

CHEMICAL COMPOSITION AND *IN VITRO* RUMEN BIOGAS PRODUCTION OF SOME PERENNIAL PLANTS SPECIES

S. Medjekal^{1*}, M. Guetouache¹, M. Ghadbane² and A. Z. M. Salem³.

¹Department of Microbiology and Biochemistry, Faculty of Sciences, Med Boudiaf University of M'sila, Po. Box 166, 28000, M'sila, Algeria.

²Department of SNV, Faculty of Sciences, Med Boudiaf University of M'sila, Po. Box 166, 28000, M'sila, Algeria.

³Universidad Autónoma del Estado de México (UAEM)

*Corresponding author's E-mail: sammedj2008@gmail.com, samir.medjekal@univ-msila.dz

ABSTRACT

The nutritive value of some Algerian perennial plants species were examined on the premise of their *in vitro* gas production, chemical composition and fermentation kinetics. The plant species were *Aristida pungens*, *Artemesia herba-alba*, *Artemesia vulgaris*, *Atriplex halimus*, *Genista saharae*, *Lygeum spartum*, *Retama retam*, *Stipa tenacissima*. L and oat hay as a standard. Important variation have been registered ($P < 0.05$) regarding all the chemical components of the perennial plants species. The crude protein (CP) content value ranged between 5.02 and 16.15 (% DM), the highest CP value was recorded for *Atriplex halimus* (*A. halimus*). Acid detergent fiber (ADF) and Neutral detergent fiber (NDF) were generally high in *Stipa tenacissima* and low in *Atriplex halimus* ($P < 0.05$). The organic matter digestibility (OMD) and the total gas production vary from 31.74 to 59.1 % and 15.46 to 39.52 (ml.g⁻¹ DM), respectively. In general, high values of Organic matter digestibility (OMD) and gas production were noted for *A. halimus* succeeded by *Genista saharae* (*G. saharae*). This necessitates prudent nutritional interventions such as supplementation with barley and wheat bran. Additionally, in order to improve fibrous feeds digestibility, some exogenous fibrolytic enzymes are of growing interest as additives to ruminant nutrition. *A. halimus* is a valuable plant that provides wildlife habitat and food for livestock. It is a very effective fodder element in mixed diets and as a supplement for livestock, mainly during the dry season in arid and semi-arid regions.

Key Words: digestibility, *in vitro* gas production, perennial plants,

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Published first online April 15, 2023

Published final August 04, 2023

INTRODUCTION

There are two types of flora: spontaneous annual herb cover, Acheb, which appears within a few days of the first rain, and can last for about a month if the rain is sufficient, and perennials, which form the grassland of the permanent flora of the grassland (Nedjraoui, 1981; Aidoud, 1989; Le Houérou, 2001a). Perennial plants species plays an important role and used for ruminant grazing because they are adaptable, drought resistant, provide reliable forage production, have extensive root systems, increase soil fertility, and require low input costs. Moreover, perennial plants-based phytoremediation can play a key role in the restoration of contaminated sites and the maintenance of ecosystem services (Awasthi *et al.*, 2017; Pandey and Singh, 2020). Advantageously, these characteristics make them ideal for inclusion in balanced and sustainable grazing systems, especially in areas with little rainfall. Additionally, numerous perennial plants are ideal for surviving the lack of moisture and heat typical of many areas of south Algeria

(Arid and Semi-Arid regions) (Singh *et al.*, 2018; Medjekal *et al.*, 2020). However and despite their potential as feeds, most of these perennial species contain large amounts of tannins, which plants have used as a defense mechanism against consumption by herbivores. The presence of these molecules in some forage cereals, legumes, grains, shrubs, and trees, usually restrict their utilization as feeding stuffs (Kumar and Vaithyanathan, 1990). In the context of pasture ecology and sustainable use, long-term monitoring and management also require information about the nutritional value of these perennial plant species (Tefera *et al.*, 2009). Nutritive value evaluation of ruminant feeds should involve both the determination of nutrient concentration as well as the digestibility potential of forage types. The most interesting 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 nutritive value of previously uninvestigated forages since *in vitro* gas production technique is quick, cheap and less time consuming. The

use of chemical composition in combination with *in vitro* digestibility and degradability are useful tools in the evaluation of the nutritive value of forage resources from rangelands (Rittner and Reed, 1992). The present study aims to evaluate the chemical composition and *in vitro* cumulative gas production of some perennial plant species in the semi-arid area of Djelfa, which is a typical pattern of the North African grassland due to its huge delay when the animals on the grassland had to build reserves to save the long dry season.

