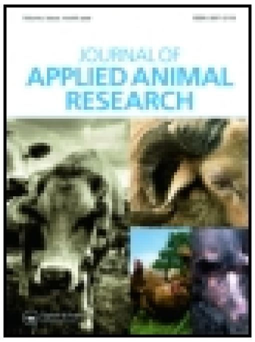

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Journal of Applied Animal Research

ISSN: 0971-2119 (Print) 0974-1844 (Online) Journal homepage: http://www.tandfonline.com/loi/taar20

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To cite this article: Héctor G. Gámez Vázquez, Jorge Urrutia Morales, César A. Rosales Nieto, César A. Meza-Herrera, Francisco G. Echavarría Chaires & Sergio Beltrán López (2017): Tillandsia recurvata and its chemical value as an alternative use for feeding ruminants in northern Mexico, Journal of Applied Animal Research, DOI: 10.1080/09712119.2017.1299013

To link to this article: http://dx.doi.org/10.1080/09712119.2017.1299013

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Published online: 14 Mar 2017.

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JOURNAL OF APPLIED ANIMAL RESEARCH, 2017
http://dx.doi.org/10.1080/09712119.2017.1299013

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Tillandsia recurvata and its chemical value as an alternative use for feeding ruminants in northern Mexico

Héctor G. Gámez Vázquez[a], Jorge Urrutia Morales[a], César A. Rosales Nieto[a], César A. Meza-Herrera[b], Francisco G. Echavarría Chaires[c] and Sergio Beltrán López[a]

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ABSTRACT

Tillandsia recurvata (Linnaeus) Linnaeus is an epiphyte that causes damage or death in trees. It is possible that the ruminant animals under extensive conditions can contribute to its control. The aim of the study was to determine the chemical and mineral value of *Tillandsia recurvata* (TR). An experiment was conducted at three different ecological environments during the four different seasons of the year in San Luis Potosi, Mexico. In each ecological environment, four samples of TR grown in mesquite trees (*Prosopis spp.*) were taken at four different season of the year to determine chemical content. Additionally, one more sample was taken to determine mineral content. Both the ecological environment and the season of the year affected ($P<.001$) the chemical and mineral content. However, according to the analyses, some mineral levels seem to be high and might compromise the health and consequently the animal production. In conclusion, TR has nutritional and mineral characteristics to be considered as a potential food source for ruminants at any time of the year. However, further research is needed to elucidate if TR can be included in the diet of ruminants in northern Mexico without compromising the health and the production.

ARTICLE HISTORY
Received 25 February 2016
Accepted 17 February 2017

KEYWORDS
Tillandsia recurvata (Linnaeus) Linnaeus; chemical content; mineral content; alternative food; ruminants

Introduction

Mesquite (*Prosopis* spp.) is a deciduous thorny tree/bush located in the arid and semiarid regions of the Americas, but its presence is more concentrated in North America (especially in Texas and throughout Mexico) and South America (Argentina – Paraguay – Chile; Rzedowski 1988). Mesquite is characterized for being an extremely hard and drought tolerant plant; additionally, it is excellent in reducing soil erosion, fix nitrogen and improves soil fertility (Tiedemann & Klemmedson 1973; Virginia 1986; Vásquez-Méndez et al. 2010). In addition, while its wood can be used to produce firewood and charcoal, mesquite also produces a fruit (pod), which is used as livestock feed (Mellado et al. 2003; Andrade-Montemayor et al. 2011). These characteristics make mesquite a very important natural resource, and mesquite is therefore considered as one of the most ecologically and economically important trees in the semiarid region of northern Mexico (Villanueva-Díaz & Hernández-Reyna 2005).

However, there are so many factors that threaten the biodiversity of mesquite; one of them is the epiphyte *Tillandsia recurvata* (Linnaeus) Linnaeus. The genus *Tillandsia* belongs to the family of the Bromeliaceae and is distributed from the southern in the United States to Patagonia in Argentina (Claver et al. 1983; Caldiz et al. 1993). *T. recurvata* is considered as an autonomous self-pollination plant that produces a great number of seeds (about 50 seeds in every capsule in a tassel; Flores-Palacios et al. 2015). Moreover, *T. recurvata* has the ability to attach on the surface of trunks and branches of various tree species (Benzing & Davidson 1979; Vergara-Torres et al. 2010; Flores-Palacios et al. 2014, 2015); however, its flowers are minimally consumed by florivory animals (Orozco-Ibarrola et al. 2015). Therefore, this epiphyte is able to spread easily in large areas. In addition, these epiphytes do not require the nutritional support of their host. Under severe invasion scenarios of these epiphytes on a tree, they can cause abscission of leaves, reduced growth and, eventually, partial or complete death of the host (Callaway et al. 2002; Flores-Palacios et al. 2014; Soria et al. 2014). This is because the epiphyte competes for sunlight with its hosts; therefore, it prevents photosynthesis in the host (Claver et al. 1983; Soria et al. 2014). Despite the serious problem caused by this invasive plant, little efforts have been made to try to control it.

