

Evaluation of eleven Mexican cultivars of prickly pear cactus trees for possibly utilization as animal feed: in vitro gas production

Paulina Vazquez-Mendoza, Luis A. Miranda-Romero, Gilberto Aranda-Osorio, Juan A. Burgueño-Ferreira & Abdelfattah Z. M. Salem

Agroforestry Systems

An International Journal incorporating
Agroforestry Forum

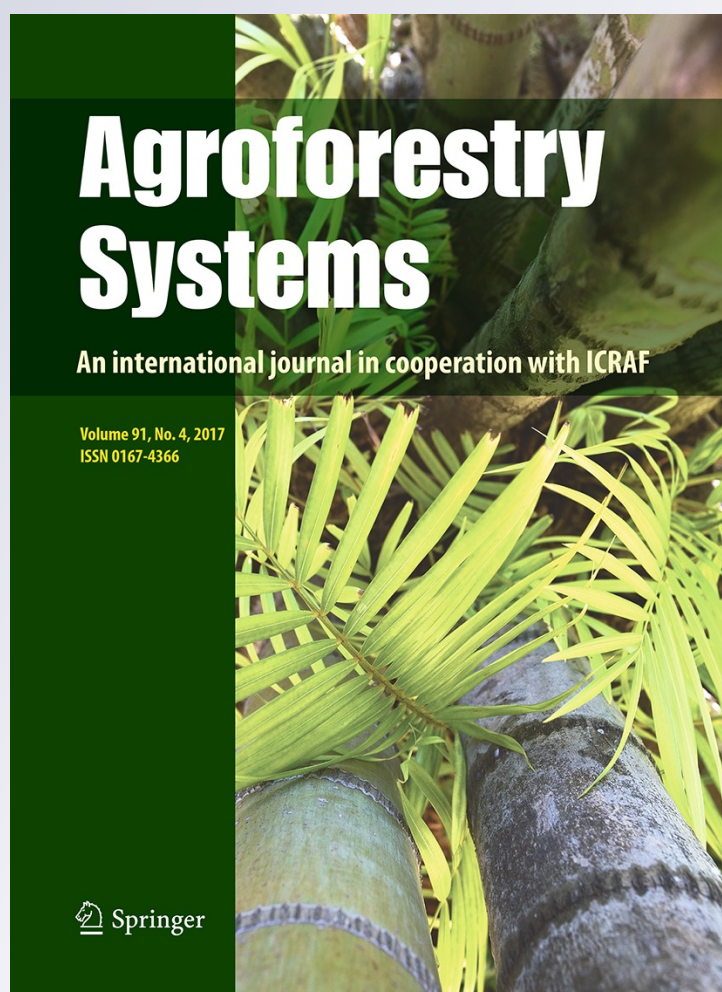
ISSN 0167-4366

Volume 91

Number 4

Agroforest Syst (2017) 91:749-756

DOI 10.1007/s10457-016-9947-6



Your article is protected by copyright and all rights are held exclusively by Springer Science +Business Media Dordrecht. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com".

Evaluation of eleven Mexican cultivars of prickly pear cactus trees for possibly utilization as animal feed: in vitro gas production

Paulina Vazquez-Mendoza · Luis A. Miranda-Romero ·
Gilberto Aranda-Osorio · Juan A. Burgueño-Ferreira ·
Abdelfattah Z. M. Salem

Received: 29 June 2015 / Accepted: 19 April 2016 / Published online: 25 April 2016
© Springer Science+Business Media Dordrecht 2016

Abstract In production systems of prickly pear fruit and prickly pear cactus, significant amounts of pruned material, which could be used as an ingredient in animal feeding, is generated. The aim of this study was to measure the nutrient content, fermentation kinetics and in vitro digestibility of eleven cultivars of cladodes of prickly pear cactus. The fermentation was measured indirectly using the gas production technique, where 500 mg of DM substrate (prickly pear cactus cultivars) were placed in amber glass flasks of 125 mL with 90 mL of ruminal inoculum under a continuous flow of CO₂. Flasks were hermetically wrapped up with a rubber stopper and a metal ring, and were placed in a water bath at 39 °C. The fermentation gas pressure was measured using a monometer at 0, 2, 4, 6, 8, 12, 16, 20, 24, 32, 38, 50 and 72 h incubation. Results show that the chemical composition ranged between (g kg⁻¹ DM): 64 and

160 g kg⁻¹ dry matter (DM), 137–293 g kg⁻¹ DM ash, 52–101 g kg⁻¹ DM crude protein, 3–22 g kg⁻¹ DM ether extract, 251–393 neutral detergent fiber and 132–192 acid detergent fiber. The gas volume was different ($p < 0.05$) among cultivars, with the Red Vigor cultivar having the largest volume at 378 mL g⁻¹ DM. The highest volume of gas was produced during the first 24 h in on average 67 % of the total produced. The in vitro DM digestibility displayed values of up to 82 % in the Roja Pelota cultivar. It can be concluded that the cladodes of prickly pear cactus from different cultivars can be used in animal feed for its good rumen fermentation characteristics.

