Nutritive value of cactus pear silages for finishing lambs

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ABSTRACT

The objective of the present research was to evaluate the nutritive value and the fermentation characteristics of cactus pear silages and diets including them for growing lambs. There were two cactus pear silage types: one made from cladodes and the other combining cladodes and cactus pear fruit. Similarly, it was calculated the gas potential emission index (GPEI; dL lamb^{-1} day^{-1}). The four diets: control (with not silage, NSD), including corn silage (CSD), or cladode cactus pear silage (CCSD), or cladode-fruit cactus pear silage (CFSD) were iso-nitrogenous (15% CP) and iso-energetic (2.7 Mcal of ME kg^{-1} of dry matter) fulfilling the requirements for finishing lambs. Eight commercial cross lambs (23±3.0 kg liveweight) were used, under a 4 x 4 replicated Latin Square design. The results indicated that the CCSD and CFSD had 3% more ($P<0.05$) dry matter (DM) content than the CSD, but the later had more ($P<0.05$) protein (80 g kg^{-1}) and greater digestibility (60%) than the CCSD and CFSD (50 g kg^{-1} and 50%). The diets with CCSD and CFSD had more ($P<0.05$) crude protein (160 g kg^{-1}) than the control and CSD (150 g kg^{-1} DM). The *in vitro* digestibility of the control diet was greater ($P<0.05$) than the other diets, although the DM voluntary intake, apparent digestibility, and the acid detergent fiber (ADF) were not different ($P>0.05$). The neutral detergent fiber (NDF) was greater ($P<0.05$) in diets including silages in comparison to the control diet. Lambs fed with control or CCSD diets had a gas potential production of 350 and 370 L lamb^{-1} d^{-1}, in comparison to 200 and 210 L lamb^{-1} d^{-1} from CSD and CFSD diets. It is concluded that the nutritive and *in vitro* fermentative qualities of the CCS and CFS were similar to CS, thus, their inclusion in diets for finishing lambs can be considered as a feeding alternative, and more importantly, CFS could mitigate the emission of greenhouse gases.

Keywords: Cladodes, fruit, anaerobic fermentation, gas emission, sheep.

INTRODUCTION

The cactus pear plant (*Opuntia* spp.) belongs to the cactaceae family and fodder is one of its most important uses, mostly in regions with water scarcity and poor soil fertility (Fuentes-Rodríguez, 1997; Nefzaoui and Ben Salem, 2002; Luttge, 2004). It is cultivated in many countries around the word, such as Brazil, Italy, South Africa, Spain, Argentina, Tunisia, Argelia and India (Ochoa and Barbera, 2017).

In Italy, the cactus pear plantations are advocated to the cactus pear fruit production for the European market, while in Brazil the cactus pear plantations are dedicated to forage production (Ochoa and Barbera, 2017). In Mexico, even though cactus pear is a common range plant, there are a few forage cultivated plantations, most of the intensive production plantations are for tender pads (“nopalitos”) with a planted area of approximately 12,731 ha and 829,468 ton of annual production, or fruit (“tuna”), with a planted area around 47,973.25 ha and 470,231.74 ton of annual production (SIAP, 2018).

In those intensive production systems, the cactus pear plants pruning is an important agronomical practice every year. Reasons for pruning include to keep the plant in shape (not too tall or too wide), stimulate the regrow and/or fruit production, or for sanitary purposes. Additionally, there are fruits that do not fulfill the market requirements, such as, out of season, small size or sanitary problems (Granados y Castañeda, 1996); all of this generate a great amounts of wasted cladodes and fruit, which is generally left on the field, to be degraded and supply organic matter to the soil. In many cases, however, the process is not well completed, becoming a reservoir for pests and diseases, thus, being a contaminant focus for the same plantation (CONAZA, 1994).

Thereby, the use of these residues for animal feeding (especially ruminants) can be an important alternative for sustainability and profitability of both agriculture and animal production systems (Ortiz-Heredia *et al*., 2013; Vazquez-Mendoza *et al*., 2015). The cladode and fruit normal DM content ranges from 10 to 20%, which makes them highly perishable (Granados y Castañeda, 1996). However, it is possible to conserve them through an anaerobic fermentation process such as the ensiling (Hiriart, 2008). Çürek and Özen (2004), ensiled young and old pre-withered cladodes of *Opuntia ficus-indica*, reporting 20% of DM concentration and 2.1% of crude protein.

However, there is still limited research information on cactus pear silage about nutrient supply, digestibility, *in vitro* fermentation, voluntary intake and environmental impact through fermentative gas emissions. Then, the objective of the present research was to determine the nutrient content, *in vitro* fermentation of cactus pear cladode silage and cactus pear cladode-fruit silage, the potential gas emission index, and the voluntary intake of diets including these silages for finishing lambs.

MATERIALS AND METHODS

Location

This research was carried out at the Milk Production Grazing Module, the Sheep Production Module, the Cactus Pear Experimental Unit, and the Livestock Microbiology Laboratory of the University of Chapingo, Mexico, located at the geographical coordinates of 19º 29' North Latitude and 98º 54' West Longitude, at 2,240 masl, with an average annual temperature and precipitation of 15.9°C and 645 mm (García, 1988).

Trails

To achieve the objectives of this research, three experiments were implemented namely: 1) Assessment of nutritive and fermentation profile of silages; 2) Performance measurement of elaboration of finishing lambs fed diets including silages; and 3) Using *in vitro* gas fermentation technique evaluation of feeds offered and rejected and feces.

