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Nutritional improvement of cactus fruit scraps with addition of alfalfa or *Atriplex halimus*, and comparison of two animal feed preservation methods (silage and solar drying)

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This work aimed to study the effect of adding alfalfa and *Atriplex halimus* L. on biochemical properties, microbial flora, ferment silage and solar-dried cactus fruit scraps. Alfalfa and *Atriplex* were added to cactus silage to improve nutrient quality. Three mixtures were prepared: M1 based on cactus, M2 based on cactus and alfalfa, and M3 based on cactus and *Atriplex*. Bran and wheat straw were added to the mixtures to improve the moisture content. After adding alfalfa and *Atriplex*, the protein content of the pre-ensiling material increased ($p < 0.05$), reaching 10.63% DM for M1, 16.35% DM for M2, and 17.22% DM for M3. During ensilage, a significant amount of sugar and protein was degraded. All silage treatments achieved stable pH values (M1: 4.35, M2: 4.55, and M3: 4.54). The M2 and M3 treatments had the highest amount of protein. After drying, the protein content of the dried treatments was higher than that of the ensiled treatments (8.05% DM for M1, 14.96% DM for M2, and 15.36% DM for M3). In both storage methods, the microbial population declined. However, silage reduces coliforms, yeasts and moulds more efficiently than solar drying. The drying operation preserves remarkedly the nutritional quality of the mixtures while ensiling reduces the number of undesirable microorganisms.

Keywords: <Please provide up to five keywords or phrases that are not already in the title>

Introduction

Ruminant farming is an important segment of the Moroccan economy since it is a significant source of income. However, due to supply limits caused by nutritional imbalances in feed diets, high expenses and the scarcity of traditional protein sources (Purser 1981; Nardone et al. 2004), herds in arid and semi-arid regions, as well as expansive livestock farms, often face prolonged periods of feed scarcity, leading to severe shortages. Hence, substantial and costly measures are required to ensure the security of the industry.

Consequently, it is critical to look for innovative and readily available foods with little market value. Morocco offers a diverse spectrum of agricultural byproducts that are either completely or partially underutilised. Cactus is one of these non-traditional food sources that may be used for animal feed in dry areas.

In Morocco, the cactus plantation has tripled from approximately 45 000 ha at the beginning of 1990 to around 150 000 ha in 2016 (Mabrouk et al. 2016). Cactus is a seasonal commodity known for yielding significant fruit quantities within a short time. The fruit maturity period is relatively brief, especially when the summer season is characterised by high temperatures. As a result, a significant portion of cactus fruits, ranging from 30 to 50%, ripens rapidly and become unsuitable for human consumption (Bendaou 2013, Ait-Oubahou and Bartali 2015). The cactus fruit is rich in nutrients such as sugars, minerals and fibres but it is low in proteins (El Hajji and Salmaoui 2020). Therefore it is essential to use these fruits in animal feed to ensure a balanced ration for the animals.

Forage plants such as alfalfa and *Atriplex* are good sources of nitrogen. The mixture of cactus and high nitrogen-rich forage plants can improve the nutritional value and provide a good-quality feed that can be available in the dry season (Nefzaoui et al. 1996; Salem et al. 2005).

This work aims to valorise the cactus fruit leftovers that are commonly wasted at the end of the season by investigating the possibilities of protein enrichment of these residues with two nitrogen sources (alfalfa and *Atriplex*) and comparing two methods of feed conservation: solar drying and silage.

Materials and methods

Sample collection

Samples of cactus fruit scraps were collected at the end of the season in the Beni Mellal region (centre of Morocco) in October 2021, when the fruits were left in the fields after harvest. Samples were immediately stored at −4 °C after collection. Alfalfa was collected during its full flowering

stage, while the *Atriplex* was collected before the flowering stage; the specimens harvested were between two and three years old. The samples of alfalfa and *Atriplex* were harvested from Beni Mellal region and used in a fresh state.

Preparation of mixtures

The mixtures were prepared by grinding cactus fruit scraps, alfalfa and *Atriplex* separately. The cactus fruits were ground whole in a stainless-steel grinder to achieve a very homogeneous paste. Bran and wheat straw were ground in the same mill. The purpose of using these two components in the experiments was to adjust the moisture content of the mixtures.

Three mixtures were prepared separately. The first mixture (M1) was made from cactus, bran and wheat straw, the second (M2) contained cactus, bran, straw and alfalfa, and the third (M3) included cactus, bran, wheat straw and *Atriplex*. The percentages of each component in every mixture are presented in Table 1.

