617	109	113	180	200	139	730	-	-
DM ingested	1078 ± 89[a]	1069 ± 100a	1083 ± 99a	1146 ± 98a	1129 ± 103[a]	949 ± 37[a]	730 ± 37[b]	1190 ± 10[a]	920 ± 15c
$BW^{0.75}$	22.06 ± 0.69	20.06 ± 0.46	22.26 ± 0.7	22.6 ± 0.96	22.4 ± 0.58	19.94 ± 0.58	16.97 ± 0.51	16.61 ± 0.335	16.24 ± 0.29
$DMI/kgBW^{0.75}$	48.86 ± 2.5	53.29 ± 3.7	48.65 ± 2.92	50.7 ± 2.2	50.4 ± 3.29	47.58 ± .38	43.01 ± 0.8	71.64 ± 0.4	56.6 ± 0.21
OM	1029 ± 84	826 ± 85	847 ± 80	919 ± 86	713 ± 29	785 ± 31	946 ± 39	896 ± 54	742 ± 12
CF	328 ± 26	180 ± 18	208 ± 19	269 ± 25	309 ± 27	480 ± 21	481 ± 19	159 ± 7	250 ± 7
CP	65 ± 5	43 ± 4	76 ± 7	80 ± 7	103 ± 12	108 ± 3	32 ± 3	58 ± 5	109 ± 6
DA / $	25.4/ 0.18	24.7/0.18	22.4/0.16	20.04 / .14	16.2/0.11	10.2/0.07	15/0.1	28.5/0.2	9.2/0.06

ab, bc, in the same line, when the letters are different, the differences are significant at ($p < 0.05$).

Price in DA/DM : Opuntia : 24DA/Kg of DM, Atriplex :10DA/ Kg of DM, Grain barley : 35DA / Kg of DM, Barley straw :15 DA/Kg of DM (DA/Algerian Dinar 1$ = 136DA)

The results of the digestibility of the different constituents of each diet are compared with each other and with the D (DM, OM, CF, and CP) of straw alone, Opuntia and Atriplex (Table 3) while the results of the feeding levels are shown in (Table 4).

Table 3
Digestibility of the various constituents in % /Kg DM, n = 8 (cross-over diets D1versus D5, D2 versus D4, and D3 versus D6)