Silage study

The corn silage used as reference was obtained by the 90 ton corn bunker silage of the University of Chapingo's Experimental Farm. The cactus pear cladode silage (CCS) and cladode-fruit silage (CFS) were made from two and three year old cladodes of *Opuntia ficus indica* cv. Rojo Vigor, and mature fruit of *Opuntia ficus indica* cv. Cristalina, harvested at the University of Chapingo's Experimental Cactus Pear Unit.

The cladode silage (CCS) was comprised of 74% cactus pear cladodes, 19% corn stalk and 7% sugar cane molasses. While the cladode-fruit silage (CFS) was made of 44% cactus pear cladodes, 30% cactus pear fruit, 23% corn stalk and 3% sugar cane molasses. These proportions were defined according to the laboratory determinations aiming to have 300 g kg^{-1} DM and 80 g kg^{-1} of soluble carbohydrates (Hiriart, 2008). The cladodes were chopped up ($\leq$ 3 cm) using a chopper slicer (PD 65 Boomeri®) and they were mixed with corn stalk chopped ($\leq$ 1 cm) and molasses, then, the content was put into a 200 L plastic container (three pseudo replicates), which were compacted and sealed off (steel strip). The density of each silage was calculated through the container's volume (52 cm diameter and 95 cm height) and the weight of the material compacted (searching to obtain a minimum of 600 kg m^{-3} density).

Feeding Trial

Four iso-nitrogenous (15% CP) and iso-energetic (2.7 Mcal of ME kg^{-1} of dry matter) diets were prepared to fulfill the requirements (NRC, 2007) for finishing lambs (targeting an average liveweight gain of approximately 300 g $lamb^{-1}$ d^{-1}). The control treatment included conventional ingredients for a representative finishing diet in the region a control diet (with not silage, NSD); the second treatment consisted of control diet with inclusion of 25% of corn silage (CSD); the third treatment consisted of control diet with the inclusion of 23% cactus pear cladodes silage (CCSD); and the fourth treatment, comprises the control diet with the inclusion of 20% cactus pear cladode-fruit silage (CFSD) (Table 1).

Table 1. Diets' composition for finishing lambs including control diet (NSD), corn silage based diet (CSD), cactus pear cladode silage based diet (CCSD) and cladode-fruit silage based diet (CFSD).

Ingridient	Diets			
	NSD	CSD	CCSD	CFSD
Corn stalk	20.0	-	-	-
Corn silage	-	25.0	-	-
Cladode silage	-	-	23.4	
Cladode-Fruit silage	-	-	-	20.2
Grinded corn	15.0	15.0	15.0	16.7
Soybean meal	16.3	12.3	14.6	13.2
Grinded sorghum	38.3	30.1	37.0	40.0
Wheat middlings	-	7.6	-	-
Sugar cane molasses	6.0	6.0	6.0	6.0
Bypass fat*	1.6	0.2	0.2	0.2
Mineral premix**	2.3	3.3	3.3	3.2
Urea	0.5	0.5	0.5	0.5
Calculated nutritional content				
Dry matter %	88.6	73.9	74.7	76.5
Crude protein %	15.0	15.0	15.0	15.0
ME (Mcal kg^{-1})	2.7	2.7	2.7	2.7
NDF %	23.5	23.9	20.5	20.4
Ratio Ca:P	2.5	2.0	2.4	2.4

*Bypass fat: 84%, crude fat; 16%, ashes; 9%, calcium. **Vitasal Ovino Plus®: calcium, 24%; phosphorus, 3%; magnesium, 2%; sodium, 8%; chlorine, 12%; potassium, 0.5%; sulphur, 0.5%; anti-oxidant, 0.5%; lasalocid, 2,000 ppm; chromium, 5 ppm; manganesium,4,000 ppm; iron, 2,000 ppm; zinc, 5,000 ppm; iodine, 100 ppm; selenium, 30 ppm; cobalt, 60 ppm; Vit. A, 500,000 UI; Vit. D, 150,000 UI; Vit. E, 1,000 UI.

The corn silage (CS) was taken from the Chapingo´s Livestock Research Unit, which was opened after 135 days of processing, taking three sub-samples at this day (D135). For the cladode silage (CCS) and cladode-fruit silage (CFS), three sub-samples per container were taken at the moment of filling the silos (D0) and at the end of the ensiling period (D120). To each sample, the following determinations were carried out: pH (Potentiometer PH212, Hanna Instruments®) (Cherney and Cherney, 2003); soluble carbohydrates content (Dubois *et al.*, 1956); ammoniac nitrogen (McCullougth, 1967); lactic acid (Taylor, 1996) and corrected dry matter (CDM) for silages of 120 days and dehydrated at 80°C in oven, according to the equation (CSIRO, 2007):

$$[\% \ CDM = 3.96 + 0.94 \ ODM]$$

Where, ODM is the DM concentration obtained by dehydration at 80°C.

Futhermore, to the diets including silages crude protein content (AOAC, 1990), neutral detergent fiber (NDF), and acid detergent fiber (ADF) were determined (Van Soest *et al*. 1991).