MATERIALS AND METHODS

Study Area: This experiment was conducted in a semi-arid area located in the Djelfa region (35°21'6"N and 3°21'39"E) in northern Algeria (Fig. 01), during the period of March 2020. Djelfa is located a 300 km South

far away from the capital of Algeria, in the middle of Algerian steppe which makes a band between the humid fertile North and the huge Algerian desert (Boubakeur, 2018). Djelfa region is characterized by altitude level of 845 m, with a climate typically Mediterranean, characterized by wet winters and hot dry summers with a mean annual precipitation of 250 mm year (2000-2010) (Nedjimi, 2012). The average minimum temperature in winter and the maximum temperature in summer are 5°C in January and 26°C in July (Medjekal *et al.*, 2015). By far the warmest months are: July, August and June in Djelfa. The coldest month is January with temperature 12°C and with an average 14 mm of precipitation. Other cold months are: December 13°C, February 14°C and November 17°C. The rainy season is generally from mid-October to May (Le Houérou, 2001b).

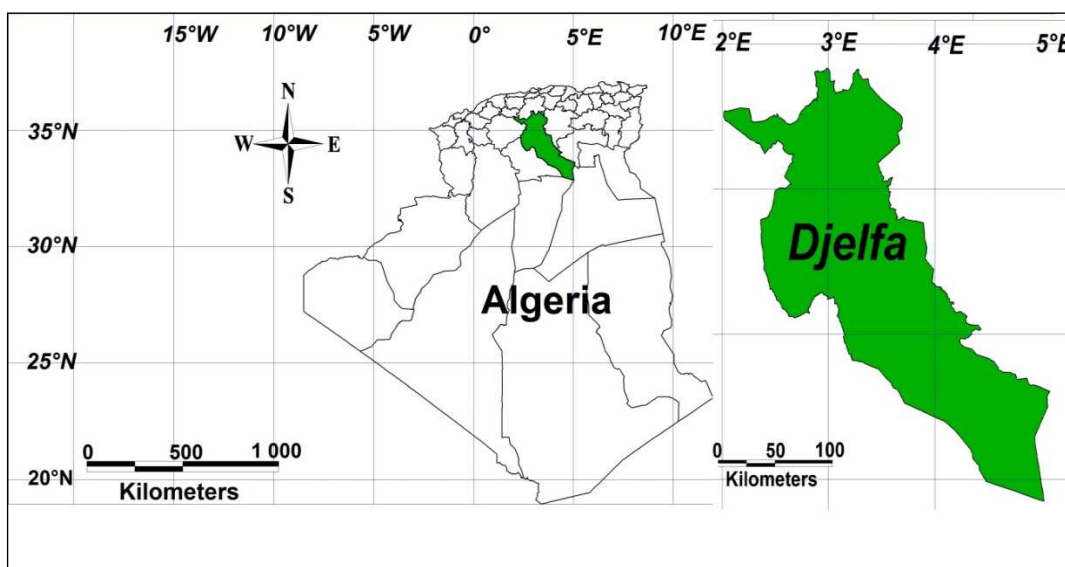


Fig. 1: The study area (MapInfo Professional 8.0)

Plants species: Eight perennial plant species were used in this study: *Aristida pungens* (*A.pungens*), *Artemesia herba-alba* (*A.herba-alba*), *Artemesia vulgaris* (*A.vulgaris*), *Atriplex halimus* (*Ahalimus*), *Genista saharae* (*G.saharae*), *Lygeum spartum*.L (*L.spartum*), *Retama retam* (*R.retam*), *Stipa tenacissima*. L (*S.tenacissima*) and oat hay as a standard. Selection of the species was based on the available information (Boufennara *et al.*, 2012; Medjekal *et al.*, 2020) on their relative abundance and on their consumption by grazing small ruminants. Samples were collected in July 2020 when plants were at flowering (*A.pungens*, *A.herba-alba*, *A.vulgaris*, *A.halimus* and *G.saharae*) or at a mature stage (final stage of biological function for the rest of the species). Sampling was carried out during the dry season, because this is the most important grazing time of the year for these plants. The branches and twigs of several

specimens of each perennial plants species were cut with scissors (total top part) and immediately taken to the laboratory, where the leaves, flowers and fruits (if any) were manually separated. Then to twelve samples of the eight substances were then immediately freeze-dried and ground using a 1 mm sieve in a hammer mill.

Chemical analysis: The dry matter (DM), the neutral detergent fiber (NDF), the acid detergent fiber (ADF), and the crude protein (CP) of ground perennial plants species are analyzed, and the content is determined following the methods of AOAC (2000). As described by Makkar *et al.* (1995), condensed tannins are determined by the butanol HCl method. All chemical analyzes were performed in triplicate.