Keywords Fermentation · Gas production · Chemical composition · Prickly pear

P. Vazquez-Mendoza · L. A. Miranda-Romero ·
G. Aranda-Osorio
Posgrado en Producción Animal, Universidad Autónoma
Chapingo, Km. 38.5 Carretera México-Texcoco,
56230 Chapingo, Mexico

J. A. Burgueño-Ferreira
Centro Internacional de Mejoramiento de Maíz y Trigo, El
Batan, 56130 Texcoco, Estado de México, Mexico

A. Z. M. Salem (✉)
Facultad de Medicina Veterinaria y Zootecnia,
Universidad Autónoma del Estado de México, Toluca,
Estado de México, Mexico
e-mail: asalem70@yahoo.com

Introduction

The prickly pear cactus (*Opuntia* spp.) is an endemic cactus of Americas with 258 identified species, a hundred of which are located in Mexico (Rodríguez et al. 2009). This plant grows in water-scarce regions, high temperatures and poor soils (Fuentes-Rodríguez 1997; Luttge 2004; De Waal et al. 2006). In arid areas of northern Mexico, the prickly pear cactus is used for animal feed as a source of fodder, energy and water (Andrade-Montemayor et al. 2011); while in the central region of Mexico it is used in the intensive production of

prickly pear fruit and tender prickly pear cactus for human consumption. In addition, a lesser amount of slightly lignified prickly pear cactus is used as animal fodder (Felker et al. 2006). The prickly pear cactus farming production in Mexico City, the states of Mexico and Puebla represents 37 % of the total Mexican production (SIAP 2010). In these farming systems, trimming of cladodes is a common practice where large quantities of waste are generated, if which are handled correctly can be a source of organic matter, however, without proper management can represents a source of contamination, pests and diseases (CONAZA 1994). Nevertheless, because of its digestible nutrients content, trimming waste of prickly pear cactus can be used in the intensive feeding of ruminants. It has been shown that it is possible to include 17 to 25 % of dried and milled prickly pear cactus forage, totally mixed rations to fatten ovine and achieve a similar growth performance to those viewed with commercial diets, therefore the use of prickly pear cactus is a viable strategy for the producer (Aguilar-Yáñez et al. 2011; Muciño-Castillo et al. 2014). However, the animal response depends more on the nutritional quality of the ingredients in the diet, and the prickly pear cactus nutrient content can vary (Granados and Castañeda 1996).

To date there are no studies of the nutrient content of trimmed cladodes waste and its fermentation by microbial inoculum from the rumen of ovine. Therefore the aim of this study was to measure the nutrient content, fermentation kinetics and in vitro digestibility of cladodes waste from eleven prickly pear cactus cultivars grown in San Sebastian Villanueva, Acatzingo, Puebla, Mexico.

Materials and methods

Vegetal material

During March 2013, eleven cultivars of prickly pear cactus were studied, ten samples of trimmed material between 1 to 3 years to cultivate were randomly taken from producers' plots from the San Sebastian Villanueva, Acatzingo, Puebla, located 19°03'37" North Latitude, 97°42'58" west longitude and 2232 m above sea level, with temperature and annual rainfall of 17.9 °C and 674 mm, and cambisol being the dominant soil type (García 1988).

The used cultivars of prickly pear fruit were: (*Opuntia ficus-indica* cv. Rojo vigor), (*Opuntia*

joconostle), (*Opuntia ficus-indica* cv. Villanueva), (*Opuntia ficus-indica* cv. Sangre de Cristo), (*Opuntia ficus-indica* cv. Burróna), (*Opuntia ficus-indica* cv. Cristalina), (*Opuntia ficus-indica* cv. Roja San Martín), (*Opuntia ficus-indica* cv. Ceniza Roja), (*Opuntia ficus-indica* cv. Roja Pelota) and cultivars for prickly pear cactus were (*Opuntia ficus-indica* cv. Atlixco) and (*Opuntia ficus-indica* cv. Milpa Alta).

Chemical analysis

Fresh cladodes of each prickly pear cactus cultivar were cut into thin slices, dried at 65 °C in a forced air oven until a constant weight was obtained and milled to 1 mm (Thomas Wiley® Mini-Mill, Texcoco, México). A composite sample of each prickly pear cactus was used to measure the content of crude protein (CP), ash (A), ether extract (EE) (AOAC 1990); neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Van Soest et al. 1991). Atomic absorption method was used to detect the contents of Ca, Mg, Na, K, Cu, Fe, Zn and Mn (A Analyst 700, Perkin-Elmer, Texcoco, México. 1996; AOAC 1990), and P by colorimetry (UV/VIS Lambda 2 spectrometer model Perkin Elmer, Texcoco, México; AOAC 1990). The contents of total carbohydrates (TC: Sniffen et al. 1992), Non-fibrous carbohydrates (NFC: NRC 2001) and hemicelluloses (HC) were calculated.