D (…)in % of DM	D1	D2	D3	D4	D5	D6	D7	D8	D9
D(DM) diet	70.75 ± 3.5[a]	53.8 ± 2,5[b]	7 – 4 ± 1.6[a]	72.4 ± 1.8[a]	64.1 ± 3.4[c]	55.2±-9[b]	44.5 ± 1.75[d]	62.5 ± 2[c]	42.7 ± 1,7[d]
D (DM) straw	44.5 ± 1.75	44.5 ± 1.75	44.5 ± 1.75 .	44.5 ± 1.75	44.5 ± 1.75	44.5 ± 1.75 .	44.5 ± 1.75	44.5 ± 1.75	44.5 ± 1.75 .
D(DM) Opuntia	62.5 ± 2	62.5 ± 2	62.5 ± 2	62.5 ± 2	62.5 ± 2	62.5 ± 2	62.5 ± 2	62.5 ± 2.	62.5 ± 2
D(DM)Atriplex	42.7 ± 1.7	42,7 ± 1.7	42.7 ± 1.7	42.7 ± 1.7	42,7 ± 1.7	42.7 ± 1.7	42.7 ± 1.7	42,7 ± 1.7	42.7 ± 1.7
D(OM) diet	72.4 ± 2.85.[a]	54.8 ± 3.5[b]	67.5 ± 5.5[c]	74.3 ± 2[a]	66,4 ± 3.5[C] .	62,1±-65c	52.35 ± 2.1[b]	62.6 ± 2.03[c]	47 ± 2,3[d]
D (OM)straw	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6	52.35 ± 1,6
D OM)Opuntia	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03	62.6 ± 2.03
D(OM)Atriplex	47 ± 2.3	47 ± 2.3	47 ± 2.3	47 ± 2.3	47 ± 2.3	47 ± 2.3	47 ± 2.3	47 ± 2.3	47 ± 2.3
D(CF)diet	61 ± 7.95 [a]	5 – 1 ± 6.35[b]	69.4 ± 4.65 [c]	72.9 ± 6.7[c]	62.2 ± 3.7[a]	49.8 ± 3.65[d]	44.7±-8[d]	82.65±-25[e]	33.7 ± 0.73[f]
D(CF) straw	44.67±-83	44.67±-83	44.67±-83	44.67±-83	44.67±-83	44.67±-83	44.67±-83	44.67±-83	44.67±-83
D(CF) Opuntia	82.64 ± 1.	82.64 ± 1.27	82.64 ± 1.27	82.64 ± 1.27	82.64 ± 1.27	82.64 ± 1. 27	82.64 ± 1.27	82.64 ± 1.27	82.64 ± 1.27
D (CF) Atriplex	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73	33.7 ± 0.73
D(CP) diet	80.±5. 31[a]	64.4 ± 5.15[b]	89.05 ± 2.55[c]	89.06±-2[c]	85.3±-8[c]	49.2±-6 [d]	45.25 ± 2.5[d]	69.5 ± 4.8[b] .	50.86±-45[d]
D(CP) straw	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5	45.25 ± 2.5
D(CP)Opuntia	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77	69.48 ± 4.77
D(CP)Atriplex	50.86±-46	50.86±-46	50.86±-46	50.86±-46	50.86±-46	50.86±-46	50.86±-46	50.86±-46	50.86±-46

[ab, bc,] in the same line, when the letters are different, the differences are significant at (p < 0.05).

Table 4
The results of the Feeding levels and Average Daily Weight gain

Diet	D1	D2	D3	D4	D5	D6	D7	D8	D9
$BW^{0.75}$	22.06 ± 0.69	20.06 ± 0.46	22.26 ± 0.7	22.61 ± 0.96	22.40 ± 0.65	19.94 ± 0.58	16.97 ± 0.51	16.24 ± 0.29	16.61 ± 0.35
FUL maintenance	0.72 ± 0.02	0.66 ± 0.01	0,73 ± 0.04	0,74 ± 0,03	0.73 ± 0.02	0.65 ± 0.01	0.56 ± 0.03	0.53 ± 0.01	0.54 ± 0.02
$DOMI/BW^{0.75}$	33.86 ± 3.83	22.6 ± 6.52	27. 3 ± 0.1	31.23 ± 2.3	27.8 ± 0.2	26.05 ± 0.9	21.16 ± 1.05	34.2 ± 1.96	20.11 ± 1.2
FL Energy	1.53 ± 0.16 [a]	1.12 ± 0.28[b]	1.22 ± 0.41[b]	1.38 ± 0.09[a]	1.24 ± 0.05[b]	1.3 ± 0.03[b]	1.24 ± 0.04 [b]	2.1 ± 0.08[c]	1.21 ± 0.05[b]
FUL ingested	1.1 ± 0.003	0.73 ± 0.004	0.89 ± 0.018	1.02 ± 0.02	0.90 ± 0. 07	0.84 ± 0.007	0.69 ± 0.001	1.11 ± 0.007	0.65 ± 0.001
ADG measured	78 ± 17	34 ± 4	81 ± 14	104 ± 9	89 ± 9	96 ± 11	− 201 ± 11	-2171 ± 37	-181 ± 39
PDIg maintenance	55.15 ± 1.72	50.15 ± 1.15	55.65 ± 1.75	56.52 ± 2.4	56.52 ± 2.4	49.85 ± 1.45	42.35±-27	40.6 ± 0.72	41.52 ± 0.87
PDIg ingested	51.84 ± 4.3	27.58 ± 2.87	67.33 ± 4.37	71.2 ± 6	67 ± 4.05	37 ± 3.62	47 ± 3.17	11 ± 1–8	60 ± 2.17
$PDI / BW^{0.75}$	2.35 ± 0.28	1.38 ± 0.2	3.04 ± 0,17	3.15 ± 0,08	3 ± 0.12	1.87 ± 0.04	0.58 ± 0.02	0.72 ± 0.04	3.61 ± 0.1
FL nitrogen	0.94 ± 0.11[a]	0.55 ± 0.22[b]	1.21 ± 0.06[c]	1.26 ± 0.03[c]	1.2 ± 0.04[c]	0.74 ± 0.01[d]	0.24 ± 0.008[e]	0.28 ± 0.01[e]	1.44 ± 0.04[c]