Additionally, in arid and semiarid regions of northern Mexico, seasonal drought causes food shortage in the rangelands for long periods, causing a recurrent state of under-nutrition in animals (Echavarría et al. 2006). When nutritional requirements are not met, the animals start to use their own body reserves which adversely affects live weight and body condition score, thus affecting negatively their reproductive and productive efficiency (Rosales Nieto et al. 2011). Additionally,

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in these regions when forage availability is scarce, especially during the dry season, goats and other ruminants consume *T. recurvata* (Flores-Flores et al. 2009; García et al. 2016). Thus, this epiphyte could be used as a source of complementary food for livestock in order to mitigate the damage caused by long periods of sub-nutrition. Moreover, we can assume that a high consumption of *T. recurvata* could contribute significantly to its control, especially in areas where high invasion of this plant has become a serious forest health problem. However, available information about the chemical value and its possible variation according to both ecological environment and season of this epiphyte is limited. Therefore, the objective of this study was to determine the content of nutrients and minerals of *T. recurvata* and assess whether it is affected by the ecological environment and the season of the year.

Material and methods

Ecological environment

The study was conducted in three ecological environments from the state of San Luis Potosi in northern Mexico (Figure 1). The three ecological environments were characterized by their dominant forest vegetation of deciduous thorny mesquite (*Prosopis*) located in the semi-temperate, dry and dry-warm climates (García 1973). Selection of each sampling site was made based on a site with low disturbance degree; the density of *Prosopis* trees per ha (over 60 trees) and with more than 20% of those trees infested with *T. recurvata*.

Semi-temperate climate: Cedral town is located in the north highlands of San Luis Potosi in northern Mexico (23° 48′ 35.2″ N, 100° 42′ 57″ W at 1700 m a.s.l.). In this location, the soil is sedimentary, average precipitation is about 414 mm per year and the annual average temperature is 17°C (minimal average of 7.7°C and maximum average of 26.2°C). The rainy season, with more than 20 mm per month, is from April to October (Medina et al. 2005). In this site, the mesquite density was 71 trees per ha. The infestation of *T. recurvata* in the threes was above 75%. In addition, the vegetation available was constituted by *Atriplex canescens*, *Larrea tridentata*, *Castela texana*, *Opuntia leptocaulis, Bouteloua chasei*, *Sporobolus airoides and Bouteloua dactyloides*.

Dry-temperate climate: Soledad de Graciano Sanchez town is located in the central highlands of San Luis Potosi in northern Mexico (22° 14′ 03″ N, 100° 53′ 11″ W at 1850 m a.s.l.). In this location, the soil is alluvial without rocks, average precipitation is about 360 mm per year and the annual average temperature is 17.1°C (minimal average of 10.2°C and maximum average of 23.8°C). The rainy season, with more than 20 mm per month, is from May to October (Medina et al. 2005). In this site, the mesquite density was 112 trees per ha. The infestation of *T. recurvata* in the threes was above 50%. In addition, the vegetation available was constituted by *Castela texana, Larrea tridentata, Condalia mexicana, Partenium incanum, Bouteloua gracilis, Bouteloua curtipendula, Sporobolus airoides and Bouteloua radicosa*.

Dry semi-warm climate: Ciudad Fernandez town is located in the medium zone (south-central) of San Luis Potosi in northern Mexico (22° 03′ 24.5″ N, 100° 01′ 23.6″ W at 1014 m a.s.l.). In this location, the soil is clay sandy loam, average precipitation is about 655 mm per year and the annual average temperature is 21.9°C (minimal of 14.5°C and maximum of 45.1°C). The rain season, with more than 20 mm per month, is from June to December (Medina et al. 2005). In this site, the mesquite density was 154 trees per ha. The infestation of *T. recurvata* in the threes was above 25%. In addition, the vegetation available was constituted by *Celtis pallida, Bouteloua curtipendula, Bouteloua radicosa, Bouteloua dactyloides and Setaria* spp.