The three types of mixtures underwent two preservation methods: ensiling and solar drying.

Silage

The three mixtures (M1, M2 and M3) were placed in plastic bags (1 kg/bag) (270 x 390 mm). Six bags per treatment were prepared, with three bags for analysis before ensiling and three bags for analysis at the end of ensiling. The bags were sealed, lined and stored for 30 days at room temperature (25 °C).

Fresh (before silage) and silage mixtures had been subjected to analysis of chemical, biochemical and microbial properties.

Solar drying

The three mixtures (M1, M2 and M3) were laid out on plastic sheets to dry under sunlight at an average temperature of 33 °C. Periodic stirring (every hour) was done to facilitate and hasten the drying process, preventing the fermentation of sugars present in the cactus. The total drying process of the three mixtures took three days.

Chemical analyses

The dry weight was determined by oven drying at 105 °C to constant weight, and ash was measured by incineration at 550 °C. Crude protein was assessed by the Kjeldahl method described by APHA (1989), fibre was determined by the Van Soest method (Van Soest et al. 1991), reducing sugars by the Bertrand method (Bertrand 1906), and total sugars by the Dubois method (Dubois et al. 1951). The pH was determined using a pH meter after mixing 20 g of the sample in a blender with 50 ml of distilled water until a fluid suspension was obtained (Habibi 2004). Elemental analyses (Ca, Fe, Mg, K, Na and Cu) were performed by atomic absorption spectroscopy. Fermentation losses were evaluated according to the weight loss expressed in percenage. All chemical analyses are presented on a dry matter (DM) basis (except DM and pH).

Microbiological analyses

The microbiological characterisation was carried out by culturing samples in selective media, as described by Leininger (1976). Plate count agar was used to determine total aerobic mesophilic flora (TAMF) after incubating at 30 °C for 72 hours. Samples were incubated with potato extract for five days at 25 °C to measure yeasts and moulds. Lactic acid bacteria were determined after 72 hours at 37 °C using de Man Rogosa and Sharpe agar. Deoxycholate agar was used to determine total and fecal coliforms, incubated for 24 hours at 37 °C and 24 hours at 44 °C, respectively. *Staphylococci* were counted on Baird Parker agar after 48 hours at 37 °C, *Escherichia coli* on MacConkey agar after 24 hours at 37 °C, and *Salmonella* spp. on salmonella-shigella agar after 48 hours at 37 °C.

Table 1: Proportions of components in the mixtures M1, M2 and M3 (%)

%	Cactus	Alfalfa	Atriplex	Wheat bran	Wheat straw
M1	75	0	0	12.5	12.5
M2	40	40	0	10	10
M3	40	0	40	10	10

Statistical analyses

Statistical analyses were performed using SPSS version 20. The effect of treatment was analysed using a unidirectional analysis of variance with treatment as the main effect. When measurements were performed on the same sample at different times, the treatment effect was analysed in a mixed model with treatment, time, and interaction of treatment and time as the main effects. The results are presented for each sample as a mean and standard deviation. For all statistical tests, significance was assigned at $p < 0.05$. All experiments were replicated three times. All microbial data were converted to Log_{10} and presented on a fresh-matter basis.

Results and discussions

Characterisation of the raw materials

The characterisation of the raw materials (Table 2) showed that the cactus fruit scraps had high water content (80.15%) and sugars (32.34% DM), moderate levels of protein (11.98% DM) and ash (6.5% DM), and low dry matter content (19.85%), which is in agreement with the results of Retamal et al. (1987), El Kossori et al. (1998), Méndez et al. (2015) and Pastorelli et al. (2022). In addition, the Ca and K contents (86.45 mg/100 g and 119.31 mg/100 g, respectively) were very high, which is consistent with the findings of Bellumori et al. (2023).

The alfalfa and the *Atriplex* characterisation (Table 2) showed high protein content (20.34% DM for alfalfa and 23.19% DM for *Atriplex*), sodium (8.29 mg/100 g for alfalfa and 19.52 mg/100 g for Atriplex)<Your original figures of "19.52mg/100g for alfalfa and 8.29mg/100g for Atriplex" do not accord with the information given in Table 2: please correct whichever information is wrong>, and low sugar content (4.21% MS for alfalfa and 3.66% DM for *Atriplex*), which is in line with Salem et al. (2002) and Salem et al. (2010).