Mean ± standard deviation.

[ab, bc,] in the same line, when the letters are different, the differences are highly significant at ($p < 0.05$).

Discussion

Diets D1 to D6 exhibited similar intake levels. Straw consumption in diets D2 to D6 was low and primarily served to stimulate salivation. Diet D1, based on whole barley grain, showed the highest straw intake (33.86 g/kg $P^{0.75}$), which was facilitated by the presence of barley grain. Diets D3 to D9 excepted D8 showed dry matter intake levels ranging from 48.65 to 56.6 g DM/kg $BW^{0.75}$, which are lower than those reported by (Correal and Sotomayor 2000) for Atriplex halimus (90 g DM/kg $BW^{0.75}$) and Atriplex nummularia (117 g DM/kg $BW^{0.75}$). This variability is influenced by several factors, including particle size (< 5 mm), digestibility, and salt (NaCl) content. Our findings sow date the particles size the consumable biomass (leaves and young tweegs) (is on the order of 8–10 mm). The dry matter intake of the ewes was not significantly affected by the dietary treatments. This suggests that the inclusion of an Opuntia-Atriplex blend at ratios of 25:75, 50:50, and 75:25, respectively, as well as the control diet, did not adversely influence the palatability of the dieds..

The D(MO) for R4 increased by 22, 12, and 27 points compared with the D(MO) of the straw based, Opuntia based, and Atriplex based diets, and increased appreciably relative to the control (R1) Statistically, there is significant difference at $p < 0.05$. (Table 3). Inclusion of Opuntia and Atriplex particularly in diets D3, D5, and D6 improved digestibility of all dietary constituents but remained below that of the control. This may be attributed to anti nutritional factors in Atriplex, such as tannins, which inhibit protein digestion by forming insoluble complexes, thus reducing the availability of Atriplex's constituents for absorption. According to (Abu Zanat et al. 2003), Atriplex halimus may contain high levels of tannins (12–15 g/kg DM). Similarly, oxalic acid present in species of the Atriplex genus (Hungerford 1990), cited by (El Shaer 2010) reduces calcium availability by forming insoluble calcium oxalate in the rumen and kidneys, which can cause renal lesions and decrease calcium absorption in the intestine. (Ben Salem et al. 2010) showed that Atriplex based rations negatively affect digestibility of all components, whereas other studies reported no influence of Atriplex on digestibility (Al Owaimer et al. 2011). According to Al Hanafi et al. (2019), the combination of *Opuntia* and *Atriplex* improves both fiber and protein digestibility. These findings align with our results, where the digestibility of crude fiber and protein in diet D4 increased by 11.9and 8.5 percentage units, respectively, compared to diet D1.In contrast, diet D9, composed exclusively of *Atriplex*, exhibited a marked reduction in both parameters. The reduced crude fiber (CF) digestibility observed in diet 2 may be explained by the higher inclusion level of *Opuntia* in the ration, which is known to exert a suppressive effect on ruminal cellulolytic bacteria due to its high concentration of soluble carbohydrates (Abidi et al., 2009).The D8 (*Opuntia alone*) resulted in body weight loss, accelerated intestinal transit, and a laxative effect, particularly when *Opuntia* exceeded 60% of dietary dry matter. Degu and Solomon