Lamb feeding management

Eight male crossed (Ramboullet/Creole) lambs of initial liveweight (LW) of 23 ± 3 kg were used, which were allocated in individual pens (2.5 x 1.5 m), with feedthrough, and automatic drinker; each lamb represented an experimental unit, and two lambs per treatment. At the beginning of the experiment, the lambs were identified, dewormed (Ivermectin and Clorsulom 1 mL 25 kg^{-1} LW; Iverfull F®), and vitamined (vitamin A, D, and E 1 mL $lamb^{-1}$; Vigantol ADE®). The feeding period lasted 60 days, which was divided in four periods of 15 days each. In the first period, two lambs where randomly assigned to one of the diets, 12 days of adaptation and the remaining three days were used for sampling: offered feed, rejected feed (orts), and feces. In the following three periods, the diets were rotated with the aim of each lamb would receive the whole set of diets in different period, under the same protocol. The feed was offered twice a day, 50% at 08:00 and 50% at 16:00 h; the amount of feed offered was daily adjusted with the aim to have at most 10% of orts. Daily feed intake was calculated from feed offered minus orts (later converted to dry matter basis).

For the feed samples in each period, the following analyses were performed (AOAC, 1990): DM, ashes, crude protein, and ether extract percentage. For feed and fecal samples analysis for NDF and ADF (Van Soest *et al*. 1991) also were performed, with the aim to estimate apparent digestibility of the DM (DMAD), the NDF (ADNDF) and the ADF (ADADF) (Church, 1993).

In vitro fermentation and degradation of the dry matter

Dry matter (DM) samples of silages, offered feed, feed rejected (orts), and feces were submitted to the gas fermentation production kinetic and *in vitro* degradation of the DM (*IV*DDM) using the gas production technique (Menke and Steingass, 1988; Theodorou *et al.,* 1994). Briefly, 500 mg DM substrate was introduced in amber glass container of 125 mL capacity and added with 90 mL of ruminal inoculum in a continuous CO_2 flow. The containers were hermetically sealed with a robber plug and a metallic ring, and they were immersed in water bath at 39ºC for 72 h. The gas volume was measured at 0, 2, 4, 6, 8, 10, 14, 18, 24, 30, 36, 42, 48, 60 and 72 h of incubation.

The ruminal inoculum was obtained by ruminal probe from two lambs, which were fed for 15 days in each experimental diet. At the sampling time the lambs had 12 h fast. The ruminal inoculum from each lamb was managed separately. They were filtered by four layers of gauze, and it was added a reduced mineral solution in a proportion of 1:9 (v/v). The mineral solution was made of K_2HPO_4 (0.45 g L^{-1}), KH_2PO_4 (0.45 g L^{-1}), $(NH_4)_2SO_4$ (0.45 g L^{-1}), NaCl (0.90 g L^{-1}), $MgSO_4$ (0.18 g L^{-1}), $CaCl_2$ (0.12 g L^{-1}), Na_2CO_3 (4 g L^{-1}) and reducing solution (20 mL L^{-1}). Each 100 mL of reducing solution was made of NaOH (0.8 mL L^{-1}), Na_2S (0.2 g L^{-1}), L-cistein (0.2 g L^{-1}) and one rezarzurine drop (Cobos and Yokoyama, 1995).

With the volume values (mL g^{-1} of substrate) it was possible to obtain the gas fractional volume production for the intervals 0-8 (Fv_{0-8}); 8-24 (Fv_{8-24}); and 24-48 (Fv_{24-48}) hours of incubation. These values (Fv_{0-8}, Fv_{8-24}, and Fv_{24-48}) were transformed to fermentation fractions (g kg^{-1}), such as fast (FF), medium (MF) and slow (SF) fermentation, according to the models:

$$Fv_{0-8} = 0.4266*(\text{mg FF})$$

$$Fv_{8-24} = 0.6152*(\text{mg MF})$$

$$Fv_{24-72} = 0.3453*(\text{mg SF}).$$

The total gas fermentable fraction (TFF) was obtained by the sum of these three fractions (Miranda-Romero *et al*., 2015; Albores-Moreno *et al*., 2018; Tirado-Estrada *et al*., 2018).

The accumulated volume for each measured time was used to calculate:

1) Maximum gas volume produced (Vm; mL g^{-1} DM).
2) Rate (S; mL h^{-1}).
3) Lag phase (L; h)

From the mathematical model (Pitt *et al*., 1999):

$$\mathbf{Vo = Vm / (1+e^{(2-4*S*(T-L)})}$$

Where:

Vo is the measured volume at specific time (T) of determination.

A new variable named "*in vivo* gas potential emission index" (*IV*GPEI; dL $lamb^{-1}$ day^{-1}) was generated according to the equation:

$$\boldsymbol{IVGPEI = [(Vmo*Of) – (Vmr*Rf)] – Vmf*F}$$

Where:

Vmo, Vmr and Vmf are the gas maximun volume (mL g^{-1}) produced by *in vitro* fermentation of the offered feed, rejected feed (orts) and feces, respectively.

Of, Rf and F are the amount (g $lamb^{-1}$ day^{-1}) of offered feed, rejected feed, and feces of lambs.

Statistical analysis

Data from silages chemical composition, fermentation fractions (fast (FF), medium (MF), low (LF) and total (TF)), digestibility and gas production variables were analyzed using a completely random design. While the diet chemical composition, fermentation fractions, the gas production kinetic parameters (Maximum Volume (Vm), Rate (S) and Lag phase (L)), the *in vivo* gas potential emission index (*IV*GPEI), and apparent digestibilities were analyzed using a Latin

Square 4 x 4 repeated design (SAS, 2013). The mean comparison was made through the Tukey Test (α=0.05).