Sampling

In each ecological environmental site, four samples of *T. recurvata* were taken in each season of the year (winter [December], spring [March], summer [June] and autumn [September]). Samples were taken from the branches of four mesquite trees with high grade of infestation of *T. recurvata* (more than 75%). The grade of infestation was determined by visual assessment by three evaluators. For this, each tree was divided into three horizontally imaginary sections. Each section was evaluated on a scale of 0 to 4, whose values correspond to 0 (0), <25 (1), 26–50 (2), 51–75 (3) and >75% (4) coverage. Then, the values obtained by the evaluators were averaged. Each sample was collected manually and contained approximately 1 kg of tassels of *T. recurvata*. The samples were stored in paper bags and each bag was properly labelled according to date and location. In addition, one more sample was taken in spring from each ecological environment following the previous protocol and analysed for minerals.

The samples for chemical content were taken to the lab (GRO LAB MÉXICO S.A de C.V) to determine the content of *ash, fat, dry matter, protein* (crude protein, soluble protein), *fibre* (acid detergent fibre, neutral detergent fibre, lignin), *carbohydrates* (non-structural carbohydrates), *total digestible nutrients* and *energy* (maintenance energy) in *T. recurvata*. Samples were analysed through a computer-based NIRS method (NIRS 5000, FOSS®). The NIRS 5000 was calibrated with the following proceeding: (a) samples selected at random, (b) analyses by primary methods, (c) reading of spectra from the same samples in the equipment NIRS, (d) adjust of curves and (e) validation of curves (comparing the results obtained by methods (b) and (c)).

The sample for minerals was dried at the research station in San Luis Potosi (22° 14′ 03″ N, 100° 53′ 11″ O and 1835 masl) at 65°C for 48 h. Then, the sample was taken to the lab of soil fertility and vegetal nutrition from the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP) in Celaya, Guanajuato, Mexico, to determine the mineral content in *T. recurvata*. The contents of calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium and zinc were determined by the atomic absorption spectroscopy method.

Satistical analyses

Data analyses were aided by the JMP Star Statistics version 4.0.3 Academic (SAS Institute 2000). Data of chemical characteristics and mineral content were analysed using analysis of variance. Fixed effects in the model were ecological environment and season of the year.

Differences between ecological environment and season of the year were analysed using the Tukey test. All 2-way interactions among the fixed effects were included in each model

Figure 1. Study sites (solid stars) in San Luis Potosí on the southern Chihuahuan desert. Solid points are the main towns in the area.

and non-significant ($P > .05$) interactions were removed from the final model.

Results

Chemical characteristics in T. recurvata

The average values of the chemical characteristics of *T. recurvata* evaluated from three different ecological environments at four different seasons of the year are presented in Table 1. In general, the percentage of dry matter was 53 ± 10% and the samples from the semi-temperate climate had the highest percentage, independently of the season of the year (Table 1). The average percentage of crude protein was 6.1 ± 0.8% and it varied among ecological environments and season of the year (Table 1). The average percentage of acid detergent fibre was 44 ± 3%, for neutral detergent fibre was 74 ± 2% and for lignin was 11 ± 1%. The fibre characteristics of *T. recurvata* varied among ecological environments and seasons of the year (Table 1). The average content of maintenance energy was 0.58 ± 0.14 Mcal and the ecological environment of Cd. Fernandez had the highest content (Table 1). The average percentage of non-structural carbohydrates was 14 ± 1% and varied among ecological environments and seasons of the year (Table 1). The average percentage of total digestible nutrients was 43 ± 3% and the ecological environment of Cd. Fernandez had the highest content (Table 1). The average percentage of fat and ashes was 1.7 ± 0.5% and 11 ± 4%, respectively, and both varied among ecological environments and seasons of the year (Table 1).

The contents of the chemical characteristics evaluated were influenced by the ecological environment assessed ($P < .05$ to $P < .001$; Table 2). The season of the year influenced almost all the chemical characteristics evaluated ($P < 0.5$ to $P < .001$; Table 2). The content of ashes had a tendency to be affected by the season of the year ($P = .07$; Table 2); but the percentage of non-structural carbohydrates was not influenced by the season of the year ($P > .05$; Table 2).