(2009) reported a weight gain of 20 g when using a diet based on Eragrostis straw and 172 g of Opuntia dry matter (DM), whereas Tegegne et al. (2005) observed a weight loss of 27 g with a diet composed of wheat straw and Opuntia, with each animal exhibiting its own individual average daily gain This response likely reflects an imbalance between fermentable energy and nitrogen availability. Diets D1, D3, D4, and D5 promoted enhanced protein digestibility, attributed to the energy provided by barley grain (D1), soluble carbohydrates from *Opuntia*, and the synergistic effect of the *Opuntia–Atriplex* combination. Specifically, protein digestibility in D4 increased by 44, 20, and 38 percentage units compared to D7, D8, respectively. Diets D6 to D8 remained deficient in fermentable nitrogen. The low protein digestibility observed is likely due to high levels of neutral detergent fiber (NDF, 49.9%) and acid detergent fiber (ADF, 33.8%) (Table 1), which limit microbial enzymatic access by encapsulating proteins within the plant cell wall matrix. Furthermore, *Atriplex halimus* contains a high proportion (40–45%) of insoluble proteins that are poorly utilized for microbial protein synthesis due to insufficient fermentable energy (Salem et al., 2012).

Table 1
Chemical composition of feed in % DM and nutritional value in kg DM

	Grain barley	***Opuntia ficus indica***	***Atriplex halimus***	**Barley straw**
DM	92.28± -27	14.63± -5	42.43± -51	9–24 ± 0.41
OM	96.5 ± 0.15	75.31±-1	80.74 ± -3	94.6 ± 0.7
CF	6.83± -02	13.37± -35	27.21± -08	48.07± -75
CP	9.8 ± 0.7	4.91 ± 1–4	12.87± -2	3.2 ± 0.81
MM	3.5 ± 0.4	24.69 ± 0.9	19.26 ± -17	5.4 ± 0.23
Fat	1.82 ± 0.2	1.7 ± 0.45	2.4 ± 0.24	-
NDF	25.9 ± 0.8	30.33 ± 2 .9	49.9 ± 0 .85	67.8 ± 2.6
ADF	6.8 ± 0.57	15.2±-9	33.8 ±-34	45.4 ± 3.59
FUL	1. 08 ± 0.09	0.63 ± 0.05	0.83 ± 0.03	0.45 ± 0.04
PDIN	64 ± 8	38 ± 10.8	120 ± 17	27 ± 8
PDIE	96 ± 2.5%	64 ± 2	98 ± 9	49 ± 6
Holdin	64 ± 8	38 ± 10.8	98 ± 9	27 ± 8

Each value is the average of four observations. ±: Standard deviation. DM: dry matter, OM: organic matter, CF: crude fibre. CP: Crude Protein, MM: total mineral matter, Fat: fat content. NDF: Neutral detergent fibre. ADF: acid detergent fibre. FUL: forage unit for lactation. PDIN: proteins digestible in the intestine. PDIE: protein digestible in the intestine through energy.