RESULTS AND DISCUSSION

The density of the cladodes silage (CCS) and the cladodes-fruit silage (CFS) was 815.6 and 718.9 kg m^{-3}, respectively, this density is close to the one recommended by Johnson *et al.* (2001), for corn silages (750 kg m^{-3}), to assure an anaerobic environment and better nutrient preservation. The DM concentration at day 120 was greater ($P<0.05$) in cladode silage and cladode-fruit silage compared to corn silage (Table 2). The DM of the three silages was appropriate to reduce nutrient losses through effluents (McDonald, 1981).

The pH of the cladode silage and cladode-fruit silage at day 0 was characteristic of the cactus pear cladodes (Saenz and Berger, 2006), but greater ($P<0.05$) than the final pH at day120 (Table 2). The corn silage pH was lower (3.7) ($P<0.05$) than the cactus pear silages (CCS and CFS); this situation could be as a result of the initial high soluble carbohydrates content of the corn has (McDonald *et al.*, 1991).

The pH of the corn silage was similar to the one found in hybrids corn by Araújo *et al.* (2012). On the other hand, the cladodes-fruit silage had a lower ($P<0.05$) pH than cladode silage at day 120, that could be due to the inclusion of cactus pear fruit, because it supplied an additional amount of soluble carbohydrates (Table 2). However, Çürek and Özen (2004), obtained lower pH values in pre-withered old cladodes compared to our results. Values of pH from 3.8 to 5.0 in forage silages indicate the dominance of lactic acid bacteria and consequently the accumulation of lactic acid, which inhibits the undesirable microorganisms and favors the preservation process (Garcés *et al.*, 2011; Díaz-Plascencia *et al.*, 2012).

The lactic acid content of the three silages was not different ($P>0.05$; Table 2), although the pH value of the cladode silage and cladode-fruit silage was greater ($P<0.05$) than the corn silage. It is possible due to the type of fiber and/or the mucilage content of these cactus pear silages could have a major buffer effect than the fiber alone of corn silage (Miranda-Romero *et al.*, 2004).

The corn silage ammonium concentration was greater ($P<0.05$) than the cladode cactus pear silage and the cladode-fruit silage (Table 2). However, the absolute value was lower and similar to the ones reported by Améndola and Topete (2013) for corn silage. The above may be attributed to the low crude protein concentration of the forage and the low proteolytic activity during the ensiling process, which was confirmed by the greater ($P<0.05$) crude protein concentrations in the cactus pear silages at the end of the ensiling process (D120), compared to D0 (Table 2), that can be due to the fermentation of the soluble carbohydrates, which decreased at the end of the ensiling process, concentrating other chemical components, like crude protein (Table 2).

Table 2. Chemical characteristics of silages at day 0 and 120: pH, dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), soluble carbohydrates (SC), lactic acid (LA) and ammoniac nitrogen (NH_3).

Silage*	Ensilage day	pH	DM g kg^{-1} FM	CP	NDF	SC	LA	NH_3
				-----g kg^{-1} DM-----		---------% DM------------		
CS	0	nd	nd	nd	nd	nd	nd	nd
CCS	0	5.6[a]	335.2[a]	48.0[c]	486.3[b]	5.6[b]	nd	nd
CFS	0	5.5[a]	329.7[a]	46.7[c]	537.0[a]	9.0[a]	nd	nd
CS	120	3.7[d]	284.7[b]	82.1[a]	538.1[a]	1.3[c]	8.0[a]	1.3[a]
CCS	120	4.6[b]	312.9[a]	52.7[b]	508.9[ab]	1.1[c]	7.7[a]	1.0[b]
CFS	120	4.1[c]	317.4[a]	58.9[b]	537.3[a]	1.2[c]	8.0[a]	0.9[b]
SEM		0.04	5.8	0.9	10.6	0.3	0.4	0.03

*CS = Corn silage; CCS = cladode cactus silage; CFS = cladode-fruit silage. SEM = standard error of the mean. [a, b, c] Means with different superscript letter in the same column are different ($P<0.05$). nd = non determined.

The fermentation fractions (fast, FF; medium, MF; and low, LF) for the three silages were not different ($P>0.05$) (Table 3). However, corn silage had a greater ($P<0.05$) total fermentable fraction (TFF), which could be attributed to a greater contribution of the MF and LF (Table 3). The *in vitro* digestibility of the DM (*IV*DDM) was greater ($P<0.05$) for the corn silage than the cactus pear silages (Table 3), that was probably due to its greater crude protein concentration (Table 2) and greater TFF (Table 3).

These fractions were estimated through the gas production technique, using a glucose, starch and cellulose as reference carbohydrates for fast, medium and low fermentation rates, respectively, with the regression models:

$$\mathbf{Vf_{0\text{-}8} = 0.4266*(mg\ FF),\ R^2=0.9441}$$

$$\mathbf{Vf_{8\text{-}24} = 0.06152*(mg\ MF),\ R^2=0.998}$$

$$\mathbf{Vf_{24\text{-}72} = 0.3453*(mg\ LF),\ R^2=0.9653}$$

Where:

$Vf_{0\text{-}8}$, $Vf_{8\text{-}24}$, $Vf_{24\text{-}72}$, correspond to the volume of gas produced during the periods: 0-8, 8-24 and 24-72 h of incubation (Miranda-Romero *et al*., 2015; Albores-Moreno *et al*., 2018; Tirado-Estrada *et al*., 2018).