In vitro gas production: Menke *et al.* (1979) describe methods for measuring gas production. 200 mg of each

sample is incubated in 50 ml of diluted ruminal fluid (10 ml of mixed ruminal fluid + 40 ml of medium prepared according to Menke and Steingass (1988) under a constant flow of CO₂). A 100 ml glass syringe is preheated to 39 ° C and flushed with CO₂. Rumen liquid is diluted (1:4 v/v) with medium containing a macro-and micro-mineral solution, resazurin, and a bicarbonate buffer solution, and is prepared as described by Menke and Steingass (1988). Rumen fluid was obtained from three mature Ouled Djellal sheep (body weight 45.06±3.46 kg) equipped with permanent rumen cannula (60 mm diameter) kept in cages and fed alfalfa hay *ad libitum* (CP 175 g, ADF 332 g, NDF 480 g and ADL 92 g/kg DM) with free access to water and a mineral/vitamin block. Rumen fluid from the three sheep was mixed, strained through various layers of cheesecloth and kept at 39°C under a CO₂ atmosphere. The medium was maintained at 39°C and flushed with CO₂. As described by Van Soest *et al.* (1966), a solution containing cysteine hydrochloride and Na₂S was added to reduce oxygen in the medium. Production of gas was measured at, 3, 6, 12, 24, 48, 72 and 96 h after incubation according to the technique of Menke and Steingass (1988) by reading plunger position and adjusted for blank. With three replicates we had six observations per sample. We used three different inocula to perform incubations (three sheep used separately to give rumen fluid) with two glass syringe per rumen fluid inoculum.

The equation of Menke *et al.* (1979) was used to determine ME (MJ/kg DM) content of the perennial species:

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.

The OMD (%) of the studied samples was determined using equation of Menke *et al.* (1979) as follows:

OMD (%) = 14.88 + 0.889GP + 0.45CP + 0.0651 XA,

GP = 24 h net gas production.

where XA: ash content (%).

Cumulative gas production results were fitted to the exponential model $P = A + B(1 - e^{-ct})$ of Ørskov and McDonald (1979), with: P (ml): gas production at time t, A (ml): gas produced from soluble fraction, B (ml): gas produced from insoluble but fermentable fraction, A + B (ml): potential of gas production and C: the fractional rate of gas production per hour (ml/h).

Statistical analysis: All data of chemical composition, gas production, fermentation kinetics parameters, metabolizable energy and organic matter digestibility were analyzed with one way analysis of variance (Steel *et al.*, 1997). A multiple comparisons of means Tukey's test was used ($P < 0.05$). SAS software package (SAS, 2000) was used to perform analysis of variance between different variables.

RESULTS

The overall chemical composition of perennial plants species measurement results are summarized in **Table 01**. There was a significant variation ($P < 0.05$) in the content of all measured nutrients, DM, Ash, ADF, NDF, CP and CT among the perennial plant species.

A. halimus showed the highest Ash content (28.72% DM), whereas the lowest concentrations were observed in *S. tenacissima* (13.21% DM). *S. tenacissima* and *A. pungens* were highest in NDF (77.52 and 74.68% DM, respectively). The same trend was observed for ADF contents (61.05 and 51.05 % DM, respectively in *S. tenacissima* and Oat hay). The highest content of CP was recorded for *A. halimus* (16.15) (% DM) and the lowest ($P < 0.05$) content of CP was recorded for *A. pungens* (4.70). However, *R. retam*, *A. vulgaris* and *A. herba alba* had registered CP content between 9 and 13 % DM, which can support moderate level of productivity in ruminants. Low CT contents were recorded for all the samples studied herein, less than 2 % DM which will be beneficial with no anti-nutritional effect on feed's protein.

Fig. 02 exhibits the cumulative gas production curve of the nine different samples grown in buffered ruminal fluid. For the different samples studied in this experiment, the profile of fermentation of the different substrates lengthens before becoming stable at 90 hours. This profile is precisely a characteristic of the fibrous substrates which express a more or less high latency time and spend a long period of stay in the rumen. The highest asymptotic gas production was observed in *A. halimus* and *G. saharae* (39.52 and 38.69 mL.g⁻¹(%DM), respectively), while *S. tenacissima* recorded the lowest value with (15.46 mL.g⁻¹ DM). As may be seen in Table 02, the gas production values after 96 hours incubation varied ($P < 0.05$) between plants species. The highest total gas production (TGP) values were recorded for *A. halimus*, *G. saharae* and *R. retam* than for the standard and *S. tenacissima*. L. The same trend was observed for ME (8.49, 8.15 and 7.96 MJ/Kg DM, respectively in *A. halimus*, *R. retam* and *G. saharae*).

The most digestible plants species were *A. halimus*, *R. retam* and *G. saharae*. Intermediate values were recorded for of *L. spartum*. and *A. vulgaris*, and the lowest OMD (% DM) values were for *S. tenacissima*. L. Fermentation kinetics parameters are also presented in Table 02. Asymptotic gas production (A) and TGP (ml) were lowest for *S. tenacissima*.L and greatest for *G. saharae*.

Table 02 shows fermentation kinetics parameters. The asymptotic gas production (A) and TGP (ml) were low for *S. tenacissima*.L and high for *G. saharae*.

Table 01: Chemical composition (% DM) of the whole perennial plants species.