Characterisation of the initial mixtures

The results of chemical and biochemical analyses of the initial mixtures (Table 3) indicate that M1 had a high content of sugars (19.14% DM for total sugars and 6.33%

Table 2: Biochemical composition of the raw materials (n = 3)

Parameters	Cactus fruits	Alfalfa	Atriplex	p-value
pH	6.65^{a} ± 0.1	6.3^{b} ± 0.05	6.33^{b} ± 0.09	0.003
DM %	19.85^{a} ± 0.86	19.83^{a} ± 1.25	21.5^{a} ± 0.67	0.177
Ashes % DM	6.5^{b} ± 0.45	6.95^{b} ± 0.63	12.97^{a} ± 1.49	0.000
Proteins % DM	11.98^{c} ± 0.11	20.34^{b} ± 0.89	23.19^{a} ± 0.74	0.000
Total sugars % DM	32.34^{a} ± 0.86	4.21^{b} ± 0.33	3.66^{b} ± 0.24	0.000
Reducing sugars % DM	22.03^{a} ± 0.42	1.91^{b} ± 0.39	1.47^{b} ± 0.16	0.000
NDF % DM	27.23^{b} ± 2.30	39.44^{a} ± 1.36	38.73^{a} ± 2.26	0.000
ADF % DM	15.67^{c} ± 1.54	23.75^{b} ± 1.7	23.80^{a} ± 1.11	0.000
ADL % DM	7.11^{b} ± 1.61	14.87^{a} ± 2.37	10.35^{b} ± 2.06	0.010
Hemicellulose % DM	11.56^{a} ± 3.84	15.69^{a} ± 0.68	14.92^{a} ± 2.43	0.135
Cellulose % DM	8.55^{b} ± 2.77	8.88^{b} ± 3.52	13.45^{a} ± 1.61	0.000
Ca (mg/100 g DM)	86.45^{a} ± 3.74	18.34^{b} ± 1.99	13.67^{b} ± 0.88	0.000
Fe (mg/100 g DM)	0.23^{b} ± 0.025	0.16^{b} ± 0.01	0.45^{a} ± 0.10	0.002
Mg (mg/100 g DM)	11.75^{a} ± 0.39	12.95^{a} ± 0.99	6.85^{b} ± 1.46	0.000
K (mg/100 g DM)	119.31^{a} ± 0.80	120.40^{a} ± 1.53	24.83^{b} ± 1.06	0.000
Na (mg/100 g DM)	6.378^{b} ± 1.02	8.29^{b} ± 1.40	19.52^{a} ± 1.72	0.000
Cu (mg/100 g DM)	0.23^{a} ± 0.03	0.25^{a} ± 0.02	0.29^{a} ± 0.04	0.176

Values for the same variable with different letters are significantly different at p = 0.05 <Please confirm that this note is correct or correct it accordingly>
DM: dry matter, NDF: neutral detergent fibre, ADF: acid detergent fibre, ADL: acid detergent lignin

Table 3: Characteristics of initial mixtures (n = 3)

Parameters	M1	M2	M3	p-value
pH	6.28^{a} ± 0.03	6.20^{a} ± 0.04	6.25^{a} ± 0.08	0.610
DM %	34.18^{a} ± 1.31	33.54^{a} ± 1.07	32.58^{a} ± 1.43	0.150
Ashes % DM	5.49^{b} ± 0.19	6.65b ± 0.61	9.18^{a} ± 0.58	0.029
Proteins % DM	10.63^{b} ± 0.22	16.35^{a} ± 0.13	17.22^{a} ± 0.39	0.000
Total sugars % DM	19.14^{a} ± 0.11	12.09^{b} ± 0.51	11.58^{c} ± 0.11	0.027
Reducing sugars % DM	6.33^{a} ± 0.79	4.67^{b} ± 1.53	4.22^{b} ± 0.00	0.001
NDF % DM	45.48^{a} ± 1.99	42.17^{ab} ± 0.47	38.59^{b} ± 0.19	0.059
ADF % DM	30.88^{a} ± 1.64	21.89^{b} ± 0.37	20.44^{b} ± 0.54	0.010
ADL % DM	5.37^{a} ± 0.77	6.91^{a} ± 0.57	6.55^{a} ± 0.25	0.281
Hemicellulose % DM	14.6^{a} ± 3.63	20.28^{a} ± 0.84	18.15^{a} ± 0.35	0.311
Cellulose % DM	25.51^{a} ± 0.87	14.98^{b} ± 0.2	13.88^{b} ± 0.78	0.002
Ca (mg/100 g DM)	140.19^{a} ± 1.87	81.07^{b} ± 4.91	42.52^{c} ± 3.74	0.001
Fe (mg/100 g DM)	0.45^{a} ± 0.02	0.20^{b} ± 0.01	0.40^{a} ± 0.02	0.002
Mg (mg/100 g DM)	54.27a ± 1.04	35.25b ± 2.58	22.98c ± 0.50	0.002
K (mg/100 g DM)	159.91a ± 7.31	136.14b ± 0.88	61.20c ± 0.24	0.001
Na (mg/100 g DM)	3.57b ± 0.51	6.38b ± 0.77	10.20a ± 1.02	0.022
Cu (mg/100 g DM)	0.37a ± 0.07	0.16a ± 0.02	0.26a ± 0.04	0.116

