Quality of fermented cactus pear (*Opuntia* spp.) and its effect on liveweight gain of Dorper lambs

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ABSTRACT

The high-water (85%) and low protein (5%) content of cactus cladodes (*Opuntia* spp.) reduce the amount of dry-matter consumed by ruminants. The objective of this study was to use protein enrichment technology to increase *Opuntia* protein content and to feed Dorper lambs, comparing the *Opuntia* protein enrichment and the basal diet in the liveweight gain. The experiment was carried out for 60 days, using a biodigester (100 kg of cactus) -Title No. 2641-IMPI. The process was based on the daily aerobic semisolid fermentation of *Opuntia* by applying yeast of the *Sacharomyces cereviceae* (1%) type, urea (1%) and ammonium sulfate (0.1%) during 20 h (1 h of movement and 1.5 h of rest) recycling the yeast for a week. Unfermented *Opuntia* cladodes were used as the control. The enriched *Opuntia* was provided in the final stage in two treatments in a completely randomized design with three replications: 1) Basal diet (control), and 2) Basal diet + fermented fresh *Opuntia*. The liveweight of each animal was recorded weekly. Analysis of variance and comparison of means were performed (Tukey HSD p=0.05 and orthogonal contrasts $p \leq 0.05$). The results of the fermentation showed that fermented *Opuntia* significantly ($p \leq 0.01$) decrease carbohydrates content (48.9 to 26.4%); increased crude protein content (5.64 to 33.17%) and energy (2.26 to 2.67 Mcal kg^{-1}) compared with unfermented *Opuntia*. However, on the seventh day of fermentation, these values decreased significantly, because of the temperature decrease. At the end of the experiment, the live-weight increased significantly 11.62 ± 0.99 kg animal^{-1} month^{-1} in groups of four lambs fed with enriched *Opuntia*, while the liveweight of animals fed with the basal diet only increased 8.42 ± 1.69 kg animal^{-1} month^{-1}, showing a difference in the liveweight gain of 800 g lamb^{-1} week^{-1} fed with fermented *Opuntia* cladodes.

***Keywords**: Opuntia*, sheep, fodder, semi-solid fermentation.

INTRODUCTION

The North of Mexico faces feed shortage during drought seasons and winter (January to May). In addition, available protein sources have a high cost, which also precluding an adequate supply of supplements (López-González *et al*., 2003). This causes malnutrition of goats, sheep and cattle limiting their productive and reproductive performance of these animals (Murillo-Amador *et al*., 2009).

In 1990, a severe drought occurred in the North of Mexico and thousands of animals died (CNN-México, 2011), showing the importance of having areas of wild or cultivated cactus (*Opuntia* spp.) to be used as fodder (López-González *et al*., 2003). Although the importance of cactus in animal feeding is known (Mondragón-Jacobo and Pérez-González, 2003; Anaya-Pérez and Bautista-Zane, 2008), its importance has principally focused on the production of fruit ("tuna") and vegetable ("nopalito"), thus, there are quite a few studies about this subject in Mexico.

Nevertheless, expansion of cactus uses provide an important opportunity in the national market, especially if it can be integrated into a feed product for livestock (SAGARPA, 2004. Nopal Product System Committee). Market acceptance of this opportunity can be further consolidated if the protein content in the cactus pear is increased.

Solid fermentation is an ancient process that is used to increase the protein content of foods and to improve the conservation or change the physical characteristics of food such as color, smell or taste. Examples of these products are the Koji, which is obtained by the cultivation of the fungus *Aspergillus oryzae* on cooked cereals, Shoyu, Miso and Ontjom (Hesseltine, 1972).

The production of enriched feedstuffs, as supplement type, is done through the process of semi-solid fermentation of cactus cladodes (one year old) by adding a mixture of minerals in the process (Tabosa *et al*., 2003). This process adapted from the "saccharin" technology of sugarcane in Cuba (Elías and Lescano, 1993) is recommended to increase the protein content of forage (Lira *et al*., 1989; Elías *et al*., 1990).

