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RESEARCH ARTICLE

Potential of *Opuntia Ficus-Indica* Cladodes In M'sila (North ALGERIA) as feed for ruminants: chemical composition and *in vitro* assessment

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ABSTRACT
The main objective of the present study was to investigate a strategy to bioconverte spineless cactus *Opuntia Ficus-Indica* (*O. ficus indica*) Cladodes, *Medicago sativa* L. (*M. sativa*) and barley straw (*H. vulgare*) based on their chemical composition, *in vitro* digestibility and fermentation parameters. The CP ranged from 51.41 to 156.09 g/kg DM, which was especially high within *M. sativa* and low in *H. vulgare*. *O. ficus indica* had the highest values in free condensed tannins. The most digestible plant sample was that from *M. sativa* and *O.ficus indica*. The maximum in vitro gas production was recorded with *M. sativa* and *H. vulgare*. The same trend was observed with the total gas production (144 h). Based on the results, it can be concluded that *O. ficus indica* could replace common plant species, especially in the arid and semi-arid areas in which the livestock production section frequently suffers low efficiency and big losses.

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KEYWORDS
In vitro gas production; *Opuntia ficus indica*; Rumen fermentation

Introduction

Due to low feed quality and availability, the majority of ruminant's production systems have deficient productivity, mainly in the arid and semi-arid areas in which the livestock production section frequently suffers low efficiency and big losses. This dilemma unfortunately is not limited only to semi-arid and arid areas of Algeria. Growing requirements for food associated with declining crop yields are high-pressuring farmers of the eastern and western steppe lands regions to develop further land with the sacrifice of grassland and browses (Mosisa et al., 2021).

Livestock population in Algeria is estimated to be 26.88 million sheep, 4.90 million goats, and 1.90 million cattle. Then, sheep breeding accounts for nearly 80% of the country's total herd (Mohamed-Cherif et al., 2019). The main popular livestock feeding mode in the arid and semi-arid regions consists of pasturing, halfway pasturing in association with littlest supplementation, and the stall feeding system at finishing of the breeding. Though, there are differences in livestock management systems, especially the global, regional, national, and local scale livestock management, which mainly depends on the main land use system. Inside numerous arid and semi-arid regions, as well as Algeria, relevant browsing administration hangs on the prevailing grassland resources and related land use/competition (Williamson & Payne, 1990).

Opuntias have been known remote time for their wide-ranging uses and properties and they are found in multiple lands: Mexico, Sicily, Chile, Brazil, Turkey, Korea, Israel, Argentina, and North Africa (Snyman, 2006; Di Bella et al., 2022). Prickly pear (*Opuntia ficus-indica*) plantations are a valuable investment for some arid and semi-arid regions around the world (Guevara et al., 2009). Commonly, unripe cladodes of prickly pear and the fruit are used for human nourishment, and its young leaves serve as nutritious vegetable and salad dish and the immature fruits for making mock-gherkins (Einkamerer et al., 2009). However, mature stems or cladodes can be used to feed (De Waal et al., 2006). Cactus fleshy leaves and pear fruits are used in multiple productive sectors like industrial. Many productive sectors use cactus pear fruits and their fleshy leaves as industrial basic materials as food additives, biopolymers, and flocculating agents for water treatment (Albergamo et al., 2022), cosmetics, and alcoholic drinks. Furthermore, the plant is a natural living fence in fields and gardens, helping to combat desertification (FAO, 2013).