Values for the same variable with different letters are significantly different at p = 0.05 <Please confirm that this note is correct as edited or correct it accordingly>
DM: dry matter, NDF: neutral detergent fibre, ADF: acid detergent fibre, ADL: acid detergent lignin

DM for reducing sugars), neutral detergent fibre (NDF) (45.48% DM), calcium (140.19 mg/100 g DM) and potassium (159.91 mg/100 g DM). The protein content was lower for M1 (10.63% DM) than for M2 (16.35% DM) and M3 (17.22% DM), and these results were similar to our previous findings (El Hajji et al. 2022). M2 had a high protein content (16.35% DM) that was higher than the 14.60% DM reported by Ravari et al. (2022), a medium content of sugars (12.09% DM for total sugars and 4.67% DM for reducing sugars), calcium (81.07 mg/100 g DM) and potassium (136.14 mg/100 g DM). Furthermore, M3 recorded a high ash content (9.18% DM), protein (17.22% DM) and sodium (10.20 mg/100 g DM), but it had a low content of sugars (11.58% DM for total sugars and 4.22% DM for reducing sugars), calcium (42.52 mg/100 g DM) and potassium (61.20 mg/100 g DM).

For all three mixtures, the pH and the dry matter measurements showed that they were statistically identical (p > 0.05). M1 had the highest NDF, acid detergent fibre (ADF) and cellulose content. The acid detergent lignin (ADL) and hemicellulose levels were statistically equivalent in all three combinations (p > 0.05).

According to our results (Table 2), alfalfa and *Atriplex* improved the protein content, and the cactus improved the sugars in M2 and M3 (all statistically significant at p <0.05).

Comparing the mineral content of the mixtures, M1 had the highest levels of calcium, potassium and magnesium, while M3 had the highest level of sodium. The three mixtures recorded similar copper content.

Characterisation of the mixtures after silage

Table 4 shows the results of chemical and biochemical analyses of the ensiled mixtures. The DM content increased ($p > 0.05$) after silage, which is most likely due to the loss of water in the form of silage effluent (Khorvash et al. 2006; Rook and Hatfield 2003). The pH of all silage treatments ranged from 4.35 to 4.55, indicating that all treatments produced silage of high quality. According to Pahlow et al. (2003), silages with a dry matter content ranging from 30% to 50% may exhibit pH levels between 4.35 and 5, remaining stable after fermentation. As stated by McDonald et al. (2002) and Li et al. (2016), alfalfa is difficult to ensile successfully because of its high buffer capacity and low water soluble carbohydrate content. This was not the case in this study, which could be related to the high concentration of fermentable cactus sugars. Our findings are consistent with those of Cürek and Özen (2004), who reported values in the range of 3.54 to 4.50 while studying the fermentation parameters of cactus and legume silage. In all three treatments, a substantial amount of ash was also lost during silage production with reductions from 5.49% DM to 3.27% DM for M1, 6.65% DM to 4.88% DM for M2, and from 9.18% DM to 5.83% DM for M3, which can be attributed to water solubility and loss as effluent.

Mineral elements were largely lost in all three treatments. The sodium levels of alfalfa and *Atriplex* were higher than those of the cactus, which was reflected in the mineral value of the silages. NDF content decreased after ensiling for the three silages (from 45.48 to 43.31% DM for M1, from 42.17 to 40.92% DM for M2, and from 38.59 to 35.63% DM for M3), which is consistent with the findings of Minson (1990) and Hristov et al. (2020).

The sugar level is an important parameter in animal diets, as it is a source of energy and boosts palatability (Baumont 1996 and Mordenti et al. 2021). Although almost 50% of the sugar content was degraded in all three treatments. The sugar level was higher in silages having higher initial content, and vice-versa. Lactic acid bacteria caused this destruction by the fermentation during the silage process (Jaurena and Pichard 2001; Pahlow et al. 2003).