Enriched forages are analyzed to determine the additional amount of "microbial" protein and are fed to cattle to increase milk and meat production (Tabosa *et al*., 2003; Rodríguez *et al*., 2007). The *Opuntia* protein-enriched by aerobic fermentation has been used with favorable results in the feeding of ruminants (Tabosa *et al*., 2003) including lambs (Cordova-Torres *et al*., 2014).

In Mexico, bio-digester models are available to carry out the aerobic liquid fermentation process of *Opuntia* (Aranda-Osorio, 2006; Aranda-Osorio *et al*., 2008). Specifically, there is a technology (machine and process) with registration title No. 2641-IMPI (Mexican Institute of Intellectual Protection), whose machine performs the cutting stages of one-year old cladodes, the homogenized (mixed) of fractions "fermented ", aerated and separated from the material processed in juice and bagasse in a sequenced and automated way in a period of 24 h, with a significant increase of crude protein from 4 to 32% (Flores-Hernández *et al*., 2011). The objective of this study was to assess the effect of feeding protein-enriched *Opuntia* on Dorper lamb's liveweight gain.

MATERIALS AND METHODS

Study area

The experiment was conducted in Morelos, Zacatecas, Mexico, located at 22°53'12" N and 102°36'45" W, at 2,348 m.a.s.l. The climate of the region is classified as BWwh, with an average temperature of 14 to 16°C, with an approximate rainfall of 420 mm, although the years 1979 with 216 mm and 1990 with 650 mm stand out as extremes. The minimum temperatures occur in the months of December, January and February, with the minimum monthly average around 0°C. The maximum temperatures are registered during the months of May and June, reaching up to more than 30°C (García, 2004). The flora in the study area is constituted by magueyes (*Agave* spp.), nopales (*Opuntia* spp.), mesquites (*Prosopis* spp.), huizaches (*Acacia* spp.), among other species associated with semi-arid zones.

Opuntia processing

One-hundred kg of fresh *Opuntia* was processed by aerobic semisolid fermentation using a biodigester (NOPAFER, Title No. 2641-IMPI, Mexico). To start the fermentation process, the *Opuntia* cladodes used (Villanueva variety) were fractionated into small parts and later yeast was added of the *Saccharomyces cerevisiae* (1%) type, with urea (1%) and ammonium sulfate (0.1%). In the fermentation process, a timer was used to program movements of 1 h and 1.5 h of rest, during 24 h. In order to reduce production costs (use of yeast) the first day, 4 l of the juice product of the fermentation was taken and this was used successively until the seventh day (Flores-Hernández *et al*., 2015).

Proximal analysis

On the initial, intermediate and final week of the experiment, both the fermented and unfermented *Opuntia* dry matter (DM) was measured by the partial DM process adapted from Goering and Van Soest (1970), with additional modification of 105°C for 2 h. The crude protein (CP) was analyzed according to the CP process of animal feeding (990.03, AOAC, 2005b). The metabolizable energy (ME) was measured according to McDonald *et al*. (2010). The non-structural carbohydrates (NSC, sugar and starch) were determined by the method of Van Soest *et al*. (1991). The minerals were analyzed according to the ash process (C) of animal feed (942.05, AOAC, 2005a). The feedstuffs used in the basal diet for Dorper lambs were the commercial concentrated mix with corn stubble, to which a proximal analysis was also carried out (Table 1). Additionally, a feeding cost analysis was carried out. Analyzes were performed at Agrolab (certified laboratory of Dr. Martin J. Traxler) in Gómez Palacio, Durango, Mexico.

Experimental design

Twenty-four male lambs with an average liveweight of 26.1 ± 1.7 kg and 8 months of age were used in this study. These lambs were raised in an extensive production system; therefore, they presented a reduced growth rate. Quartets of lambs (three sheep as an experimental unit plus a lamb as a replacement) were formed with similar liveweight that were randomly distributed in each group or diet (D1 unfermented cactus and D2 fermented cactus, and their replicates). Diets were individually fed, therefore lam within treatment was the experimental unit. During the whole feeding trial lambs were equally managed.