Potential and nutritive value study of *Opuntia* could contribute to the development of the livestock sector in dry regions of Algeria. The evaluation of the nutritional value of ruminant feed should include the determination of nutrient concentration and the digestibility potential of the feed type. The most interesting

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approach to this issue has been proposed by Menke et al. (1979), as the *in vitro* gas production technique associated with chemical composition to evaluate the potential nutritional value of forages that have not been studied before, because the *in vitro* gas production technique is fast, cheap, and requires less time. The use of chemical components combined with *in vitro* digestibility and degradability is a useful tool to assess the nutritional value of pasture forage resources (Rittner & Reed, 1992). Such *in vitro* experiments supply initial details about these resources and their chemical composition and fermentation potential. The present study aims to determine the chemical composition and *in vitro* fermentation profile, of *opuntia ficus-indica* cladodes in an arid area of Algeria, as an alternative source of fodder, especially during periods of drought, versus whole plant of alfalfa and barley straw used as standards.

Material and methods

Study area

M'Sila province is located between 35°18′ and 35°32′ North and 4°15′ and 5°06′ East, 240 km south-east of Algiers, in the country's highlands. Winter is cold with low and irregular rainfall in the order of 100–250 mm/year and Summer is hot and dry while (Medjekal et al., 2018). Average annual temperatures ranged between 13°C and 23°C with extremes of −5°C in winter to 46°C in summer (Infoclimat, 2020). The state is made up of 15 Daïras (districts), and the most populous city is M'Sila, which is followed by Bousaada, known as the 'gateway to Sahara' (Figure 1).

Plants species

Three plants species were used in this study: the inermal cactus (*Opuntia ficus indica* f. inermis) cladodes and peels, whole plant alfalfa (*Medicago satifa* L.), and barley straw (*Hordium vulgare*). The choice of these species was based on their large cultivation area, high availability, palatability for ruminants, and their capacity to produce a biomass species used in conditions of absolute marginality of the soils, thus constituting a food resource for livestock in arid conditions. All the samples were collected from an arid region of Algeria, M'sila (GPS coordinates: Latitude: 35°17′03.48″ N, Longitude: 4°15′ 20.95″ E). Between six and eight samples are taken from specimens of trees or plants of the selected species, in order to have a representative sample of the total plant biomass. The cactus cladodes were cut with a machete into small cubes of approximately 40 mm × 20 mm. The aerial parts of the other samples were cut with scissors. All the samples were dried at 50°C in a ventilated oven, ground to pass through a 1-mm sieve, and then stored at ambient temperature (20–25°C) in closed containers till analysis. Plants collection was carried out during midsummer (July), corresponding to periods of drought and luck of fodder resources for ruminants.

Chemical analysis

Milled plant samples were analyzed for dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF), using the methods of (AOAC, 2000). The concentrations of condensed tannin were analyzed using butanol-HCl method reported by Makkar et al. (1995). The chemical analyses were accomplished in triplicate. ADF and NDF fiber contents were determined using an ANKOM brand apparatus (ANKOM 200 Fiber Analyser, ANKOM Technology, Macedon, NY, USA) on 0.5 g samples (Goering & Van Soest, 1970). These two determinations were made using different samples and each sample was analyzed in triplicate.

In vitro digestibility

In vitro dry matter digestibility (IVTD) was calculated using Goering and Van Soest (1970) methods of founded on a 48 h incubation in ruminal liquor accompanied by the determination of NDF fiber in post-digestion residues. Incubation in the ruminal fluid was performed in a DAISY II incubator (Model DAISY II Incubator, ANKOM Technology, Macedon, NY, USA). Ruminal fluid was obtained from a rumen fistulated sheep. All samples were analysed in duplicate on two different collections made at least 2 days apart.

IVTD was calculated as follows:

$$\text{IVTD (mg g-1 DM)} = [1 - (\text{DM weight of post-digestion NDF residue}) / \text{pre-digestion DM weight}] \times 1000$$

In vitro NDF fiber digestibility (dNDF) was calculated from NDF concentrations as follows:

$$\text{dNDF (mg g-1 NDFMS)} = [1 - (\text{DM weight of post-digestion NDF residue}) / \text{pre-digestion NDF weight}] \times 1000$$

In vitro *gas production*

Gas production measurements were performed using the method reported by Theodorou et al. (1994).