Protein is necessary for the diet because it provides amino acids and nitrogen for the production of non-essential amino acids and other nitrogenous substances (Snow and Ghaly 2007). Protein is the most vital and most expensive component of an animal's diet. The protein content decreased for all treatments after ensiling (e.g. the protein content decreased from 10.63 to 4.54% DM for M1, 16.35 to 12.66% DM for M2, and 17.22 to 12.96% DM for M3), which can be explained by proteolysis during fermentation. Our findings are consistent with prior research by Moore and Kennedy (1994), Bilal (2009) and Ni et al. (2017). The protein content of the silage mixes increased by the addition of *Atriplex* and alfalfa. The protein content of the M2 (12.66% DM) and M3 (12.96% DM) combination is comparable to the amount found in corn silage by McDonald et al. (2002) (110 g/kg DM).

According to the analytical data, the M2 and M3 silages appear to be of greater quality than the M1. This addition has boosted the nutritional content of the M2 and M3 combinations, particularly in terms of protein and sodium levels.

Characterisation of mixtures after solar drying

The biochemical characteristics of the mixtures after drying are presented in Table 5.

The drying process increased the amount of dry matter in the three mixtures (from 34.18% to 81.86% for M1, 33.54% to 80.26% for M2, and 32.58% to 78.13% for M3). The sun's action evaporated a considerable percentage of water, reduced water activity and enhanced the preservation of the mixtures. The pH of the three mixtures was statistically similar ($p > 0.05$).

The protein content was 8.05% DM for M1, 14.96% DM for M2, and 15.36% DM for M3. Because of the high protein content of alfalfa and *Atriplex*, M2 (14.96% DM) and M3 (15.36% DM) recorded higher protein content than M1 (8.05% DM). Protein levels in all three combinations were reduced after drying. Demarquilly et al. (1998) and Baumont et al. (2009) observed similar results after drying legumes, which can be explained by the activity of plant proteases. Drying preserved the quantity of protein more effectively than the ensiling process, which is consistent with the findings of Baumont (1996). However, according to Demarquilly et al. (1998), in the presence of rain, protein loss becomes more noticeable.

During the drying process, a part of the sugar content was degraded in the three mixtures (it decreased from 19.14 to 16.37% DM for M1, 12.09 to 10.56% DM for M2, and 11.58 to 9.16% DM for M3). This decrease can be ascribed to the Maillard reaction, which involves interaction between carbonyl groups of sugars and amine groups of amino acids, as well as the caramelisation reaction, where sugars react with water (Labuza 1975). Additionally, plant respiration, which converts carbohydrates into CO_2 and H_2O (Demarquilly et al. 1998), also contributed to this reduction.

The NDF, ADF, ADL, hemicellulose and cellulose values of the dried mixes are comparable to the initial mixture values, showing that the fibres did not change after drying. For instance, NDF was 45.48% for M1, 42.17% for M2 and 38.59% for M3 for the initial mix, and 42.75% for M1, 42.66% for M2 and 38.74% for M3 after drying.

The dried mixtures were rich in mineral elements, albeit the levels were lower than those found in fresh combinations. In this context, Meschy et al. (2005) noted that drying reduces the mineral content of fodder by an average of 15–20%.

The ash content of M3 was greater than that of M1 and M2, because of the high ash content of the *Atriplex*. M1 had the highest calcium (128.27 mg/100 g DM), potassium (137.85 mg/100 g DM) and magnesium (46.75 mg/100 g DM) content, whereas M3 had the highest sodium content (8.16 mg/100 g DM). Iron and copper were present in trace amounts in all mixtures.

These dried mixtures could offer essential potassium, magnesium and calcium resources for animals.

Drying had an impact on the chemical and biochemical composition of the three mixtures. Indeed, the contents of all the components decreased, but this phenomenon was less accentuated in comparison with the silage process.

Table 4: Characteristics of mixtures after ensiling (n = 3)