Most of the interactions for the chemical characteristic between the ecological environment and season of the year were not significant ($P > .05$); except for crude protein, lignin and total digestible nutrients ($P < .05$) and soluble protein ($P < .001$; Table 2).

Mineral content in T. recurvata

The mineral content in *T. recurvata* is presented in Table 3. The ecological environment influenced the content of calcium, iron, manganese, magnesium ($P < .001$), copper ($P < .01$), potassium and zinc ($P < .05$); but not the content of phosphorus and sodium ($P > .05$).

Table 1. Chemical content in *T. recurvata* from three different ecological environments (semi-temperate climate, dry-temperate climate and dry semi-warm climate) from San Luis Potosí in northern México at four different seasons of the year (winter, spring, summer and fall).

Variable	Ecological environment	Season			
		Winter	Spring	Summer	Fall
Dry matter (%)	Semi-temperate climate	58 ± 9	67 ± 6.8	61 ± 13.5	58 ± 4
	Dry-temperate climate	50 ± 3	51 ± 4	47 ± 8	42 ± 6
	Dry semi-warm climate	54 ± 10	57 ± 7.5	56 ± 11	38 ± 4
Crude protein (%)	Semi-temperate climate	6.1 ± 0.4	6.9 ± 0.6	6.9 ± 0.7	6.6 ± 0.4
	Dry-temperate climate	5.4 ± 0.2	6.1 ± 0.5	4.7 ± 0.4	6.6 ± 0.8
	Dry semi-warm climate	6 ± 0.3	6.2 ± 0.3	5.3 ± 0.6	5.9 ± 0.6
Soluble protein (%)	Semi-temperate climate	44 ± 1.5	34 ± 0.8	39 ± 2.5	43 ± 6
	Dry-temperate climate	53 ± 5	53 ± 6	50 ± 3	43 ± 3
	Dry semi-warm climate	44 ± 1	44 ± 2	46.5 ± 4.5	42 ± 2.5
Acid detergent fibre (%)	Semi-temperate climate	43.5 ± 0.5	42 ± 0.5	42.5 ± 0.3	44 ± 0.5
	Dry-temperate climate	47.5 ± 1	43.6 ± 0.4	45.5 ± 0.4	47.6 ± 1.5
	Dry semi-warm climate	47.5 ± 6	41.5 ± 0.6	44 ± 1	44 ± 0.6
Neutral detergent fibre (%)	Semi-temperate climate	72.2 ± 0.7	70.2 ± 1.2	70.2 ± 2.2	72.3 ± 1.7
	Dry-temperate climate	75.7 ± 0.5	75 ± 1	76 ± 0.6	76.1 ± 0.7
	Dry semi-warm climate	75.5 ± 0.9	74 ± 1	77 ± 0.8	76 ± 1
Lignin (%)	Semi-temperate climate	12.1 ± 0.3	11.4 ± 0.7	9.2 ± 1.1	11 ± 0.8
	Dry-temperate climate	12 ± 0.1	9.7 ± 0.4	9.2 ± 0.3	10.7 ± 0.6
	Dry semi-warm climate	14 ± 1.4	10.4 ± 0.8	10.4 ± 1	10.6 ± 0.7
Maintenance energy (Mcal)	Semi-temperate climate	0.5 ± 0.08	0.49 ± 0.09	0.53 ± 0.09	0.41 ± 0.11
	Dry-temperate climate	0.45 ± 0.04	0.64 ± 0.05	0.62 ± 0.02	0.51 ± 0.12
	Dry semi-warm climate	0.58 ± 0.07	0.78 ± 0.07	0.73 ± 0.16	0.77 ± 0.7
Non-structural carbohydrates (%)	Semi-temperate climate	14.9 ± 0.6	14.1 ± 0.7	13 ± 0.6	12.1 ± 1.1
	Dry-temperate climate	14.4 ± 0.4	13.7 ± 0.7	13.7 ± 1	11.9 ± 1.2
	Dry semi-warm climate	14.2 ± 0.6	15.3 ± 0.9	13.4 ± 1.1	13.2 ± 0.6
Total digestible nutrients (%)	Semi-temperate climate	41 ± 2	40.7 ± 2	41.4 ± 2.1	38.9 ± 2.5
	Dry-temperate climate	39.9 ± 0.9	44 ± 1.3	44 ± 0.3	41.3 ± 2.8
	Dry semi-warm climate	42.8 ± 1.3	47.3 ± 1.5	46.3 ± 1.4	47.3 ± 1.7
Fat (%)	Semi-temperate climate	1.43 ± 0.06	1.45 ± 0.17	1.46 ± 0.12	1.41 ± 0.6
	Dry-temperate climate	1.42 ± 0.09	1.57 ± 0.1	1.63 ± 0.10	2.1 ± 0.8
	Dry semi-warm climate	1.55 ± 0.15	1.67 ± 0.07	1.62 ± 0.2	2.6 ± 0.7
Ashes (%)	Semi-temperate climate	12 ± 3	13.3 ± 1.7	16.2 ± 2.8	16.1 ± 3.4
	Dry-temperate climate	13 ± 1	12 ± 1.3	12.6 ± 0.2	14 ± 3
	Dry semi-warm climate	5.7 ± 0.3	6.5 ± 0.7	6.5 ± 0.3	6.5 ± 0.7