Fermentation and in vitro digestibility

The fermentation was measured indirectly using the gas production technique (Menke and Steingass 1988; Theodorou et al. 1994), where 500 mg of DM substrate (prickly pear cactus cultivars) were placed in 125 mL amber glass flasks with 90 mL of ruminal inoculum under a continuous flow of CO₂. Flasks were hermetically wrapped up with a rubber stopper and a metal ring, and were placed in a water bath at 39 °C. The fermentation gas pressure was measured with a monometer (0–1 kg cm²; METRON® 51100, Texcoco, México) at 0, 2, 4, 6, 8, 12, 16, 20, 24, 32, 38, 50 and 72 h incubation. Measured pressures were converted into volume with the V regression model (mL) = [P (kg cm²) + 0.0495]/0.0185, this model was obtained by measuring the pressure generated by known volumes of gas injected into the flasks under the same handling conditions. The fractional gas volume was calculated (mL g⁻¹ DM) for time intervals of 0 to 8 (Fv₀₋₈), 8 to 24

(Fv₈₋₂₄) and 24 to 50 (Fv₂₄₋₅₀) hours of incubation. The accumulated volume for each measured time was also measured and used to estimate the maximum volume (Mv; mL g⁻¹ DM), the gas production rate (S; mL h⁻¹) and the phase lag (L; h) of gas production, which were adjusted with the logistic model $V_0 = Mv / (1 + e^{(2-4 * S * (TL))})$ (Pitt et al. 1999). The in vitro dry matter digestibility (IVDMD) was calculated by the difference between the weight of the starting matter before and after incubation for 72 h of incubation, and the potential emission rate of fermentation gases (PERFG), was calculated by dividing the maximum volume of gas production from every cultivar divided by its in vitro dry matter digestibility value.

The rumen inoculum was obtained from three ovine with rumen cannula fed with silage and corn stubble (70:30 DM). At the moment of sampling of ruminal fluid, the ovine were fasted for 12 h. Rumen contents were filtered through four layers of gauze and mixed with a mineral solution reduced to a 1: 9 (v/v). The mineral solution contained: K₂HPO₄ (0.45 g L⁻¹), KH₂PO₄ (0.45 g L⁻¹), (NH₄)₂SO₄ (0.45 g L⁻¹), NaCl (0.90 g L⁻¹), MgSO₄ (0.18 g L⁻¹), CaCl₂ (0.12 g L⁻¹), Na₂CO₃ (4 g L⁻¹), the reducing solution contained: NaOH (0.8 ml L⁻¹), Na₂S (0.2 g L⁻¹), L-cysteine (0.2 g L⁻¹) and 1 drop of rezarzurina (Cobos and Yokoyama 1995).

Statistical analysis

It was used a completely randomized design, using the SAS GLM procedure, and the means comparison test was done with LSMEANS, used only for Mv, S, L, Fv₀₋₈, Fv₈₋₂₄, Fv₂₄₋₅₀, IVDMD₇₂ and PERFG variables, when there were differences test Tukey was used.

Results

The nutrient contents of the eleven trimmed cladodes of prickly pear cactus cultivars are shown in Table 1. In general, the cladodes had a low content of DM and a high content of ashes. The prickly pear cactus cladodes are characterized for containing a low amount of CP, the CP in the Roja San Martin, Atlixco and Cristalina cultivars, varied between 90 and 100 g kg⁻¹ DM, the other cultivars had a lower content than between 90 and 60 g kg⁻¹ DM. The EE was lower than 18 g kg⁻¹ DM and NDF was low with a range between 251 to 383 g kg⁻¹ DM; consequently, the ADF was low (<193 g kg⁻¹ DM) for all the cultivars. Due to the low ADF, the hemicellulose represents a high proportion of NDF which varied between 36 to 65 %. The cultivars with the highest proportion of hemicellulose in the NDF were Rojo

Table 1 Chemical composition (g kg⁻¹ DM) of cladodes pruning of cactus cultivars

Cultivars	Component								
	DM g kg ⁻¹ WM	Ash g kg ⁻¹ MS	CP	EE	NDF	ADF	TC	NFC	HC
Roja Vigor	160.00	137.03	86.29	12.80	379.50	161.83	763.88	384.38	217.67
Xoconostle	111.11	224.31	75.61	22.15	393.24	192.15	677.93	284.69	201.09
Villanueva	86.96	237.47	68.08	18.90	312.90	152.99	675.55	362.65	159.91
Sangre de Cristo	113.64	215.9	58.18	8.20	290.08	174.63	717.72	427.64	115.45
Milpa Alta	90.91	229.19	67.21	5.70	299.43	188.97	697.90	398.47	110.46
Burrona	113.64	278.18	52.48	3.00	383.27	133.40	666.34	283.07	249.87
Atlixco	69.44	286.8	96.16	10.95	288.87	178.15	606.09	317.22	110.72
Cristalina	64.81	293.61	89.01	18.60	251.88	155.87	598.78	346.90	96.01
Roja San Martin	75.76	268.05	101.77	11.20	277.36	134.72	618.98	341.62	142.64
Ceniza Roja	125.00	241.21	66.06	8.50	264.62	132.38	684.23	419.61	132.24
Roja Pelota	125.00	251.92	70.98	8.60	285.17	153.82	668.50	383.33	131.35
CV	27.78	17.97	20.82	50.92	16.11	13.46	7.29	13.83	33.09
SD	28.70	43.54	15.74	5.95	50.19	21.53	48.93	49.67	50.17