Parameters	M1	M2	M3	p-value
pH	4.35^{b} ± 0.02	4.55^{a} ± 0.03	4.54^{a} ± 0.02	0.008
DM %	36.21^{a} ± 1.92	35.43^{a} ± 0.44	35.20^{a} ± 1.13	0.108
Ashes % DM	3.27^{a} ± 0.62	4.88^{a} ± 0.31	5.83^{a} ± 1.03	0.175
Proteins % DM	4.54^{b} ± 0.04	12.66^{a} ± 0.17	12.96^{a} ± 0.21	0.000
Total sugars % DM	7.06^{a} ± 0.24	4.63^{b} ± 0.03	4.27^{b} ± 0.01	0.001
Reducing sugars % DM	3.83^{a} ± 0.77	1.92^{b} ± 0.38	1.53^{b} ± 0.00	0.007
NDF % DM	43.31^{a} ± 0.63	40.92^{b} ± 0.58	35.63^{c} ± 0.57	0.003
ADF % DM	27.24^{a} ± 0.79	21.29^{a} ± 0.25	16.12^{b} ± 0.49	0.019
ADL % DM	4.91^{a} ± 0.33	9.73^{a} ± 0.08	6.94^{a} ± 1.04	0.068
Hemicellulose % DM	18.07^{a} ± 1.43	19.63^{a} ± 0.33	19.52^{a} ± 0.08	0.691
Cellulose % DM	22.33^{a} ± 1.12	11.56^{b} ± 0.17	9.118^{b} ± 0.55	0.048
Ca (mg/100 g DM)	122.20^{a} ± 2.10	52.34^{b} ± 1.87	23.83^{c} ± 1.87	0.000
Fe (mg/100 g DM)	0.27^{a} ± 0.02	0.14^{b} ± 0.00	0.27^{a} ± 0.04	0.007
Mg (mg/100 g DM)	39.24^{a} ± 1.09	27.02^{b} ± 0.29	16.44^{c} ± 0.13	0.000
K (mg/100 g DM)	123.00^{a} ± 4.01	111.85^{a} ± 1.83	40.92^{b} ± 0.47	0.000
Na (mg/100 g DM)	2.04^{c} ± 0.51	3.83^{b} ± 0.26	6.38^{a} ± 0.26	0.008
Cu (mg/100 g DM)	0.23^{a} ± 0.05	0.07^{ab} ± 0.03	0.13^{b} ± 0.01	0.097

Values for the same variable with different letters are significantly different at p = 0.05<Please confirm that this note is correct as edited or correct it accordingly>
DM: dry matter, NDF: neutral detergent fibre, ADF: acid detergent fibre, ADL: acid detergent lignin

Table 5: Characteristion of mixtures after drying (n = 3)

Parameters	M1	M2	M3	p-value
pH	6.05^{a} ± 0.09	5.91^{a} ± 0.03	6.12^{a} ± 0.01	0.152
DM %	81.86^{a} ± 0.91	80.26^{ab} ± 2.64	78.13^{b} ± 2.99	0.062
Ashes % DM	4.58^{b} ± 0.50	5.92^{b} ± 0.05	8.17^{a} ± 0.14	0.008
Proteins % DM	8.05^{b} ± 0.25	14.96^{a} ± 0.24	15.36^{a} ± 0.43	0.000
Total sugars % DM	16.37^{a} ± 1.86	10.56^{b} ± 0.65	9.16^{b} ± 0.20	0.016
Reducing sugars % DM	5.37^{a} ± 0.44	3.00^{b} ± 0.23	2.84^{b} ± 0.45	0.012
NDF % DM	42.75^{a} ± 3.09	42.66^{a} ± 1.47	38.74^{a} ± 2.17	0.291
ADF % DM	30.40^{a} ± 0.89	22.19^{b} ± 2.84	19.59^{b} ± 0.69	0.018
ADL % DM	5.77^{a} ± 0.79	7.29^{a} ± 0.69	6.83^{a} ± 2.63	0.674
Hemicellulose % DM	12.35^{a} ± 3.98	20.47^{a} ± 1.37	19.15^{a} ± 1.48	0.095
Cellulose % DM	24.62^{a} ± 0.09	14.9^{b} ± 3.53	12.76^{b} ± 1.93	0.028
Ca (mg/100 g DM)	128.27^{a} ± 1.64	69.86^{b} ± 1.64	31.31^{c} ± 2.80	0.000
Fe (mg/100 g DM)	0.36^{a} ± 0.01	0.15^{b} ± 0.01	0.33^{a} ± 0.02	0.003
Mg (mg/100 g DM)	46.75^{a} ± 0.32	31.59^{b} ± 0.88	19.90^{c} ± 0.50	0.000
K (mg/100 g DM)	137.85^{a} ± 6.6	118.99^{b} ± 1.53	50.83^{c} ± 1.53	0.001
Na (mg/100 g DM)	2.30^{c} ± 0.26	4.59^{b} ± 0.51	8.16^{a} ± 0.51	0.006
Cu (mg/100 g DM)	0.30^{a} ± 0.06	0.11^{a} ± 0.01	0.19^{a} ± 0.01	0.072

Values for the same variable with different letters are significantly different at p = 0.05<Please confirm that this note is correct as edited or correct it accordingly>
DM: dry matter, NDF: neutral detergent fibre, ADF: acid detergent fibre, ADL: acid detergent lignin

Table 6 shows the statistic mixed ANOVA analysis of biochemical values, considering the storage mode (silage or drying), mixture type (M1, M2 and M3), and their interaction.