Plants species	DM	Ash	ADF	NDF	CP	CT
<i>Aristida pungens</i>	84.35 ^b	15.64 ^d	51.05 ^b	74.68 ^{ab}	4.70 ^f	1.41 ^{ab}
<i>Artemesia herba -alba</i>	76.44 ^d	23.24 ^b	38.57 ^{cd}	46.17 ^e	9.08 ^{cd}	1.66 ^a
<i>Artemesia vulgarus</i>	81.44 ^c	18.56 ^c	33.66 ^d	35.20 ^f	9.62 ^c	1.33 ^{ab}
<i>Atriplex halimus</i>	71.22 ^e	28.72 ^a	17.28 ^e	32.67 ^f	16.15 ^a	1.44 ^{ab}
<i>Genista saharae</i>	87.77 ^a	12.22 ^e	46.75 ^{bc}	52.56 ^d	8.88 ^{cd}	1.30 ^b
<i>Lygeum spartum.L</i>	86.90 ^a	13.09 ^e	50.01 ^b	69.69 ^c	7.52 ^{de}	1.49 ^{ab}
<i>Retama retam</i>	86.97 ^a	13.03 ^e	45.49 ^{bc}	51.92 ^d	13.69 ^b	1.46 ^{ab}
<i>Stipa tenacissima. L</i>	87.66 ^a	13.21 ^e	61.05 ^a	77.52 ^a	5.02 ^f	1.36 ^{ab}
Oat hay	83.60 ^{bc}	16.39 ^d	53.68 ^{ab}	73.90 ^b	6.09 ^{ef}	1.46 ^{ab}
S.E.M	0.6733	0.3697	9.664	1.5304	0.3237	0.0143
Significance	***	***	***	***	***	***

a, b, c, d, e, f. Means of column with different letters are significantly different ($p < 0.05$); S.E.M: standard error mean; DM: Dry matter %, CP: Crude protein, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, CT: Condensed tannin, *** $P < 0.001$

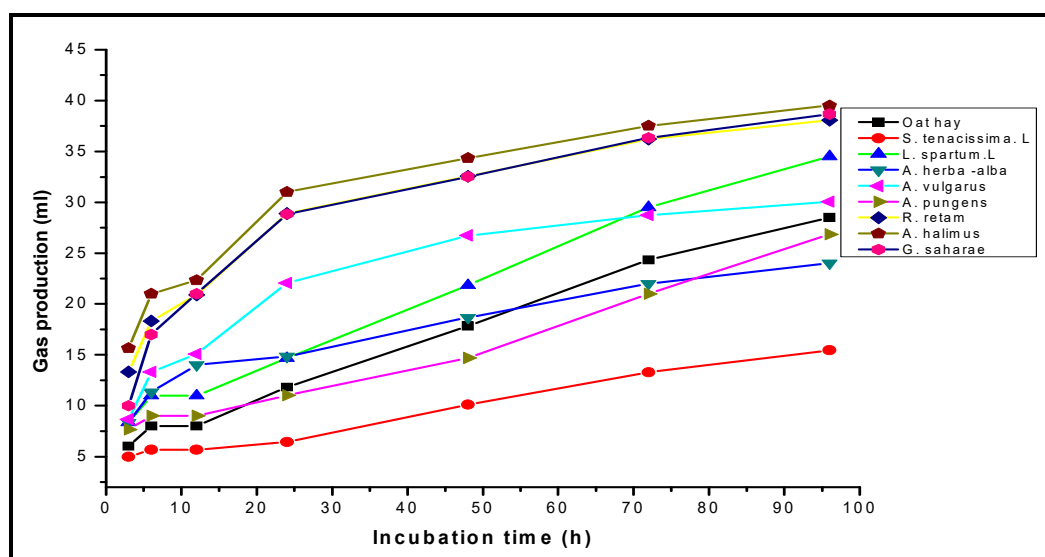


Fig. 2: Cumulative gas production profiles (OriginPro 2008)

Table 02: Gas production kinetics, metabolisable energy and organic matter digestibility of the perennial plants species.

Species	A (ml)	B (ml)	C (ml/h)	TGP (ml)	ME (MJ/Kg DM)	OMD (%)
<i>Aristida pungens</i>	7.58 ^{cd}	21.6 ^d	0.0091 ^c	26.85 ^{bcd}	6.12 ^{de}	41.88 ^{de}
<i>Artemesia herba -alba</i>	8.26 ^{bc}	25.57 ^{bcd}	0.0225 ^{bc}	24.01 ^{cd}	5.98 ^{de}	41.83 ^{de}
<i>Artemesia vulgarus</i>	6.57 ^{cde}	23.97 ^{cd}	0.0410 ^b	30.07 ^{abc}	6.83 ^{bcd}	47.15 ^{bcd}
<i>Atriplex halimus</i>	13.73 ^a	21.34 ^d	0.0407 ^b	39.52 ^a	8.49 ^a	59.15 ^a
<i>Genista saharae</i>	8.95 ^{bc}	31.06 ^{bc}	0.3614 ^a	38.69 ^a	7.96 ^{abc}	54.06 ^{bcd}
<i>Lygeum spartum.L</i>	7.73 ^{bc}	31.88 ^{bc}	0.0044 ^c	34.51 ^{abc}	7.32 ^{abcd}	49.80 ^{abcd}
<i>Retama retam</i>	11.17 ^{ab}	30.75 ^{bc}	0.0402 ^b	38.07 ^{ab}	8.15 ^{ab}	55.74 ^{ab}
<i>Stipa tenacissima. L</i>	3.08 ^e	32.22 ^b	0.0034 ^c	15.46 ^d	4.59 ^e	31.74 ^e
Oat hay	4.09 ^{de}	45.54 ^a	0.0033 ^c	28.51 ^{abc}	6.42 ^{cd}	44.04 ^{cd}
S.E.M	1.54	7.84	0.0001	16.84	0.32	13.80
Significance	***	***	***	***	***	***