Regarding growth performance and energy balance, Diet D1 achieved the best results. However, the inclusion of barley makes this diet unsustainable under arid conditions. Diet D2 recorded a DOMI/$BW^{0.75}$ of 24.86 and an energy balance (FUL) of 1.12, ± 0.28 which is sufficient only for maintenance and is associated with a high risk of pregnancy toxemia. Weight losses have also been reported in other studies using 100% Opuntia-based diets.. Generally speaking, all diets have an acceptable energy level (Table 4). Diet D6 exhibited an FL (energy) of 1.3 ± 0.05, while the FL nitrogen) was 0.74 ± 0.04. Diets D7 to D9 were the most unbalanced in terms of both energy and nitrogen balances. Their respective FL energy values were: 1.24 ± 0.04, 2.1 ± 0.08, and 1.21 ± 0.05. The corresponding FL nitrogene values were: 0.24 ± 0.008, 0.28 ± 0.01, and 1.44 ± 0.04, respectively. The increase inFL nitrogene observed in diet D9 is attributed to the higher protein contribution from Atriplex. Weight loss was observed in ewes fed these diets: -200.96 ± 12.90 g, -217.17 ± 37.35 g, and − 180.26 ± 39 g, respectively. The measured ADG for the diets D3. D4, and D5 was approximately 81, 104, and 89 g, respectively. Diet 4 provided the most balanced nutritional profile that better met the demands of late gestation. The straw–Opuntia–Atriplex combination at a 50–50% ratio proved to be only slightly less effective than the straw–barley association in covering the energy needs of pregnant ewes. However, this combination was superior to the conventional diet in terms of nitrogen balance, with a ration cost of 20.04 DZD compared to 25.4 DZD for the conventional ration.

Prior to the implementation of the dietary treatments, glucose levels were within the normal ovine range (0.4–0.7 g/L), as reported by Haddad (1981). A significant reduction in blood glucose concentration was observed in group D9, likely due to stress associated with dietary transition and the physiological condition of the animals, particularly the final third of gestation. In contrast, group D8 maintained stable glycemic levels, which could be explained by the therapeutic properties of Opuntia in inhibiting hepatic glucose production, as reported by (Andrade-Cetto A) and (Wiedenfeld H. (2011) and Jakobek (2015). These findings are consistent with those of Louacini et al. (2015), Abbeddou et al. (2011), who reported that feeding non-pregnant ewes with 100% Opuntia did not alter blood glucose concentrations. Similar results have been reported by a growing body of research on incorporating different levels of cactus into goat diets, Gu.C.et al (2020. However, our results differ from those of (Cardoso et al., 2019) ,who reported increased blood glucose levels in male Ines lambs fed varying

levels of thornless cactus (*Nopallea cochenillifera*). Similarly, (El Gindy et al. 2021) found that glucose concentrations significantly increased in lactating Barki ewes with higher inclusion of prickly pear bark in the diet.Regarding renal function markers, no significant differences in urea and creatinine concentrations were observed in groups D3 to D7 (urea) and D2 (creatinine) when compared to the control group (D1). These values remained within normal ranges, indicating preserved renal function in animals fed a mixture of *Atriplex* and *Opuntia*, in agreement with the findings of (Alhanafi et al. 2019). Liver enzyme levels (AST and ALT) were also unaffected in the treatment groups D2 through D5, and in D6 for ALT, when compared to the control group (D1) (Table 5). These results corroborate earlier studies incorporating cacti into the diets of lambs and lactating ewes (Cardoso et al. 2019) and (Dey et al. 2015) and support the findings of (Alhanafi et al.2019), who reported that a diet combining *Atriplex* and *Opuntia* did not alter AST or ALT levels

Table 5
Biochemical parameters before and after incorporation of the Opuntia - Atriplex combination per diet and per batch n = 8.