The composition of diets: 1) Basal diet (200 g of commercial concentrate feed for lambs and 2.5 kg of corn stubble; the concentrate consisted principally of sorghum and corn grain); and for the diet 2) Basal diet + fresh fermented *Opuntia,* in the following quantities, 2.5 kg of corn stubble, 2 kg of fresh fermented *Opuntia* (200 g DM), plus 100 g of commercial concentrate for lambs. Table 2 shows the nutritional composition of the diets. Both diets were balanced according to the data of the proximal analysis of its components for growing-finishing lambs. Diets were offered twice a day at 08:00 and 15:00 h, based on the 4% average body weight. Water was *ad libitum* in both treatments. The experiment lasted 60 days (8 days of adaptation and 52 days of experimentation). For practical purposes, liveweight was divided by two to obtain monthly average liveweight gain. During the experimentation phase, lambs were weighed every week to obtain weekly and monthly liveweight gain.

Economic analysis of the fermentation process

The production cost of fermented *Opuntia* obtained with the protein enrichment technology was compared with the cost of feeding commercial concentrate. The costs of planting and maintenance of *Opuntia* vary greatly depending on the conditions of each region, then, only the costs of machine fermentation process were included.

Statistical analysis

Bartlett's test was performed on the data to test the homogeneity of variance. Data were compared using univariate analysis of variance (ANOVA) according to an experimental design of one-way of classification. The differences among the means of variables associated to the proximal analysis of the components of the diets were determined by Tukey's HSD multiple range test at p=0.05 level. However, the differences within variables between diets were made by orthogonal contrasts (p≤0.05), that is, independent comparisons of means. The first contrast was made by comparing diet 1 (Basal diet -control diet-) versus diet 2 (Basal diet + fresh fermented *Opuntia* -experimental diet-). In all cases, mean values were considered significantly different when p≤0.05. The statistical analyzes were performed with Statistica v. 13.5 (TIBCO Software Inc., 2018).

RESULTS AND DISCUSSION

Proximal analysis of Opuntia before and after the fermentation process

Table 1 shows the results of the proximal analysis of *Opuntia* before and after the aerobic semisolid fermentation process, observing a significant (p≤0.001) increase (more than five times higher) in the crude protein content due to the fermentation process; however, a significant ($p \leq 0.01$) decrease in the content of non-fibrous carbohydrates (sugars and starch) was observed, which was reduced by almost half in the fresh fermented *Opuntia* compared to the unfermented one. This is the result of the consumption of carbohydrates by the active growing yeast. When oxygen is present, the yeast grows efficiently from the carbohydrates and nitrogen in the medium to produce the biomass and CO_2. When there is no oxygen or it is scarce, the yeast population changes to anaerobic metabolism reducing biomass and alcohol production (Sarmiento-Herrera, 2003).

The metabolizable energy (ME) was slightly higher in fermented *Opuntia* (2.67 ± 0.05 Mcal kg^{-1}) compared to unfermented (2.61 ± 0.05 Mcal kg^{-1}) and although it seems to be minimal, it is important because of their value as a forage. The amount of ME obtained (2.67 Mcal kg^{-1}) exceeds the pasture (2.08 Mcal kg^{-1}) and it is almost the same as *Medicago sativa* (2.64 Mcal kg^{-1}) according to Felker (2003).

On the other hand, it is emphasized that the fermentation process with the yeast reused daily for a week may be affected by the low temperatures registered in the region during the experimental period, which fluctuated between 25.5°C (maximum) and 12.3°C (minimum), with an average of 18.8°C. The optimal temperature for the fermentation process is around 27 ± 2°C (Flores-Hernández *et al*., 2014); however, the pH remained in ranges of 3.86 to 4.45, considered the recommendable limits (3.5 to 5.0) according to Rose (1987).

Another important factor to consider is the sanity of the fermentation process. In this study, to facilitate the transfer of the fermented *Opuntia*, the bio-digester was installed on one side of the lamb's management pen; however, the risk of contamination increased, affecting the efficiency of the fermentation process registered with a reduction of crude protein to 26.03 ± 1.69% and an increase in the ammoniacal nitrogen content found in the samples on the seventh-day. Therefore, it is recommended to install the bio-digester away from livestock although it involves an increase in cost in the transfer of the fermented *Opuntia*.