a, b, c, d, e. Means of column with different letters are significantly different ($p < 0.05$); A (ml): initial gas produced from soluble fraction; B (ml) gas produced from insoluble but fermentable fraction; C: the fractional rate of gas production per hour (ml/h). S.E.M.: standard error mean; NS: Non-significant, TGP: gas production rate (ml); ME: Metabolisable energy (MJ/kg DM); OMD: Organic matter digestibility %, *** $P < 0.001$

DISCUSSION

The high fiber (NDF and ADF) content recorded by the perennial plants species studied in this experiment and the low protein are usual of steppique and arid region grasses as reported by, Arhab *et al.* (2009), Boufennara *et al.* (2012) and Medjekal *et al.* (2020). Despite mature perennial plants species were largely utilized in livestock production overall the long months dry season, their nutritive value is commonly poor because of low protein content and the excessive fiber resulting in low ruminants livestock production. This necessitates prudent nutritional interventions such as supplementation with barley and wheat bran. The significant differences through perennial forages in the NDF and ADF content may be explained by some internal morphological or anatomical differences in relation with the cell wall structure and inflexibility (Wilson, 1994) and leaves to twigs proportion in the used samples in our experiment. Crude protein contents in *A. halimus* was similar to those described by Bouazza *et al.* (2012) and Boufennara *et al.* (2012), however the NDF and ADF values were higher. This reveals the capacity of *Atriplex* spp. to produce annual ruminants feed and their far-more salt acceptance than many other grassland species (Azam *et al.*, 2012).

A. herba-alba is largely used during spring by small ruminant's producers. In fact, *A. herba-alba* is particularly the shrublands most abundant plant species of the North African's steppe (Le Houérou, 1989). In comparison with CP content of *A. herba-alba* collected from Tunisian rangelands (Ben Salem *et al.*, 1994), our samples shows slightly higher values. However, samples for the same plant species from Morocco recorded significantly high CP contents (El Aich (1992). Moreover, in this experiment, low tannin concentrations and intermediate digestibility were recorded for all the perennial plants species.

Condensed tannins (CT) are secondary plant polyphenol molecules that have been considered as anti-nutritional due to their capacity to link protein in feeds, microbial cells, and enzymes, hence, disrupting microbial digestion and retarding ruminal protein and dry matter digestion (McSweeney, 2001). The analysis method could affect condensed tannins compounds in the plants material, because the chemicals used may have different reactivity against the type and the amount of condensed tannins present in each sample. The absence of precise laboratory methods and adequate compounds used as standards are the main difficulties of CT analysis. According to Bouazza *et al.* (2012) colorimetry should be used with caution as quantitative analysis methods. Hence, the difference between our CT value and other values reported in the literature may be due to the growth stages of the plants, the nature of the common measurements, the standards quantification, the nature of

the tannins in the different food species and the influence of soil and climatic factors (Rubanza *et al.*, 2005).

Forages nutritive value rely on how appropriately they are solubilized and well degraded inside the digestive system and then, how many nutrients and energy can be supplied to rumen microbiota and ruminant (Longo *et al.*, 2012). One of the big advantages of the *in vitro* gas production technique was the prevalent correlation between the *in vitro* gas production and feed degradability, in relation with the chemical composition of feed (Menke and Steingass, 1988; López, 2005).. The *in vitro* gas production method was esteemed to be hypersensitive in detection of suchlike variations more than other *in vitro* gravimetric technique (Williams, 2000). Bouazza *et al.* (2012) announced a high OMD values for *A. halimus* rather than the values in our experiment, specifying no relation with the high gas production potential (parameter B); these authors considered the higher content of CP of *A. halimus* as a factor that contributed to its elevated OMD values.