DM dry matter, CP crude protein, EE ether extract, NDF neutral detergent fiber, ADF acid detergent fiber, TC total carbohydrates, NFC non-fibrous structural carbohydrates, HC hemicellulose, CV coefficient of variation, SD standard deviation, WM wet matter

Table 2 Mineral concentrations (g kg⁻¹ DM) of cladodes of prickly pear cultivars pruning

Cultivars	P g kg ⁻¹ DM	Ca g kg ⁻¹ DM	Mg	K	Na	Cu mg kg ⁻¹ DM	Fe	Zn	Mn
Roja Vigor	1.61	19.53	16.18	29.57	0.25	2.38	91.88	54.01	220.18
Xoconostle	1.06	24.18	14.63	34.61	0.27	4.78	46.27	109.56	144.30
Villanueva	2.48	26.31	10.54	45.18	0.46	2.32	60.15	59.19	128.38
Sangre de Cristo	0.99	33.56	14.60	28.32	0.16	7.11	30.59	65.04	131.08
Milpa Alta	1.14	27.23	16.90	23.29	0.16	14.20	28.65	75.68	65.31
Burrona	1.89	32.29	18.36	18.43	0.41	9.31	75.34	95.06	80.57
Atlixco	1.01	30.74	17.64	32.36	0.22	4.49	58.43	71.88	196.40
Cristalina	2.76	35.43	9.95	43.58	0.25	2.33	60.34	358.14	232.60
Roja San Martín	1.16	31.94	15.18	37.20	0.24	2.46	63.18	20.45	124.09
Ceniza Roja	1.24	40.10	13.24	29.47	0.27	3.59	77.11	329.15	227.14
Roja Pelota	1.27	13.13	8.23	18.20	0.23	4.79	46.36	52.49	145.42
CV	40.66	26.66	23.43	30.19	34.82	70.47	33.31	97.52	37.38
SD	0.61	7.62	3.31	9.41	0.09	3.70	19.33	114.42	57.63

CV coefficient of variation, SD standard deviation

Vigor (57 %) and Burrona (65 %). The total carbohydrates in the cultivars presenting values between 598 and 763 g kg⁻¹ DM, the content of non-fibrous carbohydrates cultivars ranged between 283 and 427 g kg⁻¹ DM and represent a 46 % average from the total carbohydrates.

The variability in the mineral content of cladodes was also wide (Table 2). Among the macrominerals, Ca, K and Mg were those found in greater concentrations; with contents ranging from 11 to 41, 18 to 45 and

18 to 8 g kg⁻¹ DM respectively; the ones with the least amount were P and Na with values from 0.9 to 2 and 0.1 to 0.4 g kg⁻¹ DM. The microminerals with the most cladodes were the Mg with values from 65 to 227, Zn from 20 to 358 and Fe from 28 to 91 mg kg⁻¹ DM, Cu presented low amounts with 2 and 9 mg kg⁻¹ DM.

The values of the variables for the fermentation kinetics of gas production (Mv, Fv₀₋₈, Fv₈₋₂₄, Fv₂₄₋₅₀, S and L), in vitro digestibility and the potential emission rate of gas are shown in Table 3. There were

Table 3 Variables of gas production and fermentation kinetics (Mv, Vf₀₋₈, Vf₈₋₂₄, Vf₂₄₋₅₀, S and L), in vitro digestibility and potential emission rate of fermentation gases in cladodes pruning of cultivars of prickly pear cactus

Cultivars	Mv mL g ⁻¹ DM	Fv ₀₋₈	Fv ₈₋₂₄	Fv ₂₄₋₅₀	S (mL h ⁻¹)	L (h)	IVDMD (%)	PERFG (mL g ⁻¹ DMD)
Roja Vigor	378.33 ^a	132.63 ^{ab}	167.03 ^a	84.91 ^a	0.0400 ^{abc}	2.83 ^a	76.19 ^{bc}	496.99 ^a
Xoconostle	289.90 ^b	102.60 ^{ab}	129.22 ^b	63.93 ^{ab}	0.0406 ^{abc}	2.72 ^a	75.55 ^{bc}	384.08 ^b
Villanueva	305.03 ^b	134.25 ^a	123.02 ^{bc}	59.10 ^b	0.0456 ^a	1.85 ^{abc}	78.46 ^{ab}	388.84 ^b
Sangre de Cristo	266.33 ^b	102.79 ^{ab}	99.66 ^{bcde}	65.49 ^{ab}	0.0353 ^{bc}	0.86 ^{bcd}	72.30 ^{cd}	369.07 ^b
Milpa Alta	244.40 ^b	93.91 ^b	83.09 ^{de}	65.39 ^{ab}	0.0320 ^c	0.28 ^d	69.82 ^d	350.12 ^b
Burrona	254.93 ^b	111.53 ^{ab}	93.96 ^{cde}	55.27 ^b	0.0410 ^{abc}	0.94 ^{bcd}	71.58 ^{cd}	356.32 ^b
Atlixco	241.20 ^b	86.54 ^b	97.29 ^{cde}	59.10 ^b	0.0356 ^{bc}	1.82 ^{abc}	69.76 ^d	347.34 ^b
Cristalina	244.80 ^b	105.49 ^{ab}	90.44 ^{de}	53.60 ^b	0.0383 ^{abc}	0.79 ^{cd}	72.47 ^b	339.44 ^b
Roja San Martín	235.13 ^b	97.12 ^b	98.72 ^{bcde}	45.43 ^b	0.0426 ^{ab}	1.86 ^{abc}	72.94 ^{bcd}	322.04 ^b
Ceniza Roja	248.00 ^b	111.65 ^{ab}	80.91 ^c	56.22 ^b	0.0360 ^{bc}	0.00 ^d	73.69 ^{bcd}	336.70 ^b
Roja Pelota	271.77 ^b	101.92 ^{ab}	112.94 ^{bcd}	61.36 ^b	0.0400 ^{abc}	1.99 ^{ab}	82.78 ^a	328.30 ^b
SEM	14.29	6.38	6.15	4.49	0.0017	0.22	3.21	20.06