The results of the present study coincide with those of Araújo *et al*. (2008) who reported an increase in the protein content of cactus from 8.0 to 9.17%, when added 3% of commercial *Saccharomyces cerevisiae*. Neutral detergent fiber (NDF) increased from 46.8 to 48.47% and acid detergent fiber (ADF) increased from 25.6 to 27.73 %. According to Ramírez-Tobias *et al*. (2007) the use of *Opuntia* as fodder is extended and its nutritional quality is variable. However, is not precisely know how the species and maturity of the cladode affect its nutrient content.

In this sense, Mondragón-Jacobo *et al*. (2003) reported nutritional quality of cactus pear developed under hydroponic conditions, where ashes content varied from 18.68 to 30.31%, being highest than other forages such as oat hay, corn and sorghum stubble; the protein content ranged from 11.72 to 18.07% after N fertilization for LCNF and "Pabellón Amarillo" cultivars, respectively, being similar than *Medicago sativa*, corn silage and orchard grass, although higher than wild cactus pear and corn stubble; while the *in vitro* DM digestibility varied from 84.9 to 95.5.

In other study developed under hydroponic conditions by Ramírez-Tobías *et al*. (2007) using four cactus species: *Nopalea cochenillifera*, *Opuntia robusta* ssp. *larreyi*, *O. undulate* × *O. tomentosa* and *O. ficus-indica* during four growth stages (very young cladodes -EC1- to well-developed cladodes -EC4-), they found that DM decreased from 5.7% in EC1 to 3.9% in EC3. Old cladodes have more DM than the young ones, and also, DM varied among species, where *O. ficus-indica* showed the highest values of 34.4% for neutral detergent fiber (NDF) and 17.6% for acid detergent fiber (ADF). Crude protein (CP) content do not varied among species but decreased among growth stages from 21.7% in EC1 to 16.9% in EC4. *Opuntia ficus-indica* showed highest values of NDF and ADF (34.4 and 17.6%, respectively).

The increase in CP using the fermentation process is relevant because of the CP content of wild *Opuntia ficus-indica* reported by Baraza-Ruiz *et al*. (2008) varied from 5.7 to 14.2% in old and young cladodes, respectively. Previous studies have reported that protein nitrogen source improves the nutritive value of cactus pear-based diets fed to lambs and increases average daily liveweight gain (Ben Salem *et al*., 2002). Recently, a study showed that cactus pear silages have a similar nutritive quality to corn silage, and their use to feed lambs might increase the fermentative value and the neutral detergent fiber apparent digestibility (Miranda-Romero *et al*., 2018).

Table 1. Proximal analysis of fresh *Opuntia* before and after of semisolid fermentation process during three weeks and proximal analysis of the components of the diets used in the feeding of Dorper lambs during two months in Morelos, Zacatecas, Mexico.

	Before		After
Crude Protein (% DM)	5.66 ± 0.02 b		32.98 ± 0.15 a
Non-fibrous Carbohydrates (% DM)	56.63 ± 7.73 a		26.73 ± 0.39 b
Metabolizable Energy (Mcal kg^{-1})	2.28 ± 0.02 a		2.61 ± 0.05 a
Minerals (Ashes) % DM	19.74 ± 1.36 a		20.44 ± 2.7 a
Dry Matter (%)	9.38 ± 2.45 a		9.28 ± 1.05 a
	Corn stubble	**Commercial concentrate for lambs**	**Fresh fermented *Opuntia***
Crude Protein (% DM)	5.89 ± 0.81 c*	21.83 ± 1.85 b	32.98 ± 0.15 a
Non-fibrous Carbohydrates (% DM)	32.0 ± 1.27 b	52.2 ± 2.03 a	26.73 ± 0.39 b
Metabolizable Energy (Mcal kg^{-1})	2.14 ± 0.03 bc	2.92 ± 0.01 a	2.61 ± 0.05 a
Minerals (Ashes) % DM	9.42 ± 1.21 b	7.58 ± 0.97 c	20.44 ± 2.7 a
Dry Matter (%)	91.48 ± 2.23 a	89.70 ± 2.34 ab	9.28 ± 1.05 a

*Values represent the mean ± standard error. Values in the same row followed with different letter differ (Tukey HSD *p*=0.05). Due to the great palatability of the diet with fermented cactus a 100% feed intake was registered, while in the basal diet approximately 7% was left in the feed containers.