In addition, the same authors recorded higher levels ($P < 0.01$) of gas production and ME in *A. halimus* in comparison with some foliage from fodder trees and shrubs, which is in agreement with the findings of the present study. Gas production after 96 hours of incubation was higher in *A. halimus* and *G. saharae* ($p < 0.05$), compared to the standard and all other samples which is in agreement with cell wall concentration. Indeed, gas production is closely associated with the amount of fermentable substrate in the diets. Consistent with our result, Haddi *et al.*, (2003) reported significant differences in gas production at 24 hours between the five halophytic shrubs, including *Atriplex halimus*, *Salsola vermiculata* and *Suaeda mollis*. Similar observations to our study were also noted by Kamalak *et al.*, (2005) for the so-called hay, *Gundelia tournifortii*, and by Kaplan *et al.*, (2014) for the minor hay *Sanguisorba*. According to Fagg and Stewart (1994), legumes native to arid regions, such as *C. saharae*, because of their symbiotic nitrogen fixation with legume-nodding bacteria (collectively called rhizobia) contribute in their majority to soil fertilization by increasing soil nitrogen and organic matter content. They also provide high quality forage, prevent erosion, and contribute to soil stabilization and restoration of arid and semi-arid ecosystems.

Conclusion: Perennial plants species evaluated in the present study show high content of fibre and low crude protein concentration. This necessitates prudent nutritional interventions such as supplementation with barley and wheat bran. Additionally, as additives to ruminant nutrition, exogenous fibrolytic enzymes are of growing interest as a way of improving digestibility of fibrous feeds. *A. halimus* should continue to be used in soil protection and low intensity farming systems of semi-arid and arid zones where, together with harvest

residues and rough grazing, it can form part of a balanced diet for livestock. In all cases, *A. halimus* is interesting as a perennial species because it is relatively requiring little in terms of management and is able to thrive on degraded soils.

Acknowledgements: Medjekal Samir gratefully acknowledges financial support received from the University Mohamed Boudiaf of M'sila, ALGERIA.

Conflict of interest: No potential conflict of interest was reported by the authors.

REFERENCES

- Aidoud, A. (1989). Contribution to the study of grazed ecosystems of the Algero-Oran high plains. Functioning, evaluation, and evolution of plant resources. Doctoral thesis, University of Sciences and technology, Houari Boumedien, Algiers, Departement of Biology, Algiers, 240 p (In French).
- Arhab, R., D. Macheboeuf, M. Aggoun, H. Bousseboua, D. Viala and J.M. Besle (2009). Effect of polyethylene glycol on *in vitro* gas production and digestibility of tannin containing feedstuffs from North African arid zone. *Trop. Subtrop. Agroecosystems*. 10: 475-486
- Awasthi, A., K. Singh and R.P. Singh (2017). A concept of diverse perennial cropping systems for integrated bioenergy production and ecological restoration of marginal lands in India. *Ecol. Eng.* 105: 58-65. <https://doi.org/10.1016/j.ecoleng.2017.04.049>
- Azam, G., C.D. Grant, I.K. Nuberg, R.S. Murray and R.K. Misra (2012). Establishing woody perennials on hostile soils in arid and semi-arid regions e a review. *Plant Soil*. 360: 55-76. <https://doi.org/10.1007/s11104-012-1215-6>
- Ben Salem, H., A. Nefzaoui and H. Abdouli (1994). Palatability of shrubs and fodder trees measured on sheep and dromedaries. 1. Methodological approach. *Anim. Feed Sci. Technol.* 46:143-153. [https://doi.org/10.1016/0377-8401\(94\)90072-8](https://doi.org/10.1016/0377-8401(94)90072-8)
- Bouazza, L., R. Bodas, S. Boufennara, H. Bousseboua and S. Lopez (2012). Nutritive evaluation of foliage from fodder trees and shrubs characteristic of Algerian arid and semi-arid areas. *J. Anim. Feed Sci.* 21:521-536. <https://doi.org/10.22358/jafs/66126/2012>
- Boubakeur, G. (2018). Climatic drought in the semi-arid region of djelfa –algeria (analyses of the rainfall data from 1975 to 2016). *Larhyss. J.* 33:123-140.
- Boufennara, S., S. Lopez, H. Bousseboua, R. Bodas and L. Bouazza (2012). Chemical composition and digestibility of some browse plant species collected from Algerian arid rangelands. *Span. J. Agric. Res.* 10: 88-98. <http://dx.doi.org/10.5424/sjar/2012101-134-11>
- Bouznit, M., M.P. Pablo-Romero and A. Sánchez-Braza (2020). Measures to Promote Renewable Energy for Electricity Generation in Algeria. *Sustainability*. 12: 1468. <https://doi.org/10.3390/su12041468>
- Djellouli, Y. (1990). Flores and climates in northern Algeria. Climatic determinisms of the distribution of plants. PhD Dissertation. Algiers: University of Sciences and Technology Houari Boumediene. (In French).
- El Aich, A. (1992). Fodder trees and shrubs in range and farming systems in North Africa. In: Legume Trees and Other Fodder Trees as Protein Sources for Livestock. FAO Animal Production and Health, Paper 102. FAO, Rome, pp. 61-73.
- Fagg, C.W and J.L. Stewart (1994). The value of Acacia and Prosopis in arid and semi-arid environments. *J. Arid Environ.* 27: 3-25. <https://doi.org/10.1006/jare.1994.1041>
- Haddi, M.L., S. Filacorda, K. Meniai, F. Rollin and P. Susmel (2003). *In vitro* fermentation kinetics of some halophyte shrubs sampled at three stages of maturity. *Anim. Feed Sci. Technol.* 104:215-332. [https://doi.org/10.1016/S0377-8401\(02\)00323-1](https://doi.org/10.1016/S0377-8401(02)00323-1)
- Huyenl, N.T., C. Fryganas, G. Uittenbogaard, I. Mueller-Harvey, M.W.A. Verstegen, W.H Hendriks and W.F. Pellikaan (2016). Structural features of condensed tannins affect *in vitro* ruminal methane production and fermentation characteristics. *J. Agric. Sci.* 154:1474-1487. doi:10.1017/S0021859616000393
- Kamalak, A., O. Canbolat, Y. Gurbuz, A. Erol and O. Ozay (2005). Effect of maturity stage on chemical composition, *in vitro* and *in situ* dry matter degradation of tumbleweed hay (*Gundelia tournefortii* L). *Small Rumin. Res.* 58: 149-156. <https://doi.org/10.1016/j.smallrumres.2004.09.011>
- Khattab, I.M.A. (2000). Nitrogen metabolism in ruminant nutrition. Effect of feeding some rangeland desert plants on productivity for sheep and goats in North Western Coastal Zone. M. Sc. Thesis, Faculty of Agriculture University of Alexandria
- Kaplan, M., A. Kamalak, A.A. Kzsra and İ. Guven (2014). Effect of Maturity Stages on Potential Nutritive Value, Methane Production and Condensed Tannin Content of Sanguisorba minor Hay. *Kafkas. Univ. Vet. Fak Derg* 20: 445-449. DOI: 10.9775/kvfd.2013.10383
- Kumar, R and S. Vaithyanathan (1990). Occurrence, nutritional significance and effect on animal productivity of tannins in tree leaves. *Anim.*