The maximum volumes (Vm) of gas (Table 3), generated from the fermentation of the three silages were not significantly different ($P>0.05$). While the rate of gas production (S) was greater ($P<0.05$) for the cladode-fruit silage compared to the cladode silage, this probably due to the higher content of soluble carbohydrates coming from the fruit (Table 2).

Table 3. Fast (FF), medium (MF), low (LF), and total (TFF) fermentable fractions; Maximum volume (Vm); Gas production rate (S); and *in vitro* digestibility of the dry matter (*IV*DDM) from three types of silages at 120 days of ensiling process.

Silage*	FF	MF	LF	TFF	Vm	S	*IV*DDM
	----------------------------%---------------------------				mL g^{-1} DM	mL h^{-1}	%
CS	17.5^{a}	16.6^{a}	25.8^{a}	60.1^{a}	225.0^{a}	0.0215^{ab}	60.5^{a}
CCS	15.8^{a}	11.2^{a}	21.0^{a}	48.1^{b}	231.6^{a}	0.0203^{b}	52.3^{b}
CFS	16.1^{a}	11.1^{a}	22.4^{a}	49.7^{b}	271.1^{a}	0.0242^{a}	54.8^{b}
SEM	0.5	1.4	1.5	2.7	13.0	0.0009	11.6

*CS = corn silage, CCS = cladode cactus silage, CFS = cladode plus fruit silage. SEM= standard error of the mean. $^{a.b.c.}$ Means with different superscript letter in the same column are different (P<0.05).

The maximum volumes (Vm) of gas (Table 3), generated from the fermentation of the three silages were not significantly different (P>0.05). While the rate of gas production (S) was greater (P<0.05) for the cladode-fruit silage compared to the cladode silage, this probably due to the higher content of soluble carbohydrates (Table 2).

Diets:

Dry matter concentration was greater (P<0.05) in the control (with not silage, NSD) diet (Table 4). When cladode silage or cladode-fruit silage were included, the ash content is higher (P<0.05) compared to the control diet due to the fact that the cladodes have a high content in minerals (around 26% of the DM) (Azócar, 2002; Vazquez-Mendoza *et al*., 2016). However, the cladode-fruit silage diet presented lower ash content (P<0.05) compared to the cladode silage diet, because the ash content in the cactus pear fruit is lower (around 4% of the DM; Chiteva and Wairagu, 2013; Vazquez, 2016).

Table 4. Dry matter (DM), ash (ash), ether extract (EE), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of the diets including silages for finishing lambs.

Diet*	DM	Ash	EE	CP	NDF	ADF
	g kg^{-1} FF	---------------------------------- g kg^{-1} DM -----------------------------------				
NSD	928.3^{a}	90.4^{c}	32.6^{a}	156.9^{ab}	292.4^{ab}	164.9^{ab}
CSD	761.2^{d}	108.5^{bc}	28.2^{a}	151.6^{b}	302.3^{a}	214.9^{a}
CCSD	777.6^{c}	156.7^{a}	35.0^{a}	161.2^{a}	250.9^{b}	124.2^{bc}
CFSD	798.7^{b}	130.4^{b}	27.7^{a}	160.2^{a}	331.4^{a}	111.2^{c}
SEM	3.6	5.7	3.9	2.1	11.9	12.5

*NSD = Not silage diet, CSD = corn silage diet, CCSD = cladode cactus silage diet, CFSD = cladode-fruit silage diet; FF = Fresh feed basis; SEM = standard error of the mean. $^{a.b.c.}$ Means with different superscript letter in the same column are different (P<0.05).

Ether extract was not significantly different ($P>0.05$) among diets (Table 4), although ranged from 27.7 to 35.0 g kg^{-1} DM. Diets were formulated to have 15% crude protein, which is achieved for all diets. The lowest value (15.16 %) is observed for the corn silage (CSD) diet (Table 4).

The corn silage diet and the cladode-fruit silage diet had greater ($P<0.05$) neutral detergent fiber (NDF) than the cladode silage diet, however, the acid detergent fiber (ADF) was greater ($P<0.05$) in corn silage diet in comparison to cactus pear silage diets (CCSD and CFSD) (Table 4). That implies that the corn silage diet had less hemicellulose (estimated by difference between NDF and ADF) and greater cellulose and lignin (estimated as the ratio ADF/NDF) compared to the cladode-fruit silage diet (87 *vs*. 220 g kg^{-1} and 71 *vs*. 330 g kg^{-1}, respectively). This can be attributed to the pectin supply by the peel of the cactus pear fruit (Mercado, 2004) and the mucilage of the cladode (Goycoolea and Cárdenas, 2003).

The total fermentable fraction (TFF) in the control diet, corn silage diet and the cladode-fruit silage diet, was greater ($P<0.05$) for the offered feed than for the rejected feed (Table 5). It demonstrates the selective activity of lambs during the feed intake, because they consumed the most fermentable part of the feed and rejected the less fermentable (Kyriazakis and Oldham, 1997), which is directly related to the energetic content (Distel and Villalba, 2007). The other three fermentable fractions (FF, MF and LF), presented a similar pattern to the TFF for the control and the cladode silage diets. However, for the cladode-fruit silage diet, the medium fermentation fraction (MF) was the only one that showed this pattern (Table 5). Then, it was considered that the MF fraction determined the lambs selective intake for the cladode-fruit silage diet.

The fermentable fractions comparison from offered feed and feces showed that the MF fraction disappeared (from 82 to 100%) in the lamb's gastrointestinal tract (Table 5). The MF fraction is associated to the starch fermentation (Miranda-Romero *et al*., 2015; Albores-Moreno *et al*., 2018; Tirado-Estrada *et al*., 2018), in that case, the disappearance of the MF fraction is as high as the apparent starch degradation of corn and sorghum in ruminants (99 %; Fahey and Berger, 1993).