Diets proximal analysis

In both diets, commercial feed (concentrate) was fed, 200 g in the control treatment and only 100 g in the experimental one, it was not completely eliminated as the lambs were used to it since weaning. Table 1 shows the proximal analysis of fermented fresh *Opuntia*, the corn stubble and the commercial concentrate for lambs. The results showed that the fermented fresh *Opuntia*, exhibited values that characterize this product as best quality than the commercial concentrate for lambs (control), both balanced according to the values from DM obtained in the proximal analysis, the fermented fresh *Opuntia* had higher content of protein and minerals while in the commercial concentrate for lambs had the highest content of non-fibrous carbohydrates and metabolizable energy.

Although the quality of a forage is defined by its nutrient content, there is a wide variation in dietary recommendations for the different lamb´s growth stages (NRC, 2007) as considered in this study. In the growing-finishing stage, the concentrated provided in this study is highly recommended, with the combination of grains, showing to be more useful, demonstrating its effectiveness as observed in other studies (Bustamante-Guerrero, 2002). Any other feedstuff used as forage is specifically related to crude protein content, energy or DM. For example, a feed with a low content of metabolizable energy (1.5 to 1.7 Mcal kg^{-1} of DM) and 50 to 60 g of CP kg^{-1} of DM is insufficient to stimulate the lambs voluntary feed intake of the forage consumed, as well as to sustain liveweight gains of 70 g $animal^{-1}$ day^{-1} (NRC, 2007). Considering the previous criteria, it would expect a greater liveweight gain in the lambs of this study, because the quality in terms of nutritive value of the diets, that is, crude protein, metabolizable energy and minerals (NRC, 2007). More than 20 years ago, Fuentes-Rodríguez (1997) concluded that *Opuntia* had a high potential for feeding goats in arid and semiarid areas of Mexico, but the nutritional value has to be improved to get a better goat’s performance and most efficient utilization of *Opuntia*. Yet, it is important to consider that complementing poor forages such as straws with cactus pear, increases straw consumption, digestibility and increased rumen microbial activity but could decreased cellulolytic activity (Ben Salem *et al*., 1996).

Liveweight gain

The average liveweight gain showed differences ($p \leq 0.01$) per day, week and month (Table 2), being highest (387 g $animal^{-1}$ day^{-1}) in lambs fed with diet 2, which included fermented fresh *Opuntia* (protein-enriched) while the lambs fed with the diet 1 (commercial concentrate) increased only 280 g $animal^{-1}$ day^{-1}.

These results are similar to those reported by Bustamante-Guerrero (2002) who used a combination of grains in the diet with *ad libitum* consumption, with liveweight gain of 375 g $animal^{-1}$ day^{-1} in Suffolk lambs; 354 g $animal^{-1}$ day^{-1} in Ramboillet/Suffolk lambs and 250 g $animal^{-1}$ day^{-1} in Pelibuey lambs. In the same sense, Aguilar-Yañez *et al*. (2011) using cactus to feed lambs, reported a daily liveweight gains of 260 and 232 g $lamb^{-1}$ day^{-1}, in those animals fed with dehydrated and fresh spineless cactus, respectively, while animals fed with control diet increased 248 g $lamb^{-1}$ day^{-1}.

The liveweight gain of lambs in the present study and the described by Aguilar-Yañez *et al.* (2011) are in the recommended range of daily liveweight gain of 257 g animal^{-1} day^{-1} reported by the NRC (2007) for 40 kg lambs. Similar liveweight gain was reported in Corridale/Criollo lambs fed with different levels of spineless cactus used in the diets (Aranda-Osorio *et al.*, 2008).

Table 2. Liveweight (LW) gain in Dorper lambs fed with two diets during two months in Morelos, Zacatecas, Mexico.

		Liveweight gain per animal		
Diets	Total LW gain (kg)	Month (kg)	Week (kg)	**Day (g)
Basal diet (commercial concentrate)	36.85 ± 1.55 b*	8.42 b	1.90 b	280 b
Basal diet + fermented fresh *Opuntia*.	47.89 ± 0.94 a	11.62 a	2.70 a	387 a

*Values represent the mean ± standard error. Values in the same column followed with different letter differ (independent comparisons or orthogonal contrasts $p \leq 0.05$). **The liveweight gain per day is the average of the week.