- Feed Sci. Technol. 30: 21-38. [https://doi.org/10.1016/0377-8401\(90\)90049-E](https://doi.org/10.1016/0377-8401(90)90049-E)
- Le Houérou, H.N. (1989). An assessment of the economic feasibility of fodder shrubs plantations (with particular reference to Africa). In: McKell CM (ed) *The Biology and Utilization of Shrubs*. Academic Press, London, pp 603-629
- Le Houérou, H.N. (2001a). Unconventionnal forage legumes for the rehabilitation of arid and semi-arid lands in the world isoclimatic mediterranean zones. *Arid. Land Res. Manag.* 15 (3):31. <http://dx.doi.org/10.1080/15324980152119766>
- Le Houérou, H.N. (2001b). Biogeography of the Arid Steppeland North of the Sahara. *J. Arid Environ.* 48 (2):103-128. <https://doi.org/10.1006/jare.2000.0679>
- Lonho, C. (2012). Chemical characterization and *in vitro* biological activity of four tropical legumes, *Stylobium aterrimum* L., *Stylobium deeringianum*, *Leucaena leucocephala*, and *Mimosa caesalpiniaefolia*, as compared with a tropical grass, *Cynodon* spp. for the use in ruminant diets. *Czech J. Anim. Sci.* 57(6): 255-264.
- López, S. (2005). *In vitro* and *in situ* techniques for estimating digestibility. In: DIJKSTRA J, FORBES JM, FRANCE J (ed) *Quantitative aspects of ruminant digestion and metabolism*. CABI Publishing, London, pp 87-121.
- Makkar, H.P.S., M. Blummel and K. Becker (1995) Formation of complexes between polyvinyl pyrrolidones or polyethylene glycols and their implication in gas production and true digestibility *in vitro* techniques. *Brit J Nutr.* 73(6): 897-913. doi: 10.1079/bjn19950095.
- MapInfo Professional 8.0. MapInfo Corporation
- McSweeney, C.S., B. Palmer, D.M. McNeill and D.O. Krause (2001). Microbial interactions with tannins: nutritional consequences for ruminants. *Anim. Feed Sci. Technol.* 91:83-93. [https://doi.org/10.1016/S0377-8401\(01\)00232-2](https://doi.org/10.1016/S0377-8401(01)00232-2)
- Medjekal, S., M. Ghadbane, H. Bousseboua (2015). Chemical Composition and *in vitro* Gas Production of Three Local Poaceae in El Djelfa's Region, North-Central Algeria. *World Appl. Sci. J.* 33 (2): 271-277. DOI: 10.5829/idosi.wasj.2015.33.02.14571
- Medjekal, S., M. Ghadbane, S. Boufennara, L. Bebderradji, R. Bodas, H. Bousseboua and S. Lopez (2020). Chemical Composition, *In Situ* Degradation, And Fermentation Kinetics Of Some Browse Plant Species Collected From Algerian Arid And Semi-Arid Areas. *J. Rangel. Sci.* 10(2): 188-203.
- Menke, K.H and H. Steingass (1988). Estimation of the energetic feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid. *Anim. Res. Dev.* 28: 7-55.
- Menke, K.H., L. Raab, A. Salewski, H. Steingass, D. Fritz and W. Schneider (1979). The estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor *in vitro*. *J. Agric. Sci. Camb.* 93 (1): 217-222. doi:10.1017/S0021859600086305
- Mohamed-Cherif, A., K. Miroud, K. Benfodil, S. Ansel, D. Khelef, R. Kaidi and K. Ait-Oudhia (2019). Cross-Sectional Survey on Toxoplasma gondii Infection in Cattle, Sheep, and Goats in Algeria: Seroprevalence and Risk Factors. *Vet. Sci.* 6: 63. <https://doi.org/10.3390/vetsci6030063>
- Nedjimi, B., B. Beladel and B. Guit (2012). Biodiversity of Halophytic Vegetation in Chott Zehrez Lake of Djelfa (Algeria). *Am. J. Plant Sci.* 3: 1527-1534. doi: 10.4236/ajps.2012.311184.
- Nedjraoui D (1981) Evolution des éléments biogènes et valeurs nutritives dans les principaux faciès de végétation des Hautes Plaines steppiques de la wilaya de Saida. Thèse de Doctorat USTHB Alger
- Origin (Pro) (Version 2008). OriginLab Corporation, Northampton, MA, USA
- Ørskov, E.R and I. McDonald (1979). The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J. Agric. Sci.* 92: 449-453. doi:10.1017/S0021859600063048
- Pandey, V.C and D.P. Singh (2020). *Phytoremediation Potential of Perennial Grasses*. Elsevier Inc. <https://doi.org/10.1016/C2018-0-02475-5>
- Rubanza, C.D.K., M.N. Shem, R. Otsyina, S.S. Bakengesa, T. Ichinohe and T. Fujihara (2005). Polyphenolics and tannins effect on *in vitro* digestibility of selected Acacia species leaves. *Anim. Feed Sci. Technol.* 119: 129-142. <https://doi.org/10.1016/j.anifeedsci.2004.12.004>
- SAS (2000). *SAS/STAT® User's Guide*, 8.1. 4th Edition. SAS Institute Inc. Cary NC
- Selzer, K., A. Hassen, A.M. Akanmu and A.Z.M. Salem (2021). Digestibility and rumen fermentation of a high forage diet pre-treated with a mixture of cellulase and xylanase enzymes. *S. Afr. J. Anim. Sci.* 51 (3):399-406. DOI: 10.4314/sajas.v51i3.14
- Singh, K., A. Awasthi, S.K. Sharma, S. Singh S.K. Tewari (2018). Biomass production from neglected and underutilized tall perennial grasses on marginal lands in India: a brief review. *Energy Ecol.* 3 (4): 207-215. <https://doi.org/10.1007/s40974-018-0094-y>