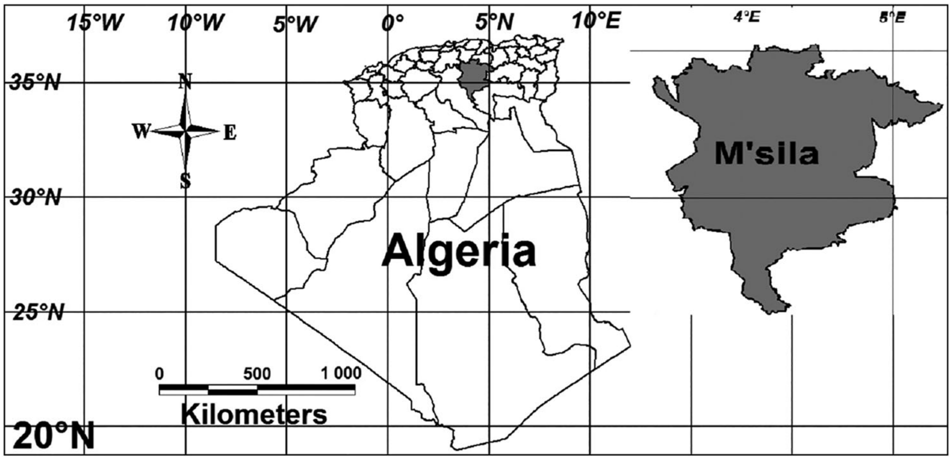

Figure 1. The study area.

Five-hundred milligrams of each sample were sealed in 120 ml serum bottles containing 50 ml of diluted rumen fluid (10 ml mixed rumen fluid + 40 ml medium) according to Menke and Steingass (1988) and prewarmed at 39°C and flushed with CO_2. Rumen fluid was obtained from three mature Merino sheep (average weight 48.04 ± 3.23 kg) equipped with permanent rumen cannula (60 mm diameter) fed with alfalfa hay ad libitum and maintained in cages with free access to water and a vitamin/mineral block. The medium was maintained at 39°C and saturated with CO_2. The oxygen reduction in the medium was performed by the addition of cysteine hydrochloride and Na_2S solution as described by Van Soest et al. (1966). The measured gas was recorded after 3, 6, 9, 12, 16, 21, 26, 31, 36, 48, 60, 72, 96, 120, and 144 h following incubations and corrected for blank.

The ME (MJ/kg DM) content of the incubated plants species was determined using equation of Menke et al. (1979) as follows:

Table 1. Chemical composition (g/kg dry matter) of studied samples.

	Plants species				
	O. ficus indica	*M. sativa*	*H. vulgare*	S.E.M	Significance
DM	949.18a	939.18a	939.74a	17.953	NS
ASH	284.07a	90.27b	71.85b	61.691	***
CP	79.04b	156.09a	51.41c	6.913	***
NDF	325.93c	470.92b	668.17a	208.468	***
ADF	119.94c	303.16b	361.52a	22.731	***
ADL	19.45c	76.94a	50.88b	1.447	***
CEL	100.82c	227.22b	311.98a	10.456	***
HMC	235.40b	197.90c	326.10a	47.069	***

DM: *Dry matter %*, ***CP***: *Crude protein*, ***NDF***: *Neutral detergent fiber*, ***ADF***: *Acid detergent fiber*, ***ADL***: *Acid detergent lignine*, ***CL***: *Cellulose*, ***HMC***: *Hemicellulose;* ***S.E.M***: *standard error mean;* $^{a,\,b,\,c}$ *Line means with common superscripts do not differ (P < 0.05).*

The ME (MJ/kg DM) = 2.20 + 0.136 GP + 0.057 CP, where GP = 24 h net gas production (ml/200 mg); CP = Crude protein.