Other countries such as Vietnam where cactus pear (*Opuntia elator*) is abundant in the area, it is not used; however, Tien and Beynen (2005) developed a study with lambs supplemented with cactus pear and groundnut, which had an average liveweight gain of 145±12.3 g lamb^{-1} day^{-1}, while those lambs fed with cactus and fish sauce gained 130±11.7 g lamb^{-1} day^{-1}, they concluded that cactus pear has potential to be used as feedstuff for lambs. In the same sense, liveweight gain in lambs has been reported by Ben Salem *et al.* (2004) and Degu *et al.* (2009), where they found average liveweight gains of 138 and 100 g lamb^{-1} day^{-1} for Barbarine and Tigray highland lambs, respectively, with spineless cactus-based diets.

When a complement of 100 g of commercial concentrate for lambs was included in the diet 2, a synergistic effect was induced, therefore, fermented fresh *Opuntia* can replace a portion of the concentrated fed. The fermented fresh *Opuntia* has an excellent acceptance (palatability) by lambs. Even when the fermented fresh *Opuntia* showed variation in chemical composition on the seventh day of the fermentation process, no noticeable effect was observed as the liveweight gain per week remained stable. These results confirm that when renewing the yeast every week, the effect of the variation on the seventh day in the chemical composition of the fermented fresh *Opuntia*, did not have a significant effect on the liveweight gain of the lambs fed with Opuntia-enriched (diet 2), apparently because it was fed in the short-term (7 days). However, the adequate conditions must be met to obtain an optimum and efficient fermentation of fresh *Opuntia*, mainly the temperature and to install the bio-digestor away from livestock management pens, although it involves an increase in the cost of transferring the fermented *Opuntia*.

According with Grünwaldt *et al.* (2015) Mexico, together with Brazil, Ethiopia, Tunisia and United States have made an important contribution of studies regarding the use of *Opuntia* in animal production. Recent studies in Brazil and Mexico showed that the addition of cactus pear in diets for small ruminants is useful as supplement feedstuff, as it reduces feed cost without reducing the production and quality of meat and milk. However, other factors need to be considered to achieve meat and milk quality, ranging from animal (sex, age, breed) to type of production system (extensive or intensive) among others (Cordova-Torres *et al*., 2017).

The inclusion of cactus pear in the diet of lambs not only increases the liveweight gain, but also influences the fatty acids profile in Santa Ines sheep when cactus pear was used as a replacement of buffelgrass (Costa *et al*., 2017). Previous studies in the Brazilian semiarid regions, Costa *et al*. (2013) concluded that cactus is recommended as forage for finishing sheep; however, reported that total substitution of corn by cactus pear, despite leading to a reduction in liveweight gain, increased the dry matter intake and improved the ability of sheep to digest the nutrients.

In other ruminant species (goat kids), Mahouachi *et al*. (2012) reported that kids fed with cactus pear produce meat with improved nutritional quality because of lower carcass fat content, lower intramuscular fat content affecting marbling while increasing quality. A higher accumulation of beneficial fatty acids, n-3 FA, and CLA was also observed, concluding that due to the increase of costs of commercial concentrates, raising kids under cactus pear feeding could be more economic than the conventional program.

In Nubia goats, Flores-Hernández *et al*. (2017) reported that live-weight gain was greater in goats fed with *Opuntia* protein enrichment diet, but the amount of forage rejected increased. *Opuntia* protein enrichment had higher nutritive quality since the liveweight gain was lower in alfalfa diet and *Opuntia* without protein enrichment.

Other results showed that diets based on spineless or spiny cactus pear promoted similar volatile fatty acids and bacterial N production and efficiencies; both diets were assayed *in vitro* experiments and showed similar nutritive value; however, *in-vivo* studies should be required to verify animal response to these species of cactus pear, to better evaluate their fodder potential (Abidi *et al*., 2009). In other animal species such as cows, the addition of 10 or 20 kg of fresh cactus pear cow^{-1} day^{-1} in the diet increased milk production in Holstein cows (Pérez-Sánchez *et al*., 2015).