The interaction between the storage method and mixture type did not affect pH, dry matter, ash, total and reducing sugars, ADF, ADL, cellulose, Ca, Fe, Mg, Na and Cu contents.

Microbial characterisation

Table 7 shows the microbial characterisation of the initial mixtures after ensiling and drying.

The assessment of endogenous microflora of the initial mixtures reveals their high charge of microorganisms. The total aerobic mesophilic flora was 7.97 log CFU/g FM for M1, 7.12 log CFU/g FM for M2, and 7.26 log CFU/g FM for M3. Yeasts were present at 10.74 log CFU/g FM for M1, 9.50 log CFU/g FM for M2, and 9.76 log CFU/g FM for M3. Lactic acid bacteria were at 3.65 log CFU/g FM for M1, 3.45 log CFU/g FM for M2, and 3.08 log CFU/g FM for M3. Moulds were detected at 0.74 log CFU/g FM for M1, 0.54 log CFU/g FM for M2, and 0.48 log CFU/g FM for M3. Additionally, total coliforms were present at 3.35 log CFU/g FM for M1, 3.02 log CFU/g FM for M2, and 3.29 log CFU/g FM for M3. Due to their pH being close to neutral, their high moisture and sugar content, and the high population of microorganisms naturally present, these mixtures provide an excellent substrate for microbial development.

Table 6: Statistical significance of the mean effects

Parameters	Storage mode (S)	Type of mixture (T)	Interaction S × T
pH	**	NS	NS
DM	**	*	NS
Ashes	*	**	NS
Proteins	**	**	*
Total sugars	**	**	NS
Reducing sugars	**	**	NS
NDF	**	NS	*
ADF	*	**	NS
ADL	**	NS	NS
Cellulose	*	**	NS
Hemicellulose	NS	*	*
Ca	**	**	NS
Fe	**	**	NS
Mg	**	**	NS
Na	*	**	NS
K	**	**	*
Cu	**	NS	NS

* = significantly different at $p < 0.05$
**= significantly different at $p < 0.01$, NS: not significant

The number of microorganisms decreased after ensiling, yeast (from 10.74 to 6.59 for M1, 9.50 to 6.02 for M2, and 9.76 to 6.24 for M3), total coliforms (from 3.35 to 0 in M1, 3.02 to 0 in M2, and 3.29 to 0 in M3) and total aerobic mesophilic flora (from 7.97 to 4.18 in M1, 7.12 to 4.01 in M2, and 7.26 to 3.94 in M3). The disappearance of total coliforms was likewise seen in all mixtures after ensiling. Seale et al. (1986) observed that the disappearance of coliforms in alfalfa silages was related to a rapid drop in pH. Even though the pH was reduced in all mixtures due to the quantity of water-soluble carbohydrates available, the yeast and mould population were still present in all mixtures even after 30 days of ensiling, probably due to their ability to grow at a low pH. According to Muck (2010), yeasts and moulds can grow at pH between 2 and 9. Lactic acid bacteria were well developed, which confirms the presence of a sufficient quantity of sugars in all three mixtures. According to Moon et al. (1981) and Seale et al. (1986), lactic acid bacteria develop rapidly at the start of the ensiling process, but their numbers drop as the process progresses. The decrease in coliforms, TAMF, yeasts and moulds observed in the present research is most probably due to the effects of organic acids (Fehrmann and Müller 1990; Pahlow 1991).

Drying affects the microbiological quality of the mixtures. Indeed, drying limits the quantity of water available for the development of microbes, resulting in their inhibition. Drying reduced the number of lactic acid bacteria, total mesophilic flora, coliforms and yeasts.

Total mesophilic flora reduced by 1.69, 1.14 and 1.11 log units for M1, M2 and M3, respectively, and yeast reduced by 1.38, 0.62 and 1.09 log units for M1, M2 and M3, respectively. Moulds reduced by 0.09 log units for M1 but remained the same for M2 and M3. Moulds can tolerate water activities of about 0.7 (Labuza 1968; Chang et al. 1974). Therefore, the destruction of this flora requires higher temperature scales.