Fermentation kinetic parameters were estimated after the gas production data were fitted to the exponential model suggested by France et al. (2000):

$$G = A\,[1\text{-}e-^{c(t-L)}]$$

In which:
G (mLg-1): The cumulative gas production at time t.
A (mLg-1): The asymptotic gas production.
c (/h-1): The fractional rate of gas production.
L (h): The lag time.

Statistical analysis

All data were analyzed using one way analysis of variance (Steel & Torrie, 1980). A multiple comparison of means Tukey's test was used ($P < 0.05$). SAS software package (SAS, 2000) was used to perform the analysis of variance between different variables.

Results and discussion

As you can see from Table 1 there were significant ($p < 0.05$) differences among studied samples in all measured nutrients except DM value. *O. ficus indica* showed the highest Ash content (284.07 g/kg DM), whereas the lowest concentrations were observed in *H. vulgare and M. sativa with* 71.85 and 90.27 g/kg DM, respectively. The CP of the studied feedstuff ranged from 51.41 to 156.09 g/kg DM and it was particularly high within *M. sativa* and low in *H. vulgare*. *O. ficus indica* showed low value with 79.04 g/kg DM. Higher cell wall components concentrations were observed in *H. vulgare* than in *M. sativa* and *O. ficus indica*. The NDF and ADF contents ranged respectively from 325.93–668.17 g /kg DM and from 119.94 to 361.52 g /kg DM, with the highest values for *H. vulgare*. The same trend was observed for CEL and HMC contents with values ranging from (100.82 and 311.98 g/kg DM) and (197.90 and 326.10 g/kg DM) respectively. *M. sativa* showed the highest ADL content (76.94 g /kg DM), whereas the lowest concentrations were observed in *O. ficus indica* (19.45 g /kg DM).

It is well known that the chemical composition of forages influences directly on digestibility and *in vitro* fermentation, and thus the amount of end-products particularly VFAs released. In the present study, there were significant differences among studied samples in all measured nutrients; this difference in chemical components between plant families was anticipated because nutrients build up in plants is affected by genotypic factors (genus) (Minson, 1990). The CP contents of the plant species studied in our experiment were within the range of reported values in previous literature (Pinos-Rodríguez et al., 2010; Bouazza et al., 2020). The CP contents were always above than is the minimum content of 7–8% DM required for adequate rumen function and feed intake of ruminants (Bouazza et al., 2012). Due to the relatively high CP content of *O. ficus indica*, this feed resource can be considered a suitable supplement for crop residues such as poor-quality natural grasses (low N content), straw and shrubs. *O. ficus indica* showed the highest ash content than the two other samples which depends on soil, plant species, and management factors (Spear, 1994). This mineral content is much higher than that reported for some legumes and grasses forages by Medjekal et al. (2020). This shows that feeding sheep with *O. ficus indica* cladodes can meet their mineral requirements. High cell wall component concentrations were observed in *H. vulgare* than in *M. sativa* and *O. ficus indica*. This significant difference may be explained by some internal morphological or anatomical differences in relation to the cell wall structure and inflexibility (Wilson, 1994) and leaves to twigs proportion in the used samples in our experiment. Crop remainders are important roughage sources for ruminant animals, in particular where grassland is limited. *H. vulgare* are typically high in fiber and low in crude protein, although, their inclusion in dairy diets can be a helpful nutrition management tool for livestock production. Furthermore, in order to improve fibrous feed digestibility, some exogenous fibrolytic enzymes are of growing interest as additives to ruminant nutrition (Selzer et al., 2021).

Figure 2 exhibits the cumulative gas production curve of the three different samples grown in buffered ruminal fluid. For the different samples studied in this experiment, fermentation begins easily and there is no lag time. The highest asymptotic gas production was observed in *H. vulgare* and *M. sativa* (133.54 and 121.82 mL/g DM, respectively), while *O. ficus indica* recorded the lowest value with (114.17 mL/g DM).