	D1	D2	D3	D4	D5	D6	D7	D8	D9
Glucose before	0.51 ± 0.01^{a}	0.54 ± 0.03^{a}	0.54 ± 0.04^{a}	052 ± 0.03^{a}	0.53 ± 0.03^{a}	0.55 ± 0.03^{a}	0.55 ± 0.03^{a}	0.55 ± 0.05^{a}	0.53 ± 0.03^{a}
Glucose after	0.42 ± 0.02^{b}	0.45 ± 0.04^{b}	0.42 ± 0.05^{b}	0.44 ± 0.0^{5}b	0.43 ± 0.06^{b}	0.44 ± 0.04^{b}	0.44 ± 0.05^{b}	0.53 ± 0.05^{a}	0.37 ± 0.03^{c}
Urea before	0.35 ± 0.06^{a}	0.35 ± 0.06^{a}	0.35 ± 0.06^{a}	0.35 ± 0.05^{a}	0.28 ± 0.08^{b}	0.35 ± 0.05^{a}	0.37 ± 0.06^{a}	0.37 ± 0.05^{a}	0.35 ± .07^{a}
Urea after	0.34 ± 0.07^{a}	0.17 ± 0.03^{b}	0.27 ± 0.01^{c}	0.30 ± 0.06^{a}	0.28 ± 0.08^{c}	0.26 ± 0.09^{c}	0.28 ± 0.08^{c}	0. 04 ± 0.03^{d}	0.15 ± 0.02^{e}
Creatinine before	1–97±-13^{a}	1–45 ± 2.25^{a}	10.30 ± 2.02^{a}	10.09 ± 2.44^{a}	10.31 ± 2.44^{a}	9.65±-72^{a}	12.42 ± 2.41^{a}	10.65 ± 2.49^{a}	1–08 ±-48^{a}
Creatinine after	11.15±-83^{a}	13.10 ± 2.56^{a}	11.33±-86^{a}	11.83 ± 2.31^{a}	11.48±-94^{a}	11.02 ± 2.40^{a}	6.22 ± 0.79^{b}	5.09 ± -42^{b}	5.20 ± 0.86^{b}
AST before	88.25 ± 1-04^{a}	101 ± 12.36^{a}	71.2 ± 18.37^{a}	79.39 ± 17.98^{a}	74 ± 17.09^{a}	85.37 ± 17.47^{a}	74.5 ± 10.40^{a}	78 ± 13.68^{a}	77 ± 1-16a
AST after	78.62 ± 7.28^{bc}	70.5 ± 7.46^{bc}	75 ± 15.74^{bc}	77.62 ± 2.32^{bc}	102.37 ± 8.8^{b}	134.5 ± 30.31^{ab}	53.5 ± 5.32^{c}	42.75 ± 6.02^{c}	172 ± 14^{a}
ALT before	10.62 ± 3.24^{a}	11.37 ± 3.7^{a}	8.75 ± 2.12^{a}	12.62 ± 7.2^{a}	9.62 ± 2.66^{a}	9.12 ± 2.85^{a}	9.5 ± 2.16^{a}	10.5±-29^{a}	11 ± 2.16^{a}
ALT after	10.37 ± 2.72^{b}	7.62 ± 2.82^{b}	9.62 ± 3.24^{b}	12.37 ± 6.13^{b}	13.75 ± 4.83^{ab}	13.87 ± 4.29^{ab}	5.5±-29^{b}	4 ± 0.81^{b}	23.25 ± 3.3^{a}

a, b, c: means with different letters in the same raw are significantly different (p < 0.05). glucose, urea, creatinine, AST: aspartate aminotransferase, ALT:alanine aminotransferase.

Conclusion

This study showed that the combination of *Opuntia* cladode and Atriplex twig improved the digestibility of the constituents studied. D4 covers the energy and nitrogen requirements of gestation with a low died cost compared with the cost a conventional sheep died. The combination studied can replace the conventional ration. With an increasing rate of incorporation of Atriplex halimus, the metabolism of pregnant ewes is not compromised. The Opuntia *ficus indica* - Atriplex halimus combination is recommended for feeding sheep In conclusion, the sheep species is condemned to its food restructuring and to the search for new modes of production or to its decline flocks in arid and semi-arid zones.

Declarations

Conflicts of interest:

The authors declare no conflicts of interest concerning this research. Ethical approval No. 21/9/2021

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Data Availability Statement

The datasets used and/or analyzed during the current study are publicly available in previously published articles. Data on maintenance-fed ewes are available in Archivos de Zootecnia, Vol. 64 (248): 441–447, 2015. Data on pregnant ewes fed with Cactus–Atriplex-based diets are available in the Egyptian Journal of Veterinary Sciences, pages 1–11. Full texts are accessible online through the respective journal websites.DOI : 10.21608/ejvs.2024.310945.2306

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