- Steel, R.G.D and J.H. Torrie (1980). Principles and Procedures of Statistics. McGraw-Hill, New York
- Tefera, S., V. Mlambo, B.J. Dlamini, A.M. Dlamini, K.D.N. Koralagama, F.L. Mould (2009). Chemical composition and *in vitro* ruminal fermentation of selected grasses in the semiarid savannas of Swaziland. Afr J Range Forage Sci . 26: (1) 9-17. <https://doi.org/10.2989/AJRF.2009.26.1.2.697>
- Rittner, U and J.D. Reed (1992). Phenolics and *in vitro* degradability of protein and fibre in West African browse. J. Sci. Food Agric. 58: 21-28. <https://doi.org/10.1002/jsfa.2740580105>
- Van Soest, P.J., R.H. Wine and L.A. Moore (1966). Estimation of the true digestibility of forages by the *in vitro* digestion of cell walls. In: Proceedings of the 10th International Grassland Congress, Helsinki, Finland, 10: 438-441.
- Waghorn, G.C. (1990). Effect of condensed tannin on protein digestion and nutritive value of fresh herbage. Proceedings of the Australian Society of Animal Production. 18: 412-415.
- Walker, D.J., S. Lutts, M. Sánchez-García and E. Correal (2014). *Atriplex halimus* L.: Its biology and uses. J Arid Environ. 100-101: 111:121. <https://doi.org/10.1016/j.jaridenv.2013.09.004>
- Williams, B.A. (2000). Cumulative gas production techniques for forage evaluation. In: Givens DI, Owen E, Axford RFE, Omed HM (ed) Forage Evaluation in Ruminant Nutrition, CABI Publishing, Wallingford United Kingdom, pp 189-213.
- Wilson, J.R. (1994). Cell wall characteristics in relation to forage digestion by ruminants. J. Agric. Sci. 122: 173-182. doi:10.1017/S0021859600087347