Gas production after 144 h of incubation was higher in *H. vulgare* and *M. sativa* ($P < 0.05$), compared to *O. ficus indica* which is in agreement with cell wall concentration. Indeed, gas production is closely associated with the amount of fermentable substrate in diets. These results are in good agreement with other studies which have shown significant differences in gas production at 24 h between the four studied samples, including *O. ficus indica*, Vetch-Oat hay, *Acacia nilotica* and *Acacia saligna* (Chentli et al., 2014).

The estimated metabolizable energy (ME), *in vitro* digestibility and *in situ* DM disappearance coefficients

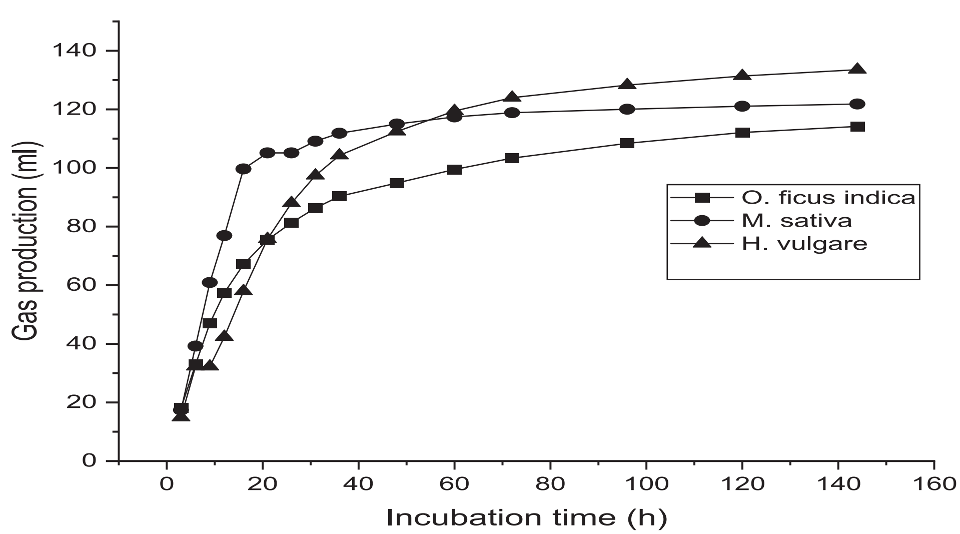

Figure 2. Cumulative gas production profiles.

Table 2. ME (MJ/kg DM) In vitro dry matter (g/g DM) digestibility and in situ dry matter disappearance (g/g DM) at different incubation time.

		Plants species				
		O. ficus indica	*M. sativa*	*H. vulgare*	S.E.M	Significance
ME[1]		8.39b	11.10a	9.49b	0.3492	***
ivDM loss[2]		0.551b	0.698a	0.697a	0.0001	***
TIVD[3]		0.774a	0.720a	0.697a	0.0054	NS
IVD-TT[4]		0.887a	0.678b	0.623c	0.0003	***
In situ DM disappearance after incubation times, h	0h	0.324a	0.319a	0.221b	0.0001	***
	12h	0.541a	0.587a	0.274b	0.0003	***
	24h	0.576b	0.654a	0.328b	0.0013	***
	96h	0.663b	0.735a	0.684ab	0.0007	***

[1]**ME:** metabolizable energy; [2]**ivDMloss:** *in vitro* dry matter loss; [3]**TIVD:** true *in vitro* digestibility; [4] **IVD-TT:** *In Vitro* Digestibility of Tilley & Terry; ***S.E.M**: standard error mean;* [a, b, c] *Line means with common superscripts do not differ (P > 0.05).*

Table 3. ME (MJ/kg DM) In vitro dry matter (g/g DM) digestibility and in situ dry matter disappearance (g/g DM) at different incubation time.