Mv maximum volume a 72 h of incubation; Vf₀₋₈, accumulate volume of 0 to 8 h; Fv₈₋₂₄, accumulate volume of 8 to 24 h; Fv₂₄₋₅₀, accumulate volume of 24 to 50 h; S rate of gas production; L time lag; IVDMD in vitro dry matter digestibility; PERFG potential emission rate of fermentation gases; DMD dry matter digested. SEM pooled standard error of the mean; Means in the same column with different letters are different (p < 0.05)

differences among cultivars of ($p < 0.05$). The Rojo Vigor cultivar had the maximum volume of gas production (Mv), higher than ($p < 0.05$; 378 mL g^{-1}), regarding the other ten cultivars, which had an Mv between 235 and 305 mL g^{-1} .

Regarding the volume of gas accumulated in the first eight hours of incubation (Fv_{0-8}) the Milpa Alta, Atlixco and Roja San Martin cultivars produced the least volume ($p < 0.05$) in comparison with the Villanueva Cultivar. The volume of gas between eight and 24 h (Fv_{8-24}), was more diversity, the Ceniza Roja, Cristalina and Milpa Alta cultivars the ones which produced less Fv_{8-24} ($p < 0.05$) regarding: Xoconostle, Villanueva, and Rojo Vigor cultivars. In the volume of gas between 24 to 50 h of incubation, the cultivars of lower Fv_{24-50} ($p < 0.05$) were the Burrona, Atlixco, Cristalina, Rojo San Martin, Ceniza Roja and Roja Pelota cultivars ($61 \text{ mL g}^{-1} \text{ DM}$), in comparison with the Rojo Vigor ($84 \text{ mL g}^{-1} \text{ DM}$). Regarding the gas production rate, the Villanueva cultivar had the highest rate (0.0456 h^{-1} ; $p < 0.05$) of gas production (S) in comparison with Milpa Alta, Sangre de Cristo, Atlixco and Ceniza Roja. The lag phase (L) was short as this was the same to or less than 2.83 h.

Regarding the *in vitro* dry matter digestibility (IVDMD) a variation between 69 and 82 % was observed. The potential emission rate of fermentation gases (mL g^{-1} digested DM), ranged between 322 and $496 \text{ mL g}^{-1} \text{ DM}$, the Roja Vigor cultivar, with the highest emission rate, was 29 % higher than the average of the other cultivars.

Discussion

Chemical composition

The composition of the prickly pear cactus varies in relation to the factors to which it is exposed (Granados and Castañeda 1996), some of them can be the cultivar, ripeness, humidity, composition of nutrients in the soil, fertilization and agronomic practices (Dubeux et al. 2006). The evaluated cultivars showed low levels of DM and EE, similar to those reported by Batista et al. (2003, 2009) and Pinos-Rodríguez et al. (2010) and in Gigante cultivars, IPA-20 Algeria and forage, respectively. The protein showed low values similar to those reported by Tegegne et al. (2007) and Tegegne (2001), under conditions without fertilization, however, this

nutrient can be affected by soil moisture and fertilization as showed by Pinos-Rodríguez et al. (2010), when evaluated the effect of irrigation and fertilization in the cladodes composition at different ages, finding a linear relationship between age and protein content, as age increases the protein content decreases. The reported values are moderate and go from 18 to 10 % at 30 and 90 days respectively, compared to the protein content in alfalfa and corn.

Regarding its fiber fractions (NDF and ADF), Pinos-Rodríguez et al. (2010) found a linear relationship, as the prickly pear cactus ripens the fiber increases too. The NDF and ADF values obtained in this study for prickly pear cactus cultivars were similar to those reported by other authors (Gebremariam et al. 2006; Batista et al. 2009; Costa et al. 2009; Barbosa et al. 2012). The hemicellulose content calculated in this study varied in ranges from 96 to $249 \text{ g kg}^{-1} \text{ DM}$, similar values to those reported in studies of Batista et al. (2003) and Abidi et al. (2009) where the estimated difference between NDF and ADF values were in average 102 and 123 respectively.