Discussion

Our results indicate that *T. recurvata* contains moderate levels of dry matter and fibre; but the protein content is low. Moreover, *T. recurvata* contains appropriate levels of manganese and zinc for ruminant animals according to the NRC (Nutritional Research Council 2007). The contents of iron (0.014 mg/kg), calcium (1.9 g/d) and magnesium (0.7 g/d) are above the requirements; however, potassium (5.6 g/d), copper (8 mg/kg DM), phosphorus (1.4 g/d) and sodium (0.75 g/d) are below (NRC 2007). In addition, we observed that the chemical content was influenced by the ecological environment and the season of the year and the mineral content was influenced by the ecological environment. Nevertheless, *T. recurvata* may be considered as an alternative food for nutrition for ruminants in northern Mexico when the vegetation available is scarce. However, further experiments are required to determine whether the consumption of *T. recurvata* by animals may cause side effects, which could compromise their productivity.

The dry matter content in *T. recurvata* reported in this experiment agrees with previous reports of fodder from trees and shrubs (Sosa et al. 2004). The variation in content of dry matter observed in this experiment could be due to the climatic conditions of each ecological environment (humidity conditions) where the experiment was carried out (Salcedo-Pérez et al. 2007). The dry matter content in the feed could be an

Table 2. Relationship between ecological environment (semi-temperate climate, dry-temperate climate and dry semi-warm climate) and season of the year (winter, spring, summer and fall) and their interaction for the chemical characteristics of *T. recurvata* from San Luis Potosí in northern México.

Variable	$P > f$		
	Ecological environment	Season	Interaction
Dry matter (%)	***	***	NS
Crude protein (%)	***	*	*
Soluble protein (%)	***	**	***
Acid detergent fibre (%)	***	***	NS
Neutral detergent fibre (%)	***	***	NS
Lignin (%)	**	***	*
Maintenance energy (Mcal)	***	***	*
Non-structural carbohydrates (%)	NS	***	NS
Total digestible nutrients (%)	***	***	*
Fat (%)	*	**	NS
Ashes (%)	***	0.07	NS

P values: $*P \leq .05$; $**P \leq .01$; $***P \leq .001$; NS: $P > .05$.

Table 3. Mineral content in *T. recurvata* from three different ecological environments from San Luis Potosí in northern México.

	Semi-temperate climate	Dry semi-warm climate	Dry-temperate climate	$P > f$
Phosphorus (%)	0.04 ± 0.005	0.07 ± 0.039	0.08 ± 0.073	NS
Calcium (%)	1.21 ± 0.15	0.55 ± 0.088	0.54 ± 0.075	***
Magnesium (%)	0.13 ± 0.016	0.18 ± 0.007	0.11 ± 0.019	***
Potassium (%)	0.57 ± 0.087	0.44 ± 0.074	0.57 ± 0.097	*
Sodium (%)	0.04 ± 0.033	0.03 ± 0	0.02 ± 0.004	NS
Copper (ppm)	5.72 ± 1.74	3.17 ± 0.42	5.90 ± 0.957	**
Zinc (ppm)	33.98 ± 10.18	30.54 ± 2.01	29.43 ± 2.19	*
Manganese (ppm)	63.74 ± 8.67	33.03 ± 2.54	73.12 ± 11.53	***
Iron (ppm)	1768.69 ± 273.8	840.89 ± 79.6	1505.54 ± 298.9	***

P values: $*P \leq .05$; $**P \leq .01$; $***P \leq .001$; NS: $P > .05$.