The disappearance of the FF fraction in the gastrointestinal tract varied from 60.4 to 75.5%, although it was expected to be of 100%, due to its association to the soluble carbohydrates (Miranda-Romero *et al*., 2015; Albores-Moreno *et al*., 2018; Tirado-Estrada *et al*., 2018). This was probably due to the material contamination from epithelium peels and the microbial flora of the intestine (Merchen, 1993). The LF fraction showed a normal lower disappearance rate (31.8 a 52.7 %) (Table 5).

The fast fraction (FF) was found to be different ($P<0.05$) among treatments for the three substrates, in comparison to the control, indicating that the inclusion of silages (corn and cactus pear) increased this fraction. Similar situation presented the medium fraction (MF), although different ($P<0.05$) to the fecal substrate only, and surprisingly, the corn (CSD) and the cladode-fruit (CFSD) silage diets were similar and greater ($P<0.05$) than the control (NSD) and the cladode silage (CCSD) diet (Table 5). The low fraction (LF) was not different ($P>0.05$) among treatments. Although, the total fraction (TF) for the offered feed was similar (P>0.05), it was different (P<0.05) for the rejected feed and feces (Table 5).

Table 5. Fast, Medium, Low, and Total Fermentable Fractions of Offered Feed (O), Rejected Feed (R), and Feces (F) of finishing lambs fed with diets including silages.

Diet*	&Fermentable Fractions											
	Fast (%)			Medium (%)			Low (%)			Total (%)		
	ΩO	R	F	O	R	F	O	R	F	O	R	F
NSD	17.3^{c}	13.2^{b}	9.2^{b}	21.3^{a}	13.7^{a}	0.4^{b}	29.2^{a}	23.4^{a}	8.2^{a}	67.9^{a}	50.3^{b}	17.7^{b}
CSD	20.7^{b}	17.9^{b}	9.8^{ab}	25.2^{a}	15.6^{a}	3.3^{a}	28.8^{a}	21.4^{a}	11.4^{a}	74.7^{a}	54.9^{b}	24.5^{a}
CCSD	25.3^{a}	29.1^{a}	13.7^{a}	23.3^{a}	18.2^{a}	0.0^{b}	29.8^{a}	28.8^{a}	7.3^{a}	74.2^{a}	76.1^{a}	21.0^{ab}
CFSD	19.2^{bc}	19.2^{b}	13.1^{ab}	20.5^{a}	16.3^{a}	3.7^{a}	26.2^{a}	19.7^{a}	7.2^{a}	67.3^{a}	55.3^{b}	24.0^{a}

* NSD = Not silage diet, CSD = corn silage diet, CCSD = cladode cactus silage diet, and CFSD = cladode-fruit silage diet. & Gas production technique was used to estimate the fermentable fractions, taking glucose, starch and cellulose as reference carbohydrates for fast (FF), medium (MF) and low (LF) fermentation rate, respectively. ΩO = Offered feed; R = Rejected feed (orts); F (feces). a,b,c, Means with different superscript letter in the same column are different (P<0.05).

The finishing lamb diet´s analyses for DM intake (DMI), DM apparent digestibility (DMAD), neutral detergent fiber apparent digestibility (NDFAD), acid detergent fiber apparent digestibility (ADFAD), total fermentable fraction disappearance (TFFD), and DM *in vitro* digestibility (DM*IV*D) are shown in Table 6. The inclusion of cactus pear silages (CCSD and CFSD) to the lamb´s finishing diets did not affect (P>0.05) DM apparent digestibility, none the acid detergent fiber digestibility in comparison to the control and corn silage diets. The neutral detergent fiber apparent digestibility was greater (P<0.05) for the cladode-fruit silage diet in relation to the control diet (Table 6), this is probably due to the mucilage and pectin supplied by the cladode and the cactus pear fruit (Zenteno-Ramírez *et al*., 2014), which are more fermentable than the cellulose (Fuente *et al*., 2009).

The DM apparent digestibility was correlated (R^2=0.975) (Table 6) to the *in vitro* DM degradation and the total fermentable fraction disappearance, calculated as a percentage of fermentable fraction disappearance of feces respect to the offered feed (Table 5). Additionally, it was similar to the DM apparent digestibility for the control (NSD), corn silage (CSD), and cladode silage (CCSD) diets with a R^2=0.9601. However, it was not correlated for the cladode-fruit silage diet (R^2=0.2687). In this diet, the disappearance of the total fermentable fraction was lower (64.3%) than the DM apparent digestibility (72.9%), this difference could be due to the pectin content of the cactus pear fruit (Mercado, 2004), which is highly soluble but not necessarily fermentable.

The relationship between *in vitro* fermentable gas production (mL g^{-1}) and the incubation time (h) is shown in Figure 1. The maximum volume (Vm) represented by the asymptote of the curve, exhibited the following tendency: $Vm_{offered}$ > $Vm_{rejected}$ > Vm_{feces}, except for the cladode silage diet, in which the Vm for offered and rejected feeds were similar. The lower fermentable gas production (mL g^{-1}) from the rejected feed compared to the offered feed, implies that the lambs consumed the most fermentable part of the diet, and that this selection activity was not performed with the cladode silage diet. The Vm for each substrate (offered feed, rejected feed, and feces) were not statistically different (P>0.05) among treatments, except for rejected feed from the cladode silage diet, which was greater (P<0.05) than the other rejected feeds.