The total carbohydrate content was an average of $670 \text{ g kg}^{-1} \text{ DM}$, lower values than those reported by Batista et al. (2003), who found an average of $751 \text{ g kg}^{-1} \text{ DM}$ of total carbohydrates in three prickly pear cactus cultivars. Silva et al. (2011) mentioned that the prickly pear cactus stands out because of a high content of non-fibrous carbohydrates, with a 49.7 % higher value than sorghum grains. Meanwhile Batista et al. (2003) reported that the carbohydrate fraction of medium and rapid fermentation constitutes as 19 and 42 % respectively of the total, due to high content of these components and low levels of lignin, the prickly pear cactus can be considered as a good source of fermentable carbohydrates for ruminants (Batista et al. 2009).

The ash content ranged between 137 to $293 \text{ g kg}^{-1} \text{ DM}$, in the studied cultivars was lower than that reported by Ben Salem et al. (2002) for the Inermis cultivar and superior to that found by Rodríguez-García et al. (2007) for the Redonda cultivar. The amount of minerals in the prickly pear cactus can be determined by the mineral content of the soil (Nobel, 2002). The water deficiency and high levels of minerals in the soil make the prickly pear cactus accumulate high amounts of Ca (Nobel 2002). McConn and Nakata (2004) found $18 \text{ g kg}^{-1} \text{ DM}$, Rodríguez-García et al. (2007) reported values between 15 to $37 \text{ g kg}^{-1} \text{ DM}$, according to the

ripening state of the cladode; and Batista et al. (2003) 70 g kg⁻¹ DM, of Ca. This last value was much higher than the one found in this study (13–40 g kg⁻¹ DM). The Ca is an essential mineral in animal nutrition; however, even though the prickly pear cactus cultivars had high content of Ca, this does not ensure that they are a source of calcium since it is found in oxalate crystals (McConn and Nakata 2004), with low availability (Ben Salem et al. 2002). On the other hand, Rodríguez-García et al. (2007) indicated that the content of calcium oxalates decrease as cladode age progresses, this can occurred for pruned cladodes, as the ones used in this study.

The P with ranges from 0.9 to 2.7 g kg⁻¹ DM was lower than those reported by Batista et al. (2003) with average values of 5.6 in three varieties of prickly pear cactus, and it remains within the values reported by Tegegne (2002) of 2.3 g kg⁻¹ DM and Rodríguez-García et al. (2007) of 1.8 g kg⁻¹ DM, who found that contrary to the case of Ca, while the cladodes age increases P concentration decreases.

The K content ranged between 18 and 45 g kg⁻¹ DM which is lower than those reported by McConn and Nakata (2004), in cladodes of different ages. Kafkafi and Xu (1999) mentioned that the K level varied in different organs of the plants, focusing in flowers and fruits and that is decreased as the cladodes age progresses on flowers and fruits and this decreases as the cladodes age advances. Tegegne (2002) reported K values of 1.7 g kg⁻¹ DM well below those found in this study.

Meanwhile, the Mg content ranged from 8 to 18 g kg⁻¹ DM in this study was higher in some cultivars to those reported by McConn and Nakata (2004) of 10 g kg⁻¹ DM and Rodríguez-García et al. (2007) of 6 g kg⁻¹ DM, meanwhile Na in prickly pear cactus cladodes is low (Ben Salem et al. 2002). Tegegne (2002) reported Na values of 0.5 g kg⁻¹ DM, higher than what was found in this study, Rodríguez-García et al. (2007) mentioned that the Na content in the prickly pear cactus is in function of its age. The content of Cu, Fe, Zn and Mg, agrees with those reported by Batista et al. (2003), except for some values of Zn of 20 to 358 mg kg⁻¹ DM and Mn 65 to 220 mg kg⁻¹ DM were higher in the current study.

Gas production and in vitro digestibility

Regarding to the released gas as a product of the fermentation of the components of the prickly pear

cactus, in this research the maximum values presented had ranges from 235 to 378 mL g⁻¹ DM at 72 h of incubation, similar to those reported by Abidi et al. (2009) with 290 mL g⁻¹ DM when a variety of thorny prickly pear cactus was evaluated. The average of gas production during the first eight hours of incubation was 107 mL g⁻¹ DM in this study, meanwhile Batista et al. (2003) and Abidi et al. (2009) report lower values with 87 and 75 mL g⁻¹ DM during the first 8 h of incubation. The average produced gas in 24 h was 106 mL g⁻¹ DM, a higher value than that found by Batista et al. (2003; 72 mL g⁻¹ DM), but the values were lower than those found by Abidi et al. (2009) with 134.5 mL g⁻¹ DM. Ben Salem et al. (2002) mentioned that the highest gas production occurred during the first 24 h of incubation without significant increases in the remaining time, which agrees with the data of this study, where 67 % of the total gas production occurs during the first 24 h of incubation. At 48 h of incubation the production of gas decreases with only 16 % of the total volume of gas, on average from hour 24 to 50 h only 60 mL g⁻¹ DM was produced, however, the values were higher than those reported by Batista et al. (2003; 35 mL g⁻¹ DM), Abidi et al. (2009; 39 mL g⁻¹ DM) and Ben Salem et al. (2002; 15.5 mL g⁻¹ DM). The degradation rate was lower than that reported by Çürek and Özen (2004), with 0.067 h⁻¹. The average of lag time was 1.45 h, higher than those reported by Batista et al. (2003; 0.63 h and 2009; 0.13 h). The IVDMD fluctuated in ranges from 69 to 82 %, values which agree with Çürek and Özen (2004; 64 %), Tegegne (2002; 69 %), Araújo et al. (2008; 78 %), Blakenship et al. (1982; 65 %), and Batista et al. (2009; 70 %). The high degradability of the prickly pear cactus is due to the amount of nonstructural carbohydrates (on average 68 %) and low lignin content.