Economic analysis of the fermentation process

The average yield of fermented fresh *Opuntia* was 95 kg (juice and bagasse) separating 5 l of juice that was reused in the next fermentation. Considering that 1 kg of fresh fermented *Opuntia* is equivalent to 100 g of DM, the technology of fermentation produces 9.5 kg (DM) of fermented *Opuntia* protein-enriched. This quantity is enough to feed 47 lambs a day (200 g animal^{-1}). The price of the commercial concentrate feed for lambs in the study area is around USD \$10.93 bag of 40 kg, that is, USD \$0.27 kg^{-1}, while to produce 9.5 kg of protein-enriched *Opuntia* it is needed USD \$1.78, for buying supplies and USD \$0.18 kg^{-1} considering the energy used by the biodigester. Thus, the amount of money saved is about USD \$0.09 kg^{-1} when using fermented *Opuntia* protein-enriched. One-hundred kilograms of fermented *Opuntia* day^{-1} require, 1 kg of urea (USD \$0.33 kg^{-1}), 100 g of ammonium sulfate (USD \$0.18 100 g^{-1}), 1 kg of dry yeast (USD \$0.59 kg^{-1}), which is reused during 7 days and USD \$0.83 day^{-1} for energy consumption. However, these costs can still be reduced by increasing the processing capacity (more than 100 kg of fermented *Opuntia* day^{-1}) of the NOPAFER equipment generally, it will require a bigger engine and so, more energy has to be used and improving the conditions to reuse the yeast for a longer time.

The cost of *Opuntia* is not included because cactus pear is a perennial plant and its cost of planting, operation and harvest varies greatly depending on the region. A general cost of *Opuntia* spineless production in the area of study can be estimated an approximate USD \$0.026 kg^{-1}. Other studies have compared the use of *Opuntia versus* maize silage, fresh or hay alfalfa, and concluded that costs per unit of production (meat or milk) using *Opuntia* are lowest being a significant source of forage for arid and semiarid areas of Mexico (Flores-Valdez and Aranda-Osorio, 1997). Also, Aranda-Osorio *et al*. (2008) concluded that adding cactus cladodes in the diet of growing-finishing lambs reduces the cost of feed, being an extra income for cactus pear farmers and enhancing this production system in Central Mexico.

CONCLUSIONS

The fermentation process of *Opuntia* compared to unfermented *Opuntia* increased crude protein from 5.6 to 32.9% DM, metabolizable energy from 2.28 to 2.61 $Mcalkg^{-1}$, although decreased the non-structural carbohydrates from 56.6 to 26.7% DM, this represents a remarkable advance in the use of *Opuntia* spineless as a feedstuff.

The lower effectiveness of the *Opuntia* fermentation process on the seventh day of reuse of the yeast, was noticed by the decrease in protein and energy content, and higher carbohydrate content in relation to the recent fermented *Opuntia*; which were influenced by the low temperature and sanitary conditions of the process.

The inclusion of *Opuntia* in the feeding of Dorper lambs indicated a higher liveweight gain of 387 g compared to only 280 g of lambs fed with a commercial concentrate feed, which is very promising because it can produce a reduction time in the feed lot and the costs of feeding.

The chemical component values of fermented *Opuntia* meet the criteria as good quality feedstuff and showed a lower cost than the commercial concentrate for lambs.

The use of fermented *Opuntia* in the feeding of lambs is highly recommended.

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CONFLICT OF INTEREST STATEMENT

The authors have declared that no competing interests exist. The research was conducted in the absence of any commercial or financial relationships that could be interpreted as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceived and designed the experiments: AFH, FJMR, GGH, JLOS, CMH, BMA. Performed the experiments: AFH, FJMR, GGH, JLOS. Analyzed the data: BMA. Contributed reagents/materials/analysis tools/publication costs: AFH, FJMR, GGH, JLOS, CMH. Wrote, edited and revised the paper in English: AFH, BMA. Approved the final version of the manuscript to be published: AFH, FJMR, GGH, JLOS, CMH, BMA. All authors agree that BMA to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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