Table 7: Microbial characteristion of initial, silage and drying mixtures ($n = 3$)

Log	Initial mixtures				After silage				After drying			
	M1	M2	M3	*p*	M1	M2	M3	*p*	M1	M2	M3	*p*
LAB	$3.65^{a} \pm 0.1$	$3.45^{a} \pm 0.4$	$3.08^{a} \pm 0.09$	0.361	$5.74^{a} \pm 0.57$	$4.69^{a} \pm 0.06$	$4.43^{a} \pm 0.37$	0.186	$1.78^{a} \pm 0.46$	$1.40^{a} \pm 0.33$	$1.95^{a} \pm 0.13$	0.370
Yeasts	$10.74^{a} \pm 0.41$	$9.50^{a} \pm 0.32$	$9.76^{a} \pm 0.61$	0.277	$6.59^{a} \pm 0.53$	$6.02^{a} \pm 0.19$	$6.24^{a} \pm 0.07$	0.536	$9.36^{a} \pm 0.42$	$8.88^{a} \pm 1.08$	$8.67^{a} \pm 0.29$	0.638
TC	$3.35^{a} \pm 0.55$	$3.02^{a} \pm 0.05$	$3.29^{a} \pm 0.29$	0.800	ABS	ABS	ABS	–	$2.37^{a} \pm 0.36$	$2.54^{a} \pm 0.19$	$2.52^{a} \pm 0.30$	0.829
TAMF	$7.97^{a} \pm 0.08$	$7.12^{b} \pm 0.03$	$7.26^{b} \pm 0.05$	0.003	$4.18^{a} \pm 0.13$	$4.01^{a} \pm 0.03$	$3.94^{a} \pm 0.06$	0.267	$6.28^{a} \pm 0.06$	$5.98^{a} \pm 0.19$	$6.15^{a} \pm 0.24$	0.376
Moulds	0.74 ± 0.04	0.54 ± 0.06	0.48 ± 0.00	0.012	$0.65^{a} \pm 0.05$	$0.60^{a} \pm 0.00$	$0.69^{a} \pm 0.09$	0.612	$0.65^{a} \pm 0.05$	$0.54^{a} \pm 0.06$	$0.48^{a} \pm 0.00$	0.157

Values for the same variable with different letters are significantly different at $p = 0.05$<Please confirm that this note is correct as edited or correct it accordingly>

ABS = absent
LAB = lactic acid bacteria
M1 = Cactus + wheat straw + wheat bran
M2 = cactus + alfalfa + wheat straw + wheat bran
M3 = cactus + Atriplex + wheat straw + wheat bran
TAMF = total aerobic mesophilic flora
TC = total coliforms

The microbial population is declining because of cellular damage at several levels, including the cell wall and DNA (Cutter 2002; Coulibaly et al. 2011). Indeed, drying affects the physical state of the lipid membrane and induces significant conformational changes in proteins, resulting in denaturation and loss of biological function (Strasser et al. 2009; García 2011). The elevation of temperature can also promote chemical reactions leading to the formation of free radicals that damage cell membranes (García 2011). Moreover, this elevation can also disturb the cell's balance by affecting various molecular processes, including replication, transcription and protein synthesis, and can lead to the malfunctioning of certain enzymes (García 2011).

Furthermore, it should be noted that no proliferation of *E. coli*, fecal coliforms, *Staphylococci* and *Salmonella*, was detected throughout the ensiling and drying process.

Conclusion

The addition of alfalfa and *Atriplex* to cactus fruit scraps improved the nutritional status of the silages and dried mixtures.

After ensiling, the addition of alfalfa (M2) and *Atriplex* (M3) led to an increase in the final pH of the silages, compared to the mixture (M1), but all silage treatments reached stable pH values (pH 4.35–4.55). Solar drying resulted in a better preservation of the nutritional quality of M1, M2 and M3 mixtures, including proteins (8.05%; 14.96% and 15.36% DM for M1, M2 and M3, respectively), sugars (16.37, 10.56 and 9.16% DM for M1, M2 and M3, respectively), ash (4.58, 5.92 and 8.17% DM for M1, M2 and M3, respectively) and mineral elements. The microorganism population was reduced in both preservation methods (solar drying and ensiling). However, the silage method was better for minimising the number of yeasts, moulds and coliforms. Drying maintains the nutritional characteristics of the mixtures. However, the problem with this method is the contamination by insects, dust and deterioration due to rain during drying.

Supplementing animal feed with *Atriplex* in place of expensive materials such as concentrated feed such as alfalfa offers an interesting alternative. This strategy has the potential to r feeding costs compared to daily alfalfa supplementation. Therefore, choosing *Atriplex* could be a more advantageous option for boosting the income of local farmers, especially during periods of drought when cost-effective solutions become crucial.

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