Conclusion

The nutrient content varied among cultivars, low contents of dry matter, high in ashes, moderate in crude protein and fibers were found. During the first 24 h, the cultivars presented more than 50 % of the total gas produced, and in some cases digestibility higher than 80 %. It can be concluded that the cladodes of prickly pear cactus from different cultivars can be used in animal feed because of their good rumen fermentation characteristics.

Acknowledgments This work was a part of PhD thesis of the first author under the supervision of Dr. Luis Alberto Miranda Romero. Authors would to thankful the financial support received from CONACYT and Universidad Autónoma Chapingo.

References

- Abidi S, Ben Salem H, Martín-García AI, Molina-Alcaide E (2009) Ruminal fermentation of spiny (*Opuntia amyclae*) and spineless (*Opuntia ficus indica* f. *inermis*) cactus cladodes and diets including cactus. *Anim Feed Sci Technol* 149:333–340
- Aguilar-Yáñez MI, Hernández-Mendo O, Guerrero-Legarreta I, Ramírez-Bribiesca JE, Aranda-Osorio G, Crosby-Galván MM (2011) Productive response of lambs fed with fresh or dehydrated spineless cactus (*Opuntia ficus-indica* L.). *J Prof Assoc Cactus Dev* 13:23–35
- Andrade-Montemayor HM, Córdova-Torres AV, García-Gasca T, Kawas JR (2011) Alternative foods for small ruminants in semiarid zones, the case of Mesquite (*Prosopis laevigata* spp.) and Nopal (*Opuntia* spp.). *Small Rumin Res* 98: 83–92
- AOAC (Asociación de Químicos Analíticos Oficiales) (1990) Official methods of analysis, 15th edn. Association of Official Agricultural Chemists, Washington, DC
- Araújo FL, Silva FLH, Brito EA, Oliveira Júnior S, Santos ES (2008) Protein enrichment of cactus pear with *Saccharomyces cerevisiae* for ruminants feeding. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* 60:401–407
- Barbosa G, Costa JRG, Medeiros AN, Egypto Queiroga RCR, Batista AMV, Medeiros GR, Filho EMB (2012) Use of different urea levels in the feeding of Alpine goats. *Revista Brasileira de Zootecnia* 41(7):1713–1719
- Batista AM, Mustafa AF, McAllister T, Wang Y, Soita H, McKinnon JJ (2003) Effect of variety on chemical composition, in situ nutrient disappearance and in vitro gas production of spineless cacti. *J Sci Food Agric* 88:440–445
- Batista AMV, Ribeyroneto AC, Lucena RB, Santos DC, Dubeux JB Jr, Mustafa AF (2009) Chemical composition and ruminal degradability of spineless cactus grown in Northeastern Brazil. *Rangel Ecol Manag* 62:297–301
- Ben Salem H, Nefzaoui A, Ben Salem L (2002) Supplementation of *Acacia cyanophylla* Lindl. foliage based diets with barley or shrubs from arid areas (*Opuntia ficus indica* f. *inermis* and *Atriplex nummularia* L.) on digestibility and growth in sheep. *Anim Feed Sci Technol* 96:15–30
- Blakenship LH, Varner LW, Lynch GW (1982) In vitro digestibility of South Texas range plants using inoculum from four ruminant species. *J Range Manag* 35:664–666
- Cobos MA, Yokoyama MT (1995) *Clostridium paraputrificum* var *ruminantum*: colonization and degradation of shrimp carapaces in vitro observed by scanning electron microscopy. In: Wallas RJ, Lahlou-Kassi A (eds). *Rumen Ecology Research Planning, Proceedings of a Workshop*, Addis Abeba, Ethiopia. International Livestock Research Institute, pp. 151–161
- CONAZA (Comisión Nacional de las Zonas Áridas) (1994) Nopal tunero (*Opuntia* spp.), cultivo alternativo para las zonas áridas y semiáridas de México. Saltillo, Coah, México
- Costa RG, Filho EMB, Medeiros AN, Givisiez PEN, Egypto Queiroga RCR, Melo AAS (2009) Effect of increasing levels of cactus pear (*Opuntia ficus-indica* L. Miller) in the diet of dairy goats and its contribution as a source of water. *Small Rumin Res* 82:62–65
- Çürek M, Özen N (2004) Feed value of cactus and cactus silage. *Turk J Vet Anim Sci* 28:633–639
- De Waal HO, Zeeman DC, Combrinck JW (2006) Wet faeces produced by sheep fed dried spineless cactus pear cladodes in balanced diets. *S Afr J Anim Sci* 36:10–13
- Dubeux C Jr, Santos MVF, Lira MA, Santos DC, Farias I, Lima LE, Ferreira RLC (2006) Productivity of *Opuntia ficus-indica* (L.). Miller under different N and P fertilization and plant population in North-East Brazil. *J Arid Environ* 67:357–372
- Felker P, Paterson A, Jenderek MM (2006) Forage potential of *Opuntia* clones maintained by the USDA National Plant Germplasm System (NPGS) collection. *Crop Sci* 46:2161–2168
- Fuentes-Rodríguez J (1997) Feeding prickly pear cactus to small ruminants in Northern Mexico. I. Goats. *J Prof Assoc Cactus Dev* 2:23–25
- García E (1988) Modificaciones al sistema de clasificación climática de Köppen (para adaptarla a las condiciones de la República Mexicana). 4th edn. México Distrito Federal
- Gebremariam T, Melaku S, Yami A (2006) Effect of different levels of cactus (*Opuntia ficus-indica*) inclusion on feed intake, digestibility and body weight gain in tef (*Eragrostis tef*) straw-based feeding of sheep. *Anim Feed Sci Technol* 131:42–51
- Granados D, Castañeda AD (1996) El nopal: historia, fisiología, genética e importancia frutícola. Editorial Trillas, México, 227 pp
- Kafkafi U, Xu GH (1999) Potassium nutrition for high crop yields. In: Oosterhuis DM, Berkowitz G (eds) *Frontiers in potassium nutrition: new perspectives on the effects of potassium on physiology of plants*. Georgia, USA, pp. 133–142
- Luttge U (2004) Ecophysiology of crassulacean acid metabolism (CAM). *Ann Bot* 93:629–652
- McConn MM, Nakata PA (2004) Oxalate reduces calcium availability in the pads of the prickly pear cactus through formation of calcium oxalate crystals. *J Agric Food Chem* 52:1371–1374
- Menke KH, Steingass H (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
- Muciño-Castillo G, Miranda-Romero LA, González-Muciño S, Bárcena-Gama R, Crosby-Galván MMM (2014) Efecto de la inclusión de harina de nopal en dietas en la fermentación in vitro y engorda de corderos. In: *Memorias of the XLI Reunión de la Asociación Mexicana para la Producción Animal y Seguridad Alimentaria A. C. y VII Reunión Nacional de Sistemas Agro y Silvopastoriles*. Mérida, Yucatán, pp. 340–345
- Nobel PS (2002) Ecophysiology of *Opuntia ficus-indica*. In: Mondragon-Jacobo C, Perez-Gonzalez S (eds) *Cactus (Opuntia spp.) as forage*. FAO Plant Protection and Production Paper 169, Rome, Italy, pp. 13–20