Table 6. Dry matter intake (DMI), DM apparent digestibility (DMAD), neutral detergent fiber apparent digestibility (NDFAD), acid detergent fiber apparent digestibility (ADFAD), total fermentable fraction disappearance (TFFD), and DM *in vitro* digestibility (DM*IV*D) of diets including silages for finishing lambs.

	DMI	**DMAD**	**NDFAD**	**ADFAD**	**TFFD[&]**	**DM*IV*D**
Diets*	**kg day^{-1}**			**----------------------------%----------------------------**		
NSD	1.3^a	74.1^a	58.3^b	46.8^a	73.9^a	81.3^a
CSD	0.7^a	67.2^a	66.8^{ab}	44.4^a	67.2^a	76.1^c
CCSD	1.1^a	70.1^a	68.4^{ab}	50.3^a	71.6^a	77.9^{bc}
CFSD	0.9^a	72.9^a	73.2^a	48.9^a	64.3^a	79.3^{ab}
SEM	0.1	2.7	2.7	3.0	2.2	0.7

[*]NSD = Not silage diet; CSD = Corn silage diet; CCSD = Cladode cactus silage diet; CFSD = Cladode plus fruit silage diet. SEM= standard error of the mean. [&]TFFD = [(TFF_{of} - TFF_f) / TFF_{of}] x 100; where: TFF_{of} = Total fermentable fraction of the offered feed (Table 5); TFF_f = Total fermentable fraction of feces (Table 5). [a.b.c.] Means with different superscript letter in the same column are different (P<0.05).

Since the volatile fatty acids (VFA) derived from ruminal fermentation of structural and non-structural carbohydrates represents 70 to 80% of the ruminant energy requirements (Beuvink and Spoelstra, 1992; Fahey and Berger, 1993), the gas maximum volume (Vm; mL g^{-1}) indirectly determines the potential content of energy of the substrate (López *et al*., 2000). This aspect has been used to estimate the metabolizable energy (ME) of the substrate from mathematical models that include the *in vitro* gas production (Williams, 2000), as well as the difference of maximum volume from the *in vitro* fermentation of offered feed and feces to estimate the *in vivo* diet's assimilation (Chávez-Hernández and Martínez-Martínez, 2014; Miranda *et al*., 2015).

In the present investigation the difference between offered feed maximum volume and feces (Table 7), showed the following sequence: cladodes silage diet (254.5 mL g^{-1}) > corn silage diet (207.5 mL g^{-1}) > not silage diet (198.1 mL g^{-1}) > cladode-fruit silage diet (170.8 mL g^{-1}). This would imply that the diet with cladode silage was better assimilated by lambs. Even though, cactus pear fruit has more digestibility and degradability than cladodes, but the amount of inclusion in the cladode-fruit silage (30% in the silage, given approximately 6% in the total diet) was not enough to show this effect.