indication of energy intake, because of the relationship with the non-structural carbohydrates and the degree of degradability of food in the rumen (Marichal et al. 2007). Thus, the digestibility of the dry matter is related to the content of cell walls, where the digestibility is lower if the lignification of the cell walls is increased (Ahn et al. 1989). The fibre content observed in *T. recurvata* was relatively high (>70%); but the characteristics of fibre (neutral and acid detergent fibre and lignin) were affected by the ecological environment and the season of the year. The total fibre content is important in defining the overall maturity of the forage at harvesting, therefore affecting its digestibility. Sosa et al. (2004) reported species of trees and shrubs with high concentrations of neutral detergent fibre and over 50% digestibility. Hence, according to our results, the digestibility of *T. recurvata* could be affected by the high-fibre content; yet the content of acid and neutral detergent fibre was not similar throughout the year. Therefore, we hypothesize that due to the variability in fibre characteristics and the dry matter content, *T. recurvata* may be highly digestible and can be used for periods during the year.

The crude protein content in *T. recurvata* was lower compared to fodder of trees and shrubs (>10%; Guerrero et al. 2010). However, it was similar to or higher in comparison to other forages commonly used in the semiarid region of Mexico, such as the prickly pear (1.9–4.5%; Pinos-Rodriguez et al. 2006), maguey (3.7–4.2%; Pinos-Rodriguez et al. 2008) or stover of corn (6.2%; Yescas-Yescas et al. 2004). Forage species with less than 8.0% of crude protein are considered deficient because they do not provide the minimum required of ammonium by ruminant animals (Norton 1994). Nonetheless, *T. recurvata*, for its chemical content, can be considered as an alternative food for animals in northern Mexico; however, producers should consider including an additional source of protein.

Our results suggest that the chemical content of *T. recurvata* depends on the ecological environment and season of the year, because the content of dry matter and crude protein tended to be higher in conditions of semi-dry-temperate environment. We have reasoned three probable hypotheses for this result.

Firstly, it is probable that *T. recurvata* adapts better to this type of climate. *T. recurvata* is an atmospheric epiphyte, which means that takes its nutriment from the atmosphere rather than its host; additionally *T. recurvata* does not need soil for its development and can survive and grow attached to both abiotic structures (electricity wire) and biotic structures (trees and shrubs; Montaña et al. 1997; Bernal et al. 2005; Abril & Bucher 2009; Vergara-Torres et al. 2010).

Secondly, pollutant emission factors might have contributed to the variability of chemical content in *T. recurvata*. The vegetation cover is low in the ecological environment of semi-temperate climate followed by the dry-temperate climate; but the vegetation cover in the dry semi-warm climate is high. The last depicts a negative relationship between vegetation cover and erosion. Perez et al. (2012) determined that the lack of vegetation cover on soil contributes to as much as 68% of erosion. Therefore, when the vegetation cover is scarce, the pollutant emission might have increased in that particular ecological environment; thus *T. recurvata* catches the nutrients of the soil that were detached by the pollutant factors. This is aligned with the fact that *T. recurvata* can adjust its growth rate in response to different conditions, showing a higher growth rate when the conditions are favourable (Laube & Zotz 2003), which appears to be associated with the presence of humidity and availability of sunlight (Lange and Medina 1979; Laube & Zotz 2003; Flores-Palacios et al. 2015).

Thirdly, the growth of *T. recurvata* could affect its chemical content. The growth of *T. recurvata* occurs from May to June (Sánchez 1980). Moreover, from November to December, *T. recurvata* has fully developed fruits (García-Franco 1996). Consequently, it is probable that the protein content would be higher in summer rather than late autumn and winter; while the fibre content would depict an inverse trend. In addition, plants of this species start flowering after five years and it is probable that the epiphytes were harvested at different ages; thus, it is quite probable that their chemical content varied. All these hypotheses helped us to explain the variation observed in the results obtained and the lack of tendency related to the season of the year.

Conclusions

Our results suggest that *T. recurvata* contained nutrients and minerals that make it suitable to be used as an alternative food at any time of the year for animals in northern Mexico. In addition, the use of *T. recurvata* in animal feeding could contribute to its control, which will help to decrease the damages caused to the flora of trees from different ecological environments. Further research is needed to elucidate the effect of feeding animals at different doses or concentrations of *T. recurvata* in diet on the health of the animals. The last is of paramount importance to promote sustainability of small ruminant production systems under marginal conditions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Consejo Nacional de Ciencia y Tecnología [grant number: CONAFOR-2006-41816].

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