- NRC (National Research Council) (2001) Nutrient requirements of dairy cattle: seventh revised edition. National Academy Press, Washington, DC
- Pinos-Rodríguez JM, Velázquez JC, González SS, Aguirre JR, García JC, Álvarez G, Jasso Y (2010) Effects of cladode age on biomass yield and nutritional value of intensively produced spineless cactus for ruminants. *S Afr J Anim Sci* 40:245–250
- Pitt RE, Cross TL, Pell AN, Shofield P, Doane PH (1999) Use of in vitro gas production models in ruminal kinetics. *Math Biosci* 159:145–163
- Rodríguez FH, Jiménez L, Rodríguez Absi JR, Jiménez GG (2009) Cultivo Orgánico del Nopal. Trillas, México
- Rodríguez-García ME, Lira C, Hernández-Becerra E, Cornejo-Villegas MA, Palacios-Fonseca AJ, Rojas-Molina I, Reynoso R, Quintero LC, Real A, Zepeda TA, Muñoz-Torres C (2007) Physicochemical characterization of nopal pads (*Opuntia ficus indica*) and dry vacuum nopal powders as a function of the maturation. *Plant Foods Hum Nutr* 62:107–112
- SIAP (Servicio de Información Agroalimentaria y Pesquera) (2010) www.siap.gob.mx/index.php?option=com_content&view=article&id=23&Itemid=3. Consultada el 17 de mayo de 2013
- Silva VL, Costa LS, Bastos MPV, Macedo Facuri LMA, Rego Júnior NO, Silva MV (2011) Caracterização físico-química e bioquímica do farelo de palma forrageira redonda (*Opuntia ficus*) utilizado na alimentação de ruminantes. *Publicações em Medicina Veterinária e Zootecnia* 5(2):1–13
- Sniffen CJ, O'Connor JD, Van Soest PJ, Fox DG, Russell JB (1992) A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *J Anim Sci* 70:3562–3577
- Tegegne F (2001) Nutritional value of *Opuntia ficus-indica* as ruminant feed in Ethiopia. In: Mondragón-Jacobo C, Pérez-González S (eds) *Cactus (Opuntia spp.) as Forage*. FAO Plant Production and Protection Paper 169. Food and Agriculture Organization of the United Nations, Rome, pp 91–99
- Tegegne F (2002) Fodder potential of *Opuntia ficus-indica*. *Acta Hort* 581:343–346
- Tegegne F, Kijora C, Peters KJ (2007) Study on the level of cactus pear (*Opuntia ficus-indica*) supplementation to sheep and its contribution as source of water. *Small Rumin Res* 72:157–164
- Theodorou MK, Williams BA, Dhanoa MS, McAllan AB, France J (1994) A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. *Feed Sci Technol* 48:185–197
- Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J Dairy Sci* 74:3583–3597