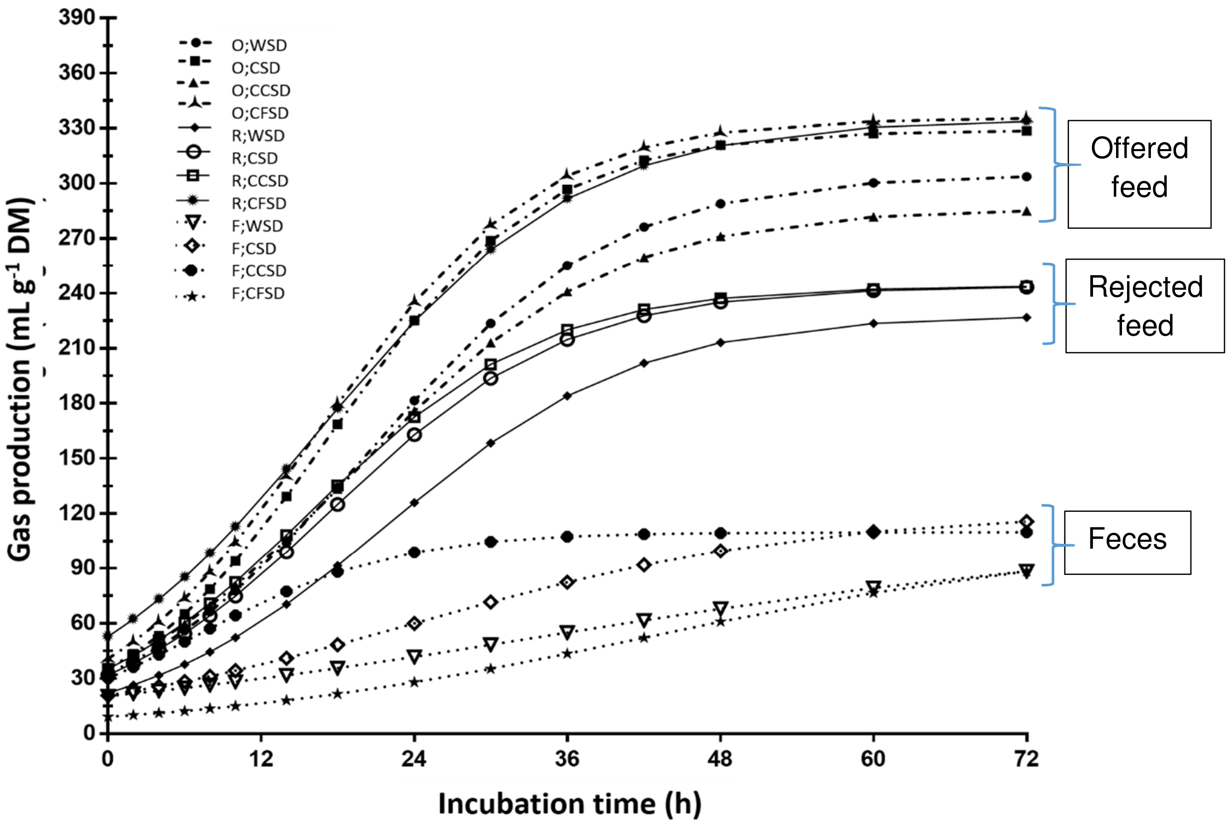

Figure 1. *In vitro* gas production fermentation kinetics of offered feed (O), rejected feed (R) and feces (F) for finishing lambs fed with diets with no silage diet (NSD), corn silage diet (CSD), cladode cactus silage diet (CCSD) and cladode-fruit silage diet (CFSD).

Lambs were selective in their feed intake, however, the offered diet´s maximum volume did not represent the maximum volume of the consumed feed, and for this reason, the *in vivo* gas potential emission index (*IV*GPEI) (Table 7), is calculated and in which total DM, offered DM, rejected DM, and feces DM were considered (g lamb^{-1} d^{-1}). The *IV*GPEI represent the gas emission and the *in vivo* diet's absorption. The *IV*GFEI was not different (P>0.05) (Table 7) among treatments, despite the difference of 170 L of gas lamb^{-1} day^{-1} (370 L (CCS) to 200 L (CFS)).

Although these results are not statistically different, biologically could be important, in this sense the standard error value (3.8 dL lamb^{-1} d^{-1}) was very high (Table 7), possibly due to the fact that index is a variable obtained from six types of measurements, in which each one has its own experimental error; furthermore, the experimental design used (Latin Square 4 x 4, replicated) included a small number of replicates (n = 8).

Even though, it was thought that the cladode silage and the cladode-fruit silage and their diets, could be considered similar in their nutritive and fermentative qualities, which was corroborated in this investigation (Tables 2, 3, 4 and 5), when the animal component was included, however, the diets with cladode silage (CCSD) and cladode-fruit silage (CFSD) diets were different. This effect was observed when the *in vitro* fermentation of the offered feed and rejected feed was evaluated (Table 7). Similarly, the animal effect was also observed when the maximum volume (Vm) and the amount of offered feed, rejected feed, and feces were considered (Table 7).

Table 7. *In vitro* gas maximum volume (Vm) of offered feed, rejected feed, feces and the *in vivo* gas potential emission index (*IV*GPEI) of finishing lambs fed with diets including silages.

Diets*	Offered feed		Rejected feed		Feces		***IV*GPEI**†
	Vm (mL g^{-1})	g d^{-1}	Vm (mL g^{-1})	g d^{-1}	Vm (mL g^{-1})	g d^{-1}	dL $lamb^{-1}$ d^{-1}
NSD	305.2	1289.0	228.3	19.7	107.1	336.1	35.3
CSD	328.5	780.6	243.9	56.0	121.0	311.1	20.0
CCSD	360.0	1175.4	335.1	66.4	105.5	273.1	37.0
CFSD	280.8	932.2	244.2	61.4	110.0	198.2	21.0
SEM	18.9	128.2	11.4	11.5	8.7	76.8	3.8

*NSD = Not silage diet, CSD = corn silage diet, CCSD = cladode silage diet, CFSD = cladode plus fruit silage diet. SEM= standard error of the mean. dL = decaliter. †*IV*GPEI = (Vmo*offered feed) - (Vmr*rejected feed) - (Vmf*feces).

In general terms, the cladode silage and the cladode-fruit silage and their diets, can be consider similar in their nutritive and fermentative quality (Tables 2, 3, 4 and 5). Although, when the animal component is included, the diets differ. This effect was observed when the *in vitro* fermentation analysis of the offered feed and rejected feed was carried out (CCSD vs. CFSD). (Table 6). Similarly, the animal effect was also observed when the maximum volume (Vm) and the amount of offered feed, rejected feed, and feces were considered (CCSD vs. CFSD) (Table 7).

The cactus pear silages (CCS and CFS) nutritive and fermentative qualities were similar to the corn silage, with the exception of *in vitro* dry matter digestibility and crude protein which were greater in the latter. The inclusion of cactus pear fruit in the silage increased the soluble carbohydrates and decreased the pH. The incorporation of cactus pear silages to the finishing lambs' diets increased the ash content and decreased the acid detergent fiber proportion and consequently, increased the fast fermentative fraction and the neutral detergent fiber apparent digestibility. Furthermore, the cladode silage could have the advantage of reducing the lambs' selective feed intake behavior.

CONCLUSIONS

The present research demonstrated that cactus pear silages (CCS and CFS) have a comparable nutritive quality to the corn silage, and their inclusion to the lamb diets could improve the fermentative quality and the neutral detergent fiber apparent digestibility. This gives the possibility to improve lamb finishing performance and profitability of the feedlot production systems.

It was also demonstrated the feasibility to estimate the *in vivo* diet's utilization and the potential gas emission by lambs through the measurement of the maximum gas volume (Vm) of the offered feed, rejected feed, and feces by the use of the *in vitro* gas production technique (environmental impact).

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