		Plants species				
		O. ficus indica	*M. sativa*	*H. vulgare*	S.E.M	Significance
ME[1]		8.39b	11.10a	9.49b	0.3492	***
ivDM loss[2]		0.551b	0.698a	0.697a	0.0001	***
TIVD[3]		0.774a	0.720a	0.697a	0.0054	NS
IVD-TT[4]		0.887a	0.678b	0.623c	0.0003	***
In situ DM disappearance after incubation times, h	0h	0.324a	0.319a	0.221b	0.0001	***
	12h	0.541a	0.587a	0.274b	0.0003	***
	24h	0.576b	0.654a	0.328b	0.0013	***
	96h	0.663b	0.735a	0.684ab	0.0007	***

[1]**ME:** metabolizable energy; [2]**ivDMloss:** *in vitro* dry matter loss; [3] **TIVD:** true *in vitro* digestibility; [4] **IVD-TT:** *In Vitro* Digestibility of Tilley & Terry; ***S.E.M**: standard error mean;* [a, b, c] *Line means with common superscripts do not differ (P > 0.05).*

are shown in Table 2. The ME contents were particularly higher in *M. sativa*, while *H.vulgare* and *O.ficus indica* had significantly lower values of ME (9.49 and 8.93 MJ/kg DM; respectively). The most digestible plant sample was that from *M. sativa* and *O.ficus indica*. Intermediate values were found for *H.vulgare*.

The digestibility of dry matter is an important factor to determine the feed quality in ruminants. Furthermore, the higher the digestibility of dry matter, the more likely the livestock will have the nutrients they can use for growth. In this experiment, plants samples digestibility was evaluated using two conventional, largely used *in vitro* techniques (Tilley & Terry, 1963; Van Soest, 1994), as well as determined when the sample was incubated in situ in the rumen. The differences in digestibility and gas production parameters between *O. ficus indica* and the two other standards can be partly due to differences in their chemical composition. As well, the presence of high contents of condensed tannins in some species may decrease their digestibility by ruminants (Barry & McNabb, 1999). Our results show that numerous species had high levels of organic matter digestibility *in vitro* as well as the *in vitro* dry matter digestibility potentials. The observed high IVD-TT in the current study (0.328–0.887 g/kg DM) was consistent with the findings of other studies (Chebli et al., 2021). *In vitro* fermentation kinetics data are shown in Table 3.

Low values of gas production and constant rate (C) were observed for *O. ficus indica* followed by *M. sativa* and *H. vulgare*. The G_{24} of investigated plant samples ranged between 162.85 (ml/g) *O. ficus indica* and 217.52 (ml/g) g for the *M. sativa*.

Gas production rates and the *In vitro* gas production potential changed significantly between the studied samples. The volume of gas produced from the incubated material is firmly depending on the chemical composition and the rate and degree of degradability of the incubated material (Blümmel et al., 1999). The production of gas from proteins is relatively low compared to polysaccharides, while the contribution of lipids is considered negligible (Getachew et al., 1998). Then, gas productions are mainly the result of fermentation of carbohydrates into acetic acid, propionic acid, and butyric acid (Menke & Steingass, 1988), and a significant difference in carbohydrate contents in the feed first affect total gas production (Deaville & Givens, 2001).

Based on the results, it can be concluded that *O. ficus indica* is an available feed resource that could replace common plant species, especially in the arid and semi-arid areas in which livestock production section frequently suffers low efficiency and big losses. Hence, the combination of such feeds having high cell wall component potential and bioactive rich compounds can be a sustainable option to enhance productivity without any adverse effect on the environment. *O. ficus indica* makes a valuable contribution to the food security and nutrition of people throughout the world wherever water is scarce. Our perspective now is to select such interesting plant species on the nutritional level which will be undeniably a major element of the future plantations of fodder resources in the feeding of the small ruminants and the development of agroforestry systems in the region. Furthermore, these plantations in agroforestry systems could consolidate the protection of the environment against erosion, allowing the fixation of the soil and its protection against